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Cognitive benefits of technologies applied to learning in education

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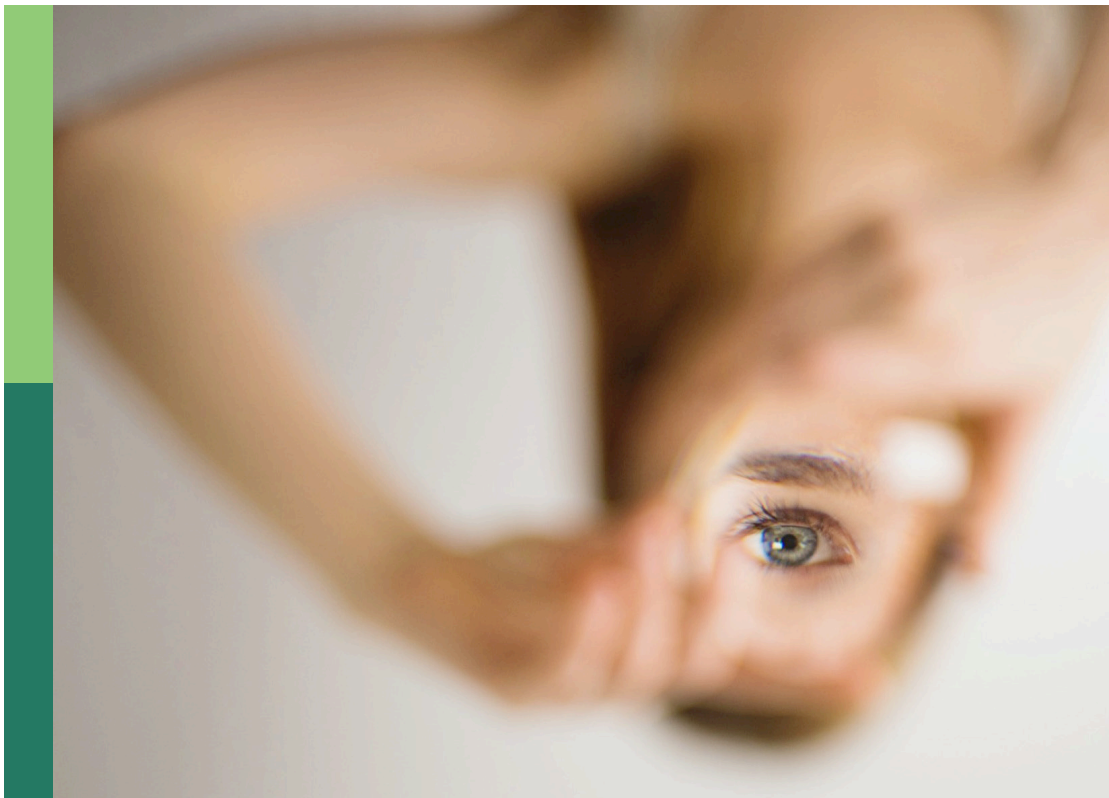

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Cognitive benefits of technologies applied to learning in education

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Editorial: Cognitive benefits of technologies applied to learning in education

Beatriz Peña-Acuña[1], Rafael Crismán-Pérez[2]*, Yolanda Navarro-Abal[3], Pedro Román-Graván[4], Pedro Tadeu[5], Manuel León-Urrutia[6], Javier Ávila-López[7], Carmen M. Toscano-Fuentes[3] and Carmen María Martín Del Pino[3]

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KEYWORDS

Cognitive, Technology, Benefits, Learning, Education

Editorial on the Research Topic
Cognitive benefits of technologies applied to learning in education

During the 2023/2024 academic year, a monographic Research Topic of the journal Frontiers has been published on the topic *Cognitive benefits of technologies applied to learning in education* (8,360 downloads and a total of 34 k downloads and views). At this point, two sections of the journal have received requests for publication: Frontiers in Education and Frontiers in Psychology. The team was composed of the following members:

1. Beatriz Peña Acuña (University of Huelva).
2. Carmen Martín del Pino (University of Huelva).
3. Carmen Toscano Fuentes (University of Huelva).
4. Francisco Javier Ávila López (University of Córdoba).
5. Pedro Tadeu (Polytechnic of Guarda Portugal).
6. Carmen del Pino (University of Huelva).
7. Yolanda Navarro Abal (University of Huelva).
8. Manuel León Urrutia (University of Southampton).
9. Pedro Roman Gravan (University of Seville).
10. Rafael Crismán Pérez (University of Seville).

A total of 84 applications for publication have been supervised and evaluated. This means that the total number of authors evaluated was 229. Of all the articles submitted, 17 applications were accepted, i.e., a percentage of approximately 20%. The titles are as follows:

Video games and metacognition in the classroom for the development of 21st century skills: a systematic review (Checa-Romero and Gimenez-Lozano).

The influence of mind mapping on computational thinking skills and self-efficacy in students' learning of graphical programming (Guo et al.).

Parents' rearing styles and adolescents' math achievement: the multiple mediating effect of self-control and math anxiety (Wang et al.).

The effect of augmented reality storybooks on the story comprehension and retelling of preschool children (Simşek).

Unlocking innovation: how enjoyment drives GenAI use in higher education (Cano and Nunez).

Toward a new model for the successful implementation of information and communication technologies in education (Lamalif et al.).

The integration of psychology and medicine: an empirical study of curriculum reform from the perspective of China (Ma et al.).

An isochronic substitution benefit study of the effects of screen time on the cognitive abilities of 3–6 children (Zhenya et al.).

Exploring the factors influencing high school students' deep learning of English in blended learning environments (Shi and Lan).

Prevalence of phubbing behavior in school and university students in Spain (Barbed-Castrejón et al.).

Ethnocultural empathy development of future language teachers through digital multiliteracy resources for low-literacy adult migrants (Fernández-Corbacho et al. a).

Immersive virtual reality for learning about ecosystems: effect of two signaling levels and feedback on action decisions (Porte et al.).

TABLE 1 List of articles.

Title	Category	Type of research
Video games and metacognition in the classroom for the development of 21st century skills: a systematic review (Checa-Romero and Gimenez-Lozano)	Teaching and Learning Methods	Systematic review
The influence of mind mapping on computational thinking skills and self-efficacy in students' learning of graphical programming (Guo et al.)	Educational technology and as a learning methodology	Quantitative (experimental)
Parents' rearing styles and adolescents' math achievement: the multiple mediating effect of self-control and math anxiety (Wang et al.)	Parenting and learning styles	Quantitative (cuasi experimental)
The effect of augmented reality storybooks on the story comprehension and retelling of preschool children (Simşek)	Teaching and Learning Methods	Quantitative (experimental)
Unlocking innovation: how enjoyment drives GenAI use in higher education (Cano and Nunez)	Educational technology and as a learning methodology	Quantitative (cuasi experimental)
Toward a new model for the successful implementation of information and communication technologies in education (Lamalif et al.)	Inclusion and educational equity	Systematic review
The integration of psychology and medicine: an empirical study of curriculum reform from the perspective of China (Ma et al.)	Teaching and Learning Methods	Quantitative (experimental)
An isochronic substitution benefit study of the effects of screen time on the cognitive abilities of 3–6 children (Zhenya et al.)	Teaching and Learning Methods	Quantitative (experimental)
Corrigendum: Ethnocultural empathy development of future language teachers through digital multiliteracy resources for low-literacy adult migrants (Fernández-Corbacho et al. b)	Teacher training	Quantitative (cuasi experimental)
Exploring the factors influencing high school students' deep learning of English in blended learning environments (Shi and Lan)	Teaching and Learning Methods	Quantitative (cuasi experimental)
Prevalence of phubbing behavior in school and university students in Spain (Barbed-Castrejón et al.)	Learning and Psichology	Quantitative (cuasi experimental)
Ethnocultural empathy development of future language teachers through digital multiliteracy resources for low-literacy adult migrants (Fernández-Corbacho et al. a)	Teacher training	Quantitative (cuasi experimental)
Immersive virtual reality for learning about ecosystems: effect of two signaling levels and feedback on action decisions (Porte et al.)	Teaching and Learning Methods	Quantitative (experimental)
Shaping the future of creative education: the transformative power of VR in art and design learning (Serna-Mendiburu and Guerra-Tamez)	Teaching and Learning Methods	Quantitative (cuasi experimental)
Educators as agents of breadth-biased learning: using social reconstructionism as rationale for embracing media multitasking and enhancing teaching practices in higher education (Kassie)	Teacher training	Systematic review
Gamification in the classroom: Kahoot! As a tool for university teaching innovation (Aibar-Almazán et al.)	Teaching and Learning Methods	Quantitative (experimental)
Assessing the intention to accept inquiry-based teaching pedagogy among Chinese university students: an extension of technology acceptance model (Hu et al.)	Teaching and Learning Methods	Quantitative (cuasi experimental)
The effect of self-directed online metacognitive listening practice on Chinese EFL learners' listening ability, metacognition, and self-efficacy (Pei et al.)	Teaching and Learning Methods	Quantitative (experimental)

Shaping the future of creative education: the transformative power of VR in art and design learning (Serna-Mendiburu and Guerra-Tamez).

Educators as agents of breadth-biased learning: using social reconstructionism as rationale for embracing media multitasking and enhancing teaching practices in higher education (Kassie).

Gamification in the classroom: Kahoot! As a tool for university teaching innovation (Aibar-Almazán et al.).

Assessing the intention to accept inquiry-based teaching pedagogy among Chinese university students: an extension of technology acceptance model (Hu et al.).

The effect of self-directed online metacognitive listening practice on Chinese EFL learners' listening ability, metacognition, and self-efficacy (Pei et al.).

In addition to the two blocks (*Frontiers in Education* and *Frontiers in Psychology*), the following topics have been taken into account:

- *Cognition*.
- *Digital Education*.
- *Frontiers in Computer Science Mission statement*.
- *Digital Learning Innovations*.

Thus, after observing the accepted publications, we can see that the category of *Teaching and Learning Methods* presents more articles within the monograph. This category has covered issues such as students "attitudes toward hybrid learning in faculties of education, the comparison of audiovisual languages in the teaching of young and adult learners or the influence of the gamified approach on students" perception during the teaching and learning processes.

On the other hand, technology and its possibilities of use in education have raised two possibilities: *technology as a tool for transparency in education* and *the use of smartphones as a tool for teenagers*.

Finally, we will also highlight the importance of a cognitivist approach in second language teaching, as well as the topic of teacher training through digital resources. See Table 1 which lists the titles and category of each publication.

We have also taken into account a double approach to the research methodology of the respective studies evaluated: quantitative research with a detailed empirical sample and mixed research. In the latter, a qualitative approach complementary to the quantitative approach has also been considered.

Furthermore, as can be seen in Table 1, research based on comprehensive reviews of the state of the research question has also been considered, from which both conclusions and a prospective of the researched topic have been added.

This monograph has made progress on the topics referred to above. This includes the study of digitization and its possibilities of interaction in fields directly or indirectly linked to education. Significant advances in the matter are remarkable. Among these developments we highlight the new possibilities of inclusion enabled by open access tools, the possibilities of gamification as an enhancement of perception and, consequently, the motivation of teaching-learning processes on the basis of common digital tools. Also the necessary digital training of teachers, the new possibilities of mental construction of learning through the use of digitization or the new possibilities of efficiency, transparency and equity of education systems according to their digitization.

As a prospective, these developments have had an updated view from numerous samples of informants in different teaching-learning procedures and their cognitive repercussions. With a view to future research, we consider it highly desirable to investigate areas such as the affective dimension of digitalization and its behavioral repercussions both from the individual and institutional point of view, based on the necessary interaction of educational procedures. We also consider it particularly interesting to investigate the possibilities of access to educational procedures based on digitalization and the hypothetical social consequences of exclusion in the case of lack of such a possibility. This opens the door to traditional alternative procedures and their limitations for social inclusion in the respective modern socio-political systems. The possibilities of exclusion open up the debate about the new educational needs of the population beyond the historically considered needs.

Author contributions

BP-A: Conceptualization, Investigation, Methodology, Project administration, Supervision, Writing – review & editing. RC-P: Conceptualization, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. YN-A: Conceptualization, Investigation, Methodology, Project administration, Supervision, Writing – review & editing. PR-G: Conceptualization, Investigation, Methodology, Project administration, Supervision, Writing – review & editing. PT: Conceptualization, Investigation, Methodology, Project administration, Supervision, Writing – review & editing. ML-U: Conceptualization, Investigation, Methodology, Project administration, Supervision, Writing – review & editing. JÁ-L: Conceptualization, Investigation, Methodology, Project administration, Supervision, Writing – review & editing. CT-F: Conceptualization, Investigation, Methodology, Project administration, Supervision, Writing – review & editing. CM: Conceptualization, Investigation, Methodology, Project administration, Supervision, Writing – review & editing.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The effect of self-directed online metacognitive listening practice on Chinese EFL learners' listening ability, metacognition, and self-efficacy

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Research into metacognitive listening instruction under the Metacognitive Pedagogical Cycle (MPC) has been growing in recent decades, but its effects on L2 listening comprehension, metacognitive awareness, and self-efficacy remain inconclusive. In this mixed-method study, we developed a self-directed online listening practice based on the MPC and investigated its effects on 89 Chinese intermediate EFL learners over 14 weeks. Learners were assigned to either an experimental group, which used the online metacognitive listening practice, or a control group, which used the traditional listening practice without stressing metacognitive awareness. Multiple data sources (listening tests, questionnaires, reflective notes, and interviews) were used to assess learners' listening comprehension, metacognitive awareness, and listening self-efficacy. Results showed that online metacognitive listening practice significantly improved the learners' listening comprehension, but there was little evidence that it increased metacognitive awareness or listening self-efficacy. This study suggests that deploying online listening practice under MPC is a more effective way to improve L2 learners' listening comprehension than traditional listening practice. However, the task-setting of MPC and the task-dependence of self-efficacy may constrain the development of some factors of metacognitive awareness and self-efficacy.

KEYWORDS

online learning, metacognitive instruction, L2 listening, metacognitive awareness, self-efficacy

1. Introduction

Listening is the first language skill that children acquire, preceding speaking, reading, and writing. Most children can develop listening ability naturally without formal instruction (Siegel, 2015). However, L2 (second language) listening is a complex and daunting task that imposes on language learners high cognitive demands (Satori, 2022; Zhang and Shen, 2023). L2 learners need to use higher-order cognitive abilities, such as metacognitive strategies, to bridge listening comprehension gaps and achieve listening success (Vandergrift, 2003; Norris et al., 2017; Goh and Vandergrift, 2021). To help develop listening skills, Vandergrift (2004, 2007) proposed Metacognitive Pedagogical Cycle (MPC), the metacognitive instruction approach that helps learners regulate their listening processes and develop strategies for improving listening comprehension. Recent studies (e.g., Graham and Macaro, 2008; Taguchi, 2017; Ahmadi Safa and Motaghi, 2021; Razavi et al., 2023) have examined the effects of the MPC on L2 listening and related cognitive factors (e.g., metacognitive awareness and self-efficacy) but the results have been inconclusive. Therefore, further investigation into the effect of

the MPC is warranted. In addition, technological advancement has provided learners with new opportunities for L2 listening. Learners now have access to a wider range of listening resources and more chances to listen in real contexts. As a result, the focus of L2 listening is shifting from class-based teaching to self-directed learning (Vandergrift, 2007). Therefore, it is necessary to incorporate metacognitive activities into a technology-enhanced listening environment (Goh and Vandergrift, 2021; Bozorgian and Shamsi, 2023). However, rare research has examined the integration of MPC with technology and tested its effect on L2 listening ability.

In this study, we developed a self-directed online listening practice package based on the MPC and, using a mixed-method study, tested its effectiveness on Chinese university learners' listening comprehension, metacognitive awareness, and self-efficacy. The online listening practice package was designed to include necessary steps in the MPC, such as prediction, monitoring, and reflection. The package was then compared with a traditional online listening practice package, which simply involved listening and answering questions or summarizing the content. The standardized listening test was used to measure L2 listening ability, and the metacognitive awareness listening questionnaire (MALQ) (Vandergrift et al., 2006) and listening self-efficacy questionnaires (LSQ) (Graham and Macaro, 2008) were used to gauge metacognitive awareness and self-efficacy. Qualitative data from reflective notes and post-interviews were also collected.

2. Related work

2.1. Research on metacognitive instruction

Metacognition is how people's cognitive processes are monitored, regulated, and orchestrated (Flavell, 1979). In recent decades, there has been a surge in metacognitive instruction studies in the L2 listening field (e.g., Vandergrift and Tafaghodtari, 2010; Cross, 2011; Bozorgian, 2014; Fahim and Fakhri, 2014; Wang, 2016). Many of these are designed based on the MPC (Vandergrift, 2004, 2007), which combines listening tasks with metacognitive activities and takes learners through the metacognitive processes of planning, monitoring, evaluation, and problem-solving in listening. Accordingly, an increasing body of evidence supports the effects of metacognitive instruction on L2 listening comprehension. For example, Vandergrift and Tafaghodtari (2010) investigated the impact of metacognitive instruction grounded in the MPC for 14 weeks. Less-skilled listeners in the metacognitive group significantly outperformed the control group in developing listening comprehension and one factor (Problem-solving) associated with metacognitive awareness. They indicated that learners' regular engagement in metacognitive processes facilitated the formation of implicit knowledge of strategies, thus promoting strategy use. Similarly, Bozorgian (2014) studied metacognitive instruction's effect on Iranian L2 learners' listening comprehension. After 8-week intervention, the learners made a significant improvement in listening comprehension and two factors associated with metacognitive awareness (Planning-evaluation and Problem-solving). Alamdari and Hosnbakhshan (2021) investigated the effects of metacognitive instruction delivered separately in L1 and L2 for Iranian upper-intermediate L2 learners. The results showed that metacognitive instruction with L1 delivery produced the most gains in listening comprehension and metacognitive awareness.

However, inconclusive evidence has also been reported. Wang (2016) examined metacognitive instruction with Chinese university EFL listeners. The study did not support the superiority of metacognitive instruction as compared to traditional instruction in enhancing listening ability. Nevertheless, the journal data showed that learners made certain improvement in metacognitive knowledge. In the present study and in the study of Wang (2016), "traditional" listening instruction is characterized as the comprehension approach (Field, 2008), in which learners listen several times (usually three times) and, with or without guidance from teachers, check their performance with comprehension questions or other tasks (e.g., the summary). "Traditional" listening instruction focuses on the listening result rather than the process and does not usually aim to enhance learners' metacognitive awareness. In addition, Taguchi (2017) failed to find a treatment effect for metacognitive instruction in developing Japanese EFL learners' listening comprehension. The author further pointed out that listeners without adequate listening practice may not benefit from metacognitive instruction, due to the lack of necessary bottom-up and top-down skills. As a result of these conflicting results, more research is required to assess metacognitive instruction in different settings and with more variables, such as self-efficacy.

2.2. Self-efficacy and L2 listening

Self-efficacy refers to one's own judgment of one's ability to complete a specific task and achieve the desired performance (Bandura, 1977), and "the control over the events that affect their lives" (Bandura, 1989, p. 1175). Self-efficacy beliefs can influence human motivations, achievements, and psychological wellbeing (Bandura, 1992). Given that the processes involved in L2 listening are difficult for learners to control, listening in L2 often results in a reduction in positive feelings of self-efficacy in learners (Graham, 2011). Thus, improving self-efficacy may be important to developing listening ability. Furthermore, previous studies (e.g., Chen, 2007; Rahimi and Abedi, 2014) demonstrated the strong links between self-efficacy, metacognition, and listening ability. Metacognition can regulate the relationships between self-efficacy and listening comprehension (Siegel, 2014). Self-efficacy and metacognition conceptually overlap since one metacognitive awareness factor, namely, Person Knowledge comprises "self-concept and self-efficacy" (Goh and Vandergrift, 2021, p. 92). Therefore, it is reasonable to expect metacognitive instruction to improve listening self-efficacy (Graham, 2011).

However, the evidence concerning the contribution of metacognitive instruction to self-efficacy development needs to be clarified. Graham and Macaro (2008) investigated the impact of strategy training with writing feedback on the listening ability and self-efficacy of L2 French learners. This study can be viewed as a metacognitive intervention (Cross, 2015) as it involved diaries and feedback. The results showed that the learners who received the metacognitive intervention reported stronger self-efficacy

beliefs than those who did not. The authors indicated that writing feedback can help learners reflect on their metacognitive knowledge and strategy use. However, Taguchi (2017) found that Japanese EFL learners improved self-efficacy beliefs under metacognitive and traditional instruction, and no significant between-group differences were observed. The author attributed the improvement in self-efficacy to the increased listening practice that both groups engaged in, as more listening practice can contribute to more successful listening experiences. Similarly, Milliner and Dimoski (2021) examined the impact of the metacognitive intervention on Japanese EFL learners' listening self-efficacy. The results showed no significant between-group differences in the listening self-efficacy scores between the metacognitive and traditional groups after training. Despite this, within-group differences indicated that the treatment did help the experimental group improve self-efficacy, but its advantage was "slightly" displayed (p. 1). Hence, given the lack of strong evidence concerning the benefits of metacognitive instruction in enhancing self-efficacy, more research is required.

2.3. Online L2 listening research

Online learning provided new opportunities for L2 listening. For instance, learners can control their listening pace by regulating speech rates and delivery ways (Robin, 2007). They also have the opportunity to listen multiple times and access a large collection of listening resources anytime and anywhere with a stable connection. Moreover, online learning can compensate for teachers' knowledge gaps concerning how to teach listening skills (Chen and Zhang, 2010).

However, research on the effects of online learning on L2 listening comprehension has produced mixed results. Certain studies (e.g., Smidt and Hegelheimer, 2004; Absalom and Rizzi, 2008) found the advantage of online listening tasks, while others (Chen and Zhang, 2010) did not. Absalom and Rizzi (2008) compared online listening tasks to text-based listening tasks with L2 Italian learners. The results showed that online listening tasks can contribute to increased vocabulary and information retention than text-based tasks. However, in the study of Chen and Zhang (2010), instruction with online learning systems did not surpass traditional listening instruction in improving Chinese EFL learners' listening comprehension. Thus far, few studies have delved into metacognitive intervention in an online setting, especially drawing on the Metacognitive Pedagogical Cycle. Barbosa-Hernández (2012) investigated the effects of metacognitive strategy instruction with online listening activities on Colombian EFL learners' listening ability. Using questionnaires, journals, and interviews, the study showed that teaching metacognitive strategies online can help students listen more carefully. For students who lacked time to participate in face-to-face courses, such instruction was especially useful.

In summary, given the inconclusive results regarding the effects of metacognitive instruction and online listening, together with the paucity of research combining both, the study attempted to fill this void by investigating the effects of online metacognitive listening practice on L2 learners' listening comprehension, metacognitive awareness, and self-efficacy. Specifically, the study aims to answer the following research questions:

- To what extent does the online metacognitive listening practice improve Chinese EFL learners' listening comprehension?
- To what extent does the online metacognitive listening practice improve Chinese EFL learners' metacognitive awareness?
- To what extent does the online metacognitive listening practice improve Chinese EFL learners' listening self-efficacy?

3. Method

3.1. Research design

This study used a pre-test–post-test control group quasi-experiment design, with a mixed research method. Quantitative and qualitative data were gathered through listening tests, questionnaires, reflective notes, and interviews. The independent variable was the metacognitive approach of online listening practice in the experimental group (vs. the traditional approach in the control group). The dependent variables were the listening comprehension ability, metacognitive awareness, and listening self-efficacy. Since both the experimental and control groups took classroom-based listening courses taught by the same teacher, this classroom-based instruction variable was controlled for.

3.2. Participants

The study participants were 89 Chinese first-year university EFL learners (8 males and 81 females) from two intact classes, with an average age of 20, ranging from 19 to 22. They were at the intermediate level (CEFR B2 level) at the time of research. From the original recruitment ($N = 100$) from the two classes, 11 students dropped out of the final data analysis as they failed to finish all questionnaires or tests. The two classes were randomly divided into experimental and control groups. Before the study, participants signed informed consent forms and were informed of participating in a study to improve their listening comprehension and the freedom to withdraw.

Moreover, we gained the instructor's permission to conduct a study in her classes, but we did not reveal the specific treatment or research questions to her. She agreed to use the online listening activities as required assignments for students (rather than as optional extra credits) to ensure the student participants engaged in the activities. To control for the in-class interventions, the researchers observed the instructor's lessons several times before the study and found that she mainly used a comprehension approach (Field, 2008) in listening instruction. The typical lesson she taught consisted of the activities of listening, answering questions, and checking, without an attempt to raise metacognitive awareness.

3.3. The self-directed online listening practice package

The self-directed online listening practice includes 28 sets of listening practice exercises (for 14 weeks), each of which was designed based on the Metacognitive Pedagogical Cycle (MPC) (Vandergrift, 2004, 2007), as shown in Table 1. Since holding synchronous discussion sessions is difficult in the online listening context, in the current online listening practice, we removed the discussion part from the MPC but included an extra biweekly reflection stage. Given both discussion and reflection can be used to evoke learners' metacognitive knowledge (Goh, 2008), this replacement was deemed appropriate. Furthermore, we added a sentential dictation practice exercise based on the listening transcript in the fourth stage of the listening practice to integrate more bottom-up listening practice in the MPC, as suggested in the study of Vandergrift and Tafaghodtari (2010).

The online listening practice was delivered through the online questionnaires embedded in web pages. The multi-page layout of the questionnaire matched the multi-stage structure of metacognitive listening. We published two sets of listening practice exercises on a website every week for learners to complete. The listening content contained 3–5 min videos of news and lectures (without subtitles) at a normal speech rate (around 140 wpm) and the topics were in line with those of the in-class listening textbooks. Learners were required to enter their names once they started listening practice, and the researchers could check their responses in the online admin panel. To increase motivation, we received the instructor's permission to combine the practice attendance with the final credits of the in-class listening course.

3.4. Instruments

3.4.1. TEM-4 test

The listening comprehension ability was gauged with the listening sections of two actual TEM-4 (Test for English Majors—Band 4) tests, as the pre-and post-tests. As a nationwide English placement test in China, TEM-4 was familiar to the participating students. Since its debut in 1992, the TEM-4 test has been regularly validated (Jin and Fan, 2011). A Sino-British cooperative validation study conducted between 1993 and 1996 demonstrated that the test was valid and had a Cronbach's alpha of 0.85 (The TEM Test Center, 1997, p. 63). The listening section of the TEM-4 test consisted of the following: (a) three long conversations followed by nine multiple-choice (MC) questions; (b) three monologs followed by nine MC questions; and (c) five short pieces of news followed by 11 MC questions. According to a pre-research survey, the participants had not previously practiced the two sets of TEM-4 tests used (as pre-and post-tests) in the study.

3.4.2. Questionnaires

The study used the Metacognitive Awareness Listening Questionnaire (MALQ) and Listening Self-efficacy Questionnaire (LSQ) to measure the learners' metacognitive awareness and listening self-efficacy. MALQ was developed and validated by Vandergrift et al. (2006). The questionnaire uses a 5-point Likert scale comprising 21 items covering five factors: Planning-evaluation, Directed Attention, Person Knowledge, (no) Mental Translation, and Problem-solving. Previous studies (e.g., Vandergrift and Tafaghodtari, 2010; Rahimi and Katal, 2013; Bozorgian and Alamdari, 2017; Mahdavi and Miri, 2019) showed that the MALQ's reliability was above an acceptable level, with Cronbach $\alpha > 0.7$.

The Listening Self-efficacy Questionnaire (LSQ), adapted from Graham and Macaro (2008), was used to measure listening self-efficacy. This questionnaire appraised listeners' beliefs in their ability to manage specific listening comprehension skills and reflected the task-specific nature of self-efficacy. The questionnaire uses a 100-point scale with four questions and is highly reliable, as reported in a study by Milliner and Dimoski (2021), with a Cronbach α of 0.89. This questionnaire was given immediately after the listening test to narrow down the delay between self-efficacy beliefs and listening performance.

The original MALQ and LSQ were translated into Chinese by two professional translators using a forward-backward translation technique (Lee et al., 2019). Before the study, the two questionnaires were tested with a cohort of 50 non-participants and exhibited acceptable reliability levels, with Cronbach α values of 0.89 and 0.85, respectively.

3.4.3. Reflective notes and interviews

As part of the metacognitive listening practice, the experimental group took biweekly reflective notes during the listening practice (a total of seven times over 14 weeks). Before the experiment, the learners were given prompts for writing notes. They were encouraged to note down learning difficulties, perceived changes in listening ability, strategy use, listening confidence, and any other thoughts for every 2 weeks of practice. The researchers reviewed the notes and provided feedback to each participant to help connect their performance and strategy use (Graham and Macaro, 2008). These reflective notes were collected with online questionnaires, and feedback was sent to each learner via the QQ instant messenger.

Additionally, around 30% of participants from the experimental group met with the researchers for semi-structured interviews after the training. During interviews, they expressed their thoughts on their improved listening abilities, strategies, confidence, and perceptions of listening practice. The interviews lasted around 5–10 min for each participant.

3.5. Procedures

The study lasted one semester, from March 2022 to July 2022, which is around 16 weeks. Week 1 and week 16 were scheduled to administer listening tests, the MALQ, and the LSQ. In the first week, the researchers conducted a single 90-min session to introduce each group to perform the online listening practice package. In week 16, 15 learners were randomly chosen from the experimental group to join the post-interview.

Each week throughout the 14 weeks, the experiment group was assigned two sets of online listening practice exercises on a

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TABLE 1 The stages of online metacognitive listening practice.

Stages	Metacognitive processes
Pre-listening—Planning stage	
Learners read the topic and related words. Then, they answered some questions to plan their listening goals (strategy use and potential listening problems), and made predictions related to information and possible words.	Planning
First listening—First verification stage	
Learners verified their initial hypotheses, made corrections as required, and noted additional information as they understood it (they evaluated the effectiveness of strategies and planned new strategies for the second listening).	Monitoring and evaluation
Second listening—Second verification stage	
Learners listened again and supplemented the information missed in the first listening (and then evaluated the effectiveness of listening strategies for the second listening and the degrees of comprehension). Then, they answered some listening comprehension questions and summarized the main contents of the listening text. After completion, they checked their answers.	Monitoring, evaluation, and problem-solving
Third listening—Final verification stage	
Learners completed the sentential dictation tasks and checked the transcripts. Then, they wrote down difficult words from the listening (and evaluated the difficulty level of the listening materials and their general performance).	Evaluation and problem-solving
Reflection stage	
Learners summarized listening problems and useful strategies in the listening process and planned strategies for the next listening.	Evaluation and problem-solving
Further reflection stage (biweekly)	
Once every 2 weeks, learners took reflective notes on learning difficulties, perceived changes in their listening ability, strategy use, listening confidence, and any other thoughts.	Evaluation and problem-solving

To increase the diversity of practice exercises, the second set of listening practice exercises each week did not involve the bracketed contents.

webpage. The first set followed the arrangement shown in Table 1. To increase the diversity of practice methods, the second set was more concise and included fewer questions than the first set but still engaged learners in the metacognitive processes of planning, monitoring, and evaluation. Learners kept reflective notes every 2 weeks and sent them to the researchers, who returned feedback to each learner within the same week.

The control group was assigned a traditional form of online listening practice package, in which they listened to the same materials three times and then answered comprehension questions or wrote a summary with sentence dictation tasks. In addition, given the increased number of activities in the experimental training, the control group was also required to listen to two extra texts and answer multiple-choice comprehension questions to ensure a comparable level of involvement in listening practice. Both groups could contact the researchers if they encountered any problems during the practice. The researchers occasionally checked the learners' responses to ensure they had completed the practice in a focused manner. The researchers sent personal notifications to ensure the engagement of learners who forgot the practice or who seemed to produce the answers hastily.

3.6. Data analysis

The IBM SPSS 24 software was used to analyze data from the listening tests (TEM-4 tests), the MALQ, and LSQ. We conducted ANCOVA tests to measure the group effects between the two groups with the pre-test scores as the covariates. Learners' responses in reflective notes and interviews were coded and analyzed in the Nvivo11 software. To increase coding reliability, two researchers of the study coded 50% of the data separately and reached an inter-coder agreement at 88%, which is an acceptable level. After negotiating with the second researcher, the first researcher coded the rest of the data and formulated the final themes.

TABLE 2 Descriptive statistics of the listening scores.

Tests	Experimental group ($n = 45$)		Control group ($n = 44$)	
	M	*SD*	*M*	*SD*
Pre-test	13.13	2.35	14.11	3.42
Post-test	15.27	2.6	13.67	3.07

4. Results

4.1. Listening test results

Descriptive analysis was conducted for the pre-and post-listening test scores, as shown in Table 2. The pre-and post-test listening scores met the assumption of homogeneity of variance in Levene's test of equality ($p = 0.15$; $p = 0.73$). According to Figure 1, as compared with the post-test, only the experimental group demonstrated an increase in post-listening scores while the control group showed a slight decrease. A similar result has been reported in the literature. For instance, in the study by Milliner and Dimoski (2021), the control group and strategy group also experienced a decrease in listening scores after the

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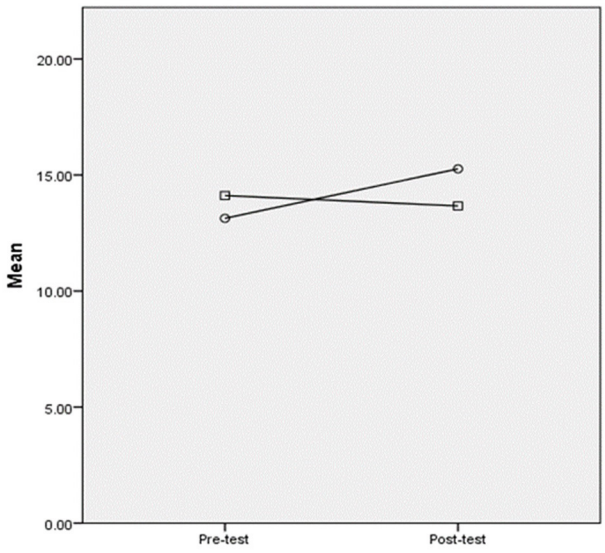

FIGURE 1
Plot comparing the pre-and post-test listening scores. ○ = The experimental group; □ the control group.

TABLE 3 ANCOVA results of the group effect on the listening scores.

Source	*df*	Mean square	*F*	*p*	η^2
Group	1	71.11	8.92	0.004**	0.09
Pre-test	1	35.74	4.49	0.03*	0.05
Residual	86	7.97			

*$p < 0.05$.
**$p < 0.01$.

training, which implies that enhancing listening abilities through practice is not easy and may require a substantial amount of time. Thereafter, we ran an ANCOVA test to examine the group effect with the pre-test scores as the covariate and the post-test as the dependent variable. According to the results of the ANCOVA test (see Table 3), the results indicated a significant group effect ($p = 0.004$) with a medium effect ($\eta^2 = 0.09$), suggesting that the online metacognitive listening practice can significantly improve the learners' L2 listening comprehension ability.

4.2. Questionnaire results

4.2.1. MALQ results

Table 4 shows the descriptive analysis of the MALQ results for each metacognitive factor. The assumption of homogeneity of variances was met for the pre-and post-test MALQ total scores ($p = 0.59$; $p = 0.15$). Table 4 shows that both the experimental and control groups improved metacognitive awareness by comparing the pre-test and post-test scores, with the largest improvements observed for Planning-evaluation and Problem-solving. Thereafter, an ANCOVA test was conducted to check the group effect among the five metacognitive factors, using post-test scores as

TABLE 4 Descriptive statistics of the metacognitive awareness factors.

Source	Factors	Experimental group ($n = 45$)		Control group ($n = 44$)	
		M	*SD*	*M*	*SD*
Pre-test	Planning-evaluation	2.73	0.75	2.59	0.81
	Directed attention	3.38	0.73	3.38	0.70
	Person knowledge	2.33	0.79	1.92	0.74
	Mental translation	2.86	0.79	2.89	0.82
	Problem-solving	2.84	0.74	2.58	0.83
	Total	2.83	0.40	2.67	0.38
Post-test	Planning-evaluation	3.40	0.57	3.05	0.59
	Directed attention	3.42	0.59	3.41	0.70
	Person knowledge	2.17	0.74	2.09	0.66
	Mental translation	2.61	0.72	2.83	0.68
	Problem-solving	3.28	0.55	3.06	0.61
	Total	2.98	0.38	2.89	0.31
Pre-post change	Planning-evaluation	0.67	0.73	0.46	0.87
	Directed attention	0.04	0.78	0.03	0.64
	Person knowledge	−0.16	0.58	0.17	0.91
	Mental translation	−0.25	0.90	−0.06	0.87
	Problem-solving	0.44	0.75	0.48	0.87
	Total	0.15	0.40	0.22	0.39

the dependent variable and pre-test scores as the covariates (see Table 5). Table 5 demonstrates a significant group effect for the Planning-evaluation factor ($p = 0.002$), but no group effects were detected regarding the total scores or the remaining factors. As shown in Figure 2, the experimental group exhibited a greater improvement for Planning-evaluation than the control group after the treatment. The results indicated that the treatment effect only existed for the Planning-evaluation factor but did not exist for the other factors or the total metacognitive scores.

4.2.2. LSQ results

Listening Self-efficacy Questionnaires (LSQ) were administered immediately after the pre-and post-listening tests. The description analysis is shown in Table 6. From Table 6 and Figure 3, it can be seen that the control group had higher self-efficacy scores as

TABLE 5 ANCOVA results of the group effect on the metacognitive awareness factors.

Source	Factors	*df*	Mean square	*F*	*p*	η^2
Group	Planning-evaluation	1	2.23	7.30	0.002**	0.08
	Directed attention	1	0.002	0.01	0.94	0.00
	Person knowledge	1	0.18	0.47	0.50	0.01
	Mental translation	1	1.06	2.39	0.13	0.03
	Problem-solving	1	0.59	1.97	0.16	0.02
	Total	1	0.02	0.18	0.68	0.00

**$p < 0.01$.

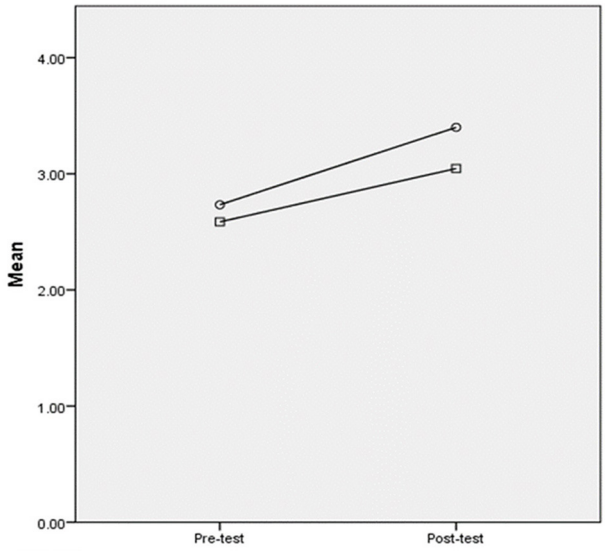

FIGURE 2
Plot comparing the pre-and post-test scores of the planning-evaluation factor. ○ = The experimental group; □ the control group.

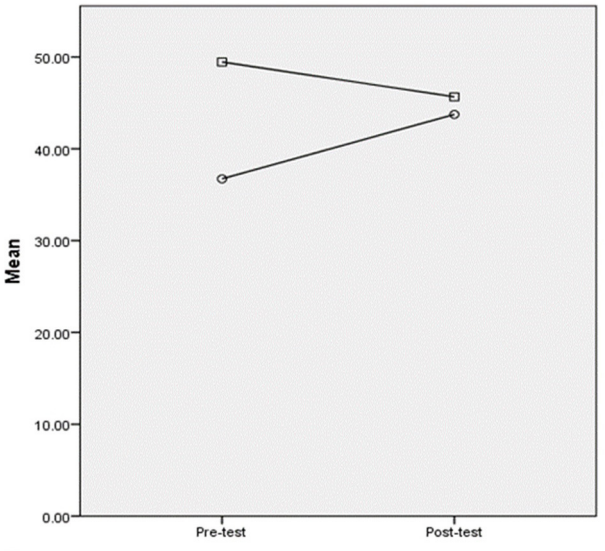

FIGURE 3
Plot comparing the pre-and post-test self-efficacy scores. ○ = The experimental group; □ the control group.

TABLE 6 Descriptive statistics of the self-efficacy scores.

Tests	Experimental group ($n = 45$)		Control group ($n = 44$)	
	M	*SD*	*M*	*SD*
Pre-test	36.72	12.58	49.31	15.34
Post-test	43.74	15.00	45.63	13.95

compared to the experimental group in the pre-test, while their scores were similar in the post-test. After training, the experimental group exhibited an increase in self-efficacy score, while the control group exhibited a decrease, which was similar to their performance in listening tests (see Figure 1). It can be implied that neither group was confident about their listening performance, given that their mean scores were <50 on a 100-scale measurement. ANCOVA was conducted to check the group differences by controlling for the pre-test scores as the covariate (see Table 7). Table 7 shows that there were no between-group differences in self-efficacy scores [$F_{(1,86)} = 0.69$, $p = 0.41$], suggesting no treatment effect on self-efficacy. We further conducted paired-sample *T*-tests to examine the within-group differences in self-efficacy scores. The experimental group's post-test scores were significantly higher than their pre-test scores [$t_{(1,44)} = -2.72$, $p = 0.009$], but no within-group differences were found in the control group [$t_{(1,43)} = 1.61$, $p = 0.11$]. This indicated that the experimental group developed listening self-efficacy after training, but superiority to the control group was not observed.

In summary, the results of the listening tests and questionnaires showed that the experimental group receiving online metacognitive listening practice outperformed the control group on the listening tests. However, the results provided scant evidence for treatment effects on metacognitive awareness and self-efficacy. A significant treatment effect was only observed for the Planning-evaluation factor, but not for listening self-efficacy. The following analysis of the reflective notes and

interviews from the experimental group can help enrich the above results.

4.3. Results from reflective notes and interviews

The analysis of the reflective notes and interview data provided us with more insights into the development of listening ability, metacognitive awareness, and self-efficacy.

First, learners acknowledged an improvement in listening comprehension ability and reported a metacognitive awareness of using strategies to solve problems in listening (e.g., planning, reflection, prediction, selective attention, directed attention, etc.), as seen in Table 8.

In the reflective notes and interviews, the learners (e.g., Sophia, Alice, and Ella) reported progress in their listening comprehension ability. Moreover, some learners (e.g., Leah, Harper, Camila, Ella, Mila, and Nova) indicated the development of listening strategies, especially those about planning (e.g., planning, prediction, and selective attention) and reflection (evaluation). Also, Mila revealed that she was developing an awareness of prediction (planning) and reflection (evaluation) during the online listening practice. These accounts illustrate the development of listening comprehension and Planning-evaluation derived from listening tests and the MALQ questionnaires.

Second, as seen in Table 9, learners perceived uncertainty in listening confidence and problems in anxiety. Meanwhile, there is a fluctuating awareness of using mental translation among these learners.

According to Audrey, Harper, and Sophia's statements, their listening confidence and anxiety were affected by the specific listening activities. For them, difficult listening tasks or tests seemed to decrease their listening confidence and increase their listening anxiety. Ruby appeared to support the use of mental translation after weighing its value, whereas Delilah held a neutral attitude toward it. Noah admitted the impossibility of avoiding mental translation. Learners appeared to have differing views about the value of avoiding mental translation, the benefits of which were not clearly shown.

In summary, the qualitative results suggested that the experimental group confirmed their progress in improving their listening ability and their metacognitive awareness of adopting strategies to manage the listening process and tackle listening problems. However, participants were uncertain regarding listening confidence, anxiety, and mental translation, which may explain the limited effects of the treatment on metacognition and self-efficacy, as reported in the quantitative results.

TABLE 7 ANCOVA results of the group effect on the self-efficacy scores.

Source	*df*	Mean square	*F*	*p*	η^2
Group	1	129.19	0.69	0.41	0.01
Pre-test	1	2,221.73	11.90	0.001*	0.12
Residual	86	186.73			

*$p < 0.05$.

5. Discussion

5.1. Listening comprehension ability

Responding to the first research question, the experimental group under the online metacognitive listening practice significantly outperformed the traditional group on the final listening test, suggesting a positive treatment effect. This result supports the previous conclusion (e.g., Vandergrift and Tafaghodtari, 2010; Cross, 2011; Bozorgian, 2014; Bozorgian and Alamdari, 2017) that increasing metacognitive awareness during the listening process does have value in improving L2 listening comprehension ability. Vandergrift and Tafaghodtari (2010) found that L2 listeners receiving metacognitive instruction significantly outperformed those of traditional listening instruction in L2 listening. They indicated that the frequent involvement in metacognitive processes enables learners to acquire the implicit knowledge of listening strategies and metacognition progressively. With this tacit knowledge, learners can regulate listening processes and establish learning automatization (Wenden, 1998), thus acting as expert listeners (Field, 2008). Similarly, in the present study, learners were allowed to constantly engage in the cycle of metacognitive processes via online listening practice, which helped them form implicit listening knowledge and facilitated learner autonomy and listening development.

This study also alludes to the critical role of self-reflection tasks, although some earlier studies (e.g., Bozorgian and Alamdari, 2017; Mahdavi and Miri, 2019) highlighted the role of discussion in metacognitive instruction. While learners have little opportunity for discussion in a self-directed online setting, they can gain metacognition awareness from reflections and external feedback. Graham and Macaro (2008) indicated that reflective diaries with written feedback could assist listeners in establishing a link between strategy use and listening performance. Goh and Vandergrift (2021) suggested that guided reflection tasks, either from discussion or self-reflection, are helpful in eliciting listeners' metacognitive knowledge. With increased metacognitive knowledge, learners can monitor their listening process and attain listening improvements independently.

5.2. Listening metacognitive awareness

For the second research question, it was found that the experimental group significantly outperformed the traditional group in only one factor of metacognitive awareness, namely, Planning-evaluation. The significant improvement in Planning-evaluation is consistent with the study of Bozorgian (2014), which showed that metacognitive instruction can significantly improve Iranian EFL learners' two sub-factors of metacognitive awareness, i.e., Planning-evaluation and Problem-solving. Similarly, limited improvement in metacognitive awareness was also noted in Vandergrift and Tafaghodtari (2010), which found that the positive

effect of metacognitive instruction is only associated with Problem-solving. Given the limited between-group differences, they inferred that the control group's improvement in metacognitive awareness might be attributed to exposure to the metacognitive listening questionnaire. This explanation can also be applied in this study, as the control group improved certain metacognitive awareness factors (as shown in Table 4).

The limited development of metacognitive awareness may also be related to the task settings of the Metacognitive Pedagogical Cycle (MPC) (Vandergrift, 2004, 2007). Most MPC tasks focus on the training of planning, verification, and evaluation strategies, thus highlighting the Planning-evaluation factor more than other factors, such as Directed Attention and Mental Translation. That is, listeners have more opportunities to practice the strategy of planning and evaluation under MPC. The experimental group's success in Planning-evaluation, not in the other factors, may be explained by such task settings. Furthermore, explanations can be framed in terms of different weights in the sub-factors of metacognitive awareness. Azmee (2022) discovered that certain factors, such as Planning-evaluation, Directed Attention, and Problem-Solving, strongly link with listening ability. In contrast, others, such as Person Knowledge and Mental Translation, only have marginal relationships with L2 listening ability.

In addition, the reflective notes and interviews from the experimental group may help explain the partial development of metacognitive awareness. These learners reported an awareness of certain strategies, such as planning and reflection but also had an uncertain attitude toward the effectiveness of mental translation.

TABLE 8 Excerpts on listening comprehension and strategy use.

Reflective notes	Codes	Themes
After 2 weeks of listening practice, I became more interested in this kind of practice, and my listening ability has improved. (Sophia 2) Initially, I hardly followed the listening *s*peed, but now I feel much better. (Alice 4)	Improvement in understanding fast speech	Improvement in listening comprehension
I can make predictions and recall some content and ideas before listening. (Leah 2)	Prediction strategy	Awareness of planning-evaluation
It is necessary to make a long-term listening plan and persist in it. (Harper 3)	Planning strategy	
I need to think about my listening problems and weakness carefully. (Camila 3)	Reflection strategy	
I should focus on the main idea and compare it with my predictions. (Ella 3)	Selective attention strategy	
Interviews	**Codes**	**Themes**
(Now) While listening, I can grasp more details and become more patient than before. (Ella)	Improved comprehension ability	Improvement in listening comprehension
Through online listening practice, I realize that listening does not just mean listening itself, but involves many activities like prediction and reflection. (Mila)	Prediction and reflection strategy	Awareness of planning-evaluation
Reflection must be helpful. Through reflection, I can find some potential problems I did not realize before. (Nova)	Reflection strategy	

The names reported here are pseudonyms. The numbers after the names denote the time of the note within seven notes in 14 weeks.

TABLE 9 Excerpts on confidence, anxiety, and mental translation.

Reflective notes	Codes	Themes
Over a long period of listening practice, I gradually obtained more confidence. (Leah 4)	Improved listening confidence	Uncertainty in confidence and problems with anxiety
I have trouble listening to some new words, which causes me to become anxious, distracted, and less confident. (Audrey 3)	Existing problems with anxiety and confidence	
With more practice and awareness, I did not translate mentally as much. (Sophia 4)	Improvement in avoiding mental Translation	Fluctuation in mental translation
I don't think metal translation is bad. The amount of time required for translation will decrease as we become more proficient. The translation itself is a just kind of understanding. (Ruby 2)	Benefits of mental translation	
I do not mentally translate short and simple sentences, but I do it for long and complex sentences. (Delilah 5)	Using mental translation in different contexts	
Interviews	**Codes**	**Themes**
I feel a little improvement in confidence. However, I still fail to do the tasks well in the tests. (Harper)	Slight improvement in confidence	Uncertainty in confidence and problems with anxiety
Once I fail to understand some parts of listening, I feel very anxious. (Sophia)	Existing problems with anxiety	
I feel it is impossible to avoid mental translation. My first task in listening is to translate what comes into my head. (Noah)	Impossibility of avoiding mental translation	Fluctuation in mental translation

The names reported here are pseudonyms. The numbers after the names denote the time of the note within seven notes in 14 weeks.

Nevertheless, it made sense that some learners retained the use of mental translation given that the use of L1 is often regarded as a helpful strategy for L2 reading and writing. For instance, Kern (1994) indicated that the use of L1 can assist learners in overcoming cognitive limits and removing affective barriers when reading, e.g., L2 writers often fall back on L1 in translating keywords (Sasaki, 2000) and thinking about the writing process (Cumming, 1990). Even if translation mentally can impede comprehension fluency, it may be helpful to jot down keywords and it can help alleviate anxiety (as shown in some learners' notes), as seen in L2 reading and writing.

5.3. Listening self-efficacy

As regards the third research question, the online metacognitive listening practice did not yield a significant treatment effect on listening self-efficacy, although within-group differences were observed in the experimental group. Nevertheless, this result agrees with the findings of Taguchi (2017) and Milliner and Dimoski (2021). Both investigated the effects of metacognitive instruction on listening self-efficacy with Japanese EFL learners. In Taguchi's study, both the experimental and control groups made improvements in listening self-efficacy, although no treatment effect was found. The author suggested that the improvement in self-efficacy in both groups was due to increased listening practice, which contributed to an increase in successful listening (mastery) experiences (Bandura, 1994) and listening self-efficacy. Milliner and Dimoski's (2021) findings are similar to those of the present study, i.e., no treatment effect for self-efficacy was detected, but the experimental group showed significant improvement in listening self-efficacy. The authors further indicated that the partial improvement in self-efficacy may help sustain the development of listening comprehension over time, given that self-efficacy beliefs can increase learners' efforts and perseverance. Since the present study and Milliner and Dimoski's (2021) study used the same questionnaire from Graham and Macaro (2008), the similar results from the two studies increase the replicability and further confirm the limited effects of the metacognitive intervention on self-efficacy.

Furthermore, listening self-efficacy appears to be task dependent. Some learners indicated that their listening confidence and anxiety are influenced by the difficult listening tasks with quick speech rates and unfamiliar words, or high-stake tests. It is plausible that difficult listening tasks reduce opportunities for successful listening experiences, i.e., mastery experiences (Bandura, 1994), thus weakening their self-efficacy beliefs. Therefore, the control group with limited intervention in improving metacognitive awareness in terms of self-managing and evaluating the listening process may have been blocked by difficult listening tasks, leading to a decline in self-efficacy. However, due to the higher pre-test scores of the control group in the present study, we cannot rule out the influence of the ceiling effect on the post-test scores. Therefore, further studies aimed at examining changes in self-efficacy should consider investigating learner groups with a similar level of self-efficacy before the study.

6. Conclusion

This study adds to the limited research on online metacognitive listening intervention and investigates its effect on listening comprehension, metacognitive awareness, and self-efficacy. The results demonstrate that the self-directed online listening practice deployed under the Metacognitive Pedagogical Cycle (MPC) can significantly improve Chinese intermediate EFL learners' listening comprehension. This finding suggests that the MPC is a promising approach for improving L2 listening in self-directed learning contexts. However, the treatment effect on metacognitive awareness and self-efficacy is not conclusive. Learners significantly improved in the only sub-factor of metacognitive awareness, i.e., Planning-evaluation, but not in the listening self-efficacy.

This study also makes some noteworthy methodological contributions. Firstly, we adapted the metacognitive pedagogical cycle into sets of self-directed online listening practice exercises, so that learners can experience metacognitive listening processes on their own. Second, we attempted to balance the efforts of the experimental and control groups by giving more practice to the control group, due to the lower task complexity. Third, the study used various data sources (i.e., listening tests, questionnaires, reflective notes, and interviews) to triangulate the findings, increasing the study's trustworthiness.

One limitation of the study is that we conducted interviews only with the experimental group, which may have resulted in missing information about the perceived change in the control group. To gain a more complete understanding of the differences between the two groups, future research should include interviews from both groups. Besides, the sample size of 89 participants in this study is relatively modest, with <50 in the experimental group, and future investigations may consider expanding the sample size to enhance the reliability. Additionally, the study removed the discussion part from the MPC due to the difficulty of implementation in an online setting, which was partly redeemed with extra reflection activities. Since previous studies (e.g., Bozorgian and Alamdari, 2017; Mahdavi and Miri, 2019) have highlighted the crucial role of discussion in developing listeners' metacognitive awareness, further studies could explore the possibility of including synchronous or asynchronous discussions during online listening.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by School of Foreign Languages, Shaoguan University. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

TP: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Writing—original draft, Writing—review & editing. JS: Conceptualization, Methodology, Supervision, Writing—review & editing. HL: Writing—review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Absalom, M., and Rizzi, A. (2008). Comparing the outcomes of online listening versus online text-based tasks in university level Italian L2 study. *ReCALL*. 20, 55–66. doi: 10.1017/S0958344008000517

Ahmadi Safa, M., and Motaghi, F. (2021). Cognitive vs. metacognitive scaffolding strategies and EFL learners' listening comprehension development. *Lang. Teach. Res.* doi: 10.1177/13621688211021821. [Epub ahead of print].

Alamdari, E., and Hosnbakhshan, L. (2021). The dilemma of metacognitive Intervention and EFL listening: Is L1 a panacea in EFL contexts? *Interdiscipl. Stud. Engl. Lang. Teach.* 1, 22–40. doi: 10.22080/ISELT.2021.20666.1004

Azmee, A. (2022). The impact of the podcast (BBC sounds) to raise metacognitive awareness in developing L2 listening comprehension among Bangladeshi undergraduate learners. *CALL-EJ*. 23, 103–119. Available online at: https://callej.org/journal/23-4/Azmee2022.pdf

Bandura, A. (1977). Self-efficacy: toward a unifying theory of behavioral change. *Psychol. Rev.* 84, 191–215. doi: 10.1037/0033-295X.84.2.191

Bandura, A. (1989). Human agency in social cognitive theory. *Am. Psychol.* 44, 1175–1184. doi: 10.1037/0003-066X.44.9.1175

Bandura, A. (1992). "Exercise of personal agency through the self-efficacy mechanism" in *Self-Efficacy: Thought Control of Action*, ed. R. Schwarzer (Washington, DC: Hemisphere), 3–38.

Bandura, A. (1994). *"Self-Efficacy" in Encyclopedia of Human Behavior*, ed. V. S. Ramachaudran (New York, NY: Academic Press), 71–81.

Barbosa-Hernández, S. P. (2012). "*Applying a metacognitive model of strategic learning for listening comprehension, by means of online-based activities, in a college course*" (Master's thesis). Universidad de La Sabana, Cundinamarca, Colombia.

Bozorgian, H. (2014). The role of metacognition in the development of EFL learners' listening skill. *Int. J. List.* 28, 149–161. doi: 10.1080/10904018.2013.861303

Bozorgian, H., and Alamdari, E. (2017). Multimedia listening comprehension: Metacognitive instruction or metacognitive instruction through dialogic interaction. *ReCALL*. 30, 131–152. doi: 10.1017/S0958344016000240

Bozorgian, H., and Shamsi, E. (2023). A review of research on metacognitive instruction for listening development. *Int. J. List*. doi: 10.1080/10904018.2023.2197008. [Epub ahead of print].

Chen, H. Y. (2007). "*The relationship between EFL learners' self-efficacy beliefs and English performance*" (Dissertation). Florida State University, Tallahassee, FL, USA.

Chen, L. M., and Zhang, R. (2010). Web-Based CALL to listening comprehension. *Curr. Issues Educ.* 13, 1–23. Available online at: https://cie.asu.edu/ojs/index.php/cieatasu/article/view/286

Cross, J. (2011). Metacognitive instruction for helping less-skilled listeners. *ELT J.* 65, 408–416. doi: 10.1093/elt/ccq073

Cross, J. (2015). Metacognition in L2 listening: clarifying instructional theory and practice. *TESOL Q.* 49, 883–892. doi: 10.1002/tesq.258

Cumming, A. (1990). Metalinguistic and ideational thinking in second language composing. *Writ. Commun.* 7, 482–511. doi: 10.1177/0741088390007004003

Fahim, M., and Fakhri, A., E. (2014). Exploring the effect of the model of metacognitive instruction on the listening performance of EFL learners. *Int. J. Res. Stud. Lang. Learn*. 3, 3–20. doi: 10.5861/ijrsll.2014.700

Field, J. (2008). *Listening in the Language Classroom*. Cambridge: Cambridge University Press.

Flavell, J. H. (1979). Metacognition and cognitive monitoring: a new area of cognitive-developmental inquiry. *Am. Psychol.* 34, 906–911. doi: 10.1037/0003-066X.34.10.906

Goh, C. (2008). Metacognitive instruction for second language listening development: theory, practice and research implications. *RELC J.* 39, 188–213. doi: 10.1177/0033688208092184

Goh, C. C., and Vandergrift, L. (2021). *Teaching and Learning Second Language Listening: Metacognition in Action*. New York, NY: Routledge.

Graham, S. (2011). Self-efficacy and academic listening. *J. English Acad. Purp.* 10, 113–117. doi: 10.1016/j.jeap.2011.04.001

Graham, S., and Macaro, E. (2008). Strategy instruction in listening for lower-intermediate learners of French. *Lang. Learn.* 58, 747–783. doi: 10.1111/j.1467-9922.2008.00478.x

Jin, Y., and Fan, J. (2011). Test for English majors (TEM) in China. *Lang. Test.* 28, 589–596. doi: 10.1177/0265532211414852

Kern, R. G. (1994). The role of mental translation in second language reading. *Stud. Second Lang. Acquis.* 16, 441–461. doi: 10.1017/S0272263100013450

Lee, W. L., Chinna, K., Lim Abdullah, K., and Zainal Abidin, I. (2019). The forward-backward and dual-panel translation methods are comparable in producing semantic equivalent versions of a heart quality of life questionnaire. *Int. J. Nurs. Pract.* 25, 1–9. doi: 10.1111/ijn.12715

Mahdavi, N., and Miri, M. (2019). Co-shaping metacognitive awareness and developing listening comprehension through process-based instruction. *Int. J. List.* 33, 53–70. doi: 10.1080/10904018.2016.1260454

Milliner, B., and Dimoski, B. (2021). The effects of a metacognitive intervention on lower-proficiency EFL learners' listening comprehension and listening self-efficacy. *Lang. Teach. Res.* doi: 10.1177/13621688211004646. [Epub ahead of print].

Norris, J. M., Davis, J. M., and Timpe-Laughlin, V. (2017). *Second Language Educational Experiences for Adult Learners*. New York, NY: Routledge.

Rahimi, M., and Abedi, S. (2014). The relationship between listening self-efficacy and metacognitive awareness of listening strategies. *Proc. Soc. Behav. Sci.* 98, 1454–1460. doi: 10.1016/j.sbspro.2014.03.565

Rahimi, M., and Katal, M. (2013). The impact of metacognitive instruction on EFL learners' listening comprehension and oral language proficiency. *J. Teach. Lang. Skills* 5, 69–90. doi: 10.22099/jtls.2013.1555

Razavi, G. S., Fakhri Alamdari, E., and Ahmadian, M. (2023). EFL listening, metacognitive awareness, and motivation: the magic of L1-mediated metacognitive intervention. *J. Psycholinguist. Res.* 52, 477–495. doi: 10.1007/s10936-022-09895-3

Robin, R. (2007). Commentary: learner-based listening and technological authenticity. *Lang. Learn. Technol.* 11, 109–115. doi: 10125/44092

Sasaki, M. (2000). Toward an empirical model of EFL writing processes: an exploratory study. *J Second Lang. Writ.* 9, 259–291. doi: 10.1016/S1060-3743(00)00028-X

Satori, M. (2022). Effects of field independence, metacognitive knowledge, and vocabulary knowledge on second language listening comprehension. *Int. J. List.* 36, 254–267. doi: 10.1080/10904018.2022.2056037

Siegel, J. (2014). Exploring L2 listening instruction: examinations of practice. *ELT J.* 68, 22–30. doi: 10.1093/elt/cct058

Siegel, J. (2015). *Exploring Listening Strategy Instruction through Action Research*. New York, NY: Palgrave Macmillan.

Smidt, E., and Hegelheimer, V. (2004). Effects of online academic lectures on ESL listening comprehension, incidental vocabulary acquisition, and strategy use. *Comput. Assist. Lang. Learn.* 17, 517–556. doi: 10.1080/0958822042000319692

Taguchi, K. (2017). *Metacognitive Listening Strategy Instruction for EFL Learners*. The Bulletin of the Institute of Human Sciences, Toyo University, 19. Available oniline at: https://www.toyo.ac.jp/uploaded/attachment/111208.pdf (accessed August 29, 2023).

The TEM Test Center (1997). *The Test for English Majors (TEM) Validation Study*. Shanghai: Shanghai Foreign Language Education Press.

Vandergrift, L. (2003). Orchestrating strategy use: toward a model of the skilled second language listener. *Lang. Learn.* 53, 463–496. doi: 10.1111/1467-9922.00232

Vandergrift, L. (2004). Listening to learn or learning to listen? *Annu. Rev. Appl. Linguist.* 24, 3–25. doi: 10.1017/S0267190504000017

Vandergrift, L. (2007). Recent development in second and foreign language listening comprehension research. *Lang. Teach.* 40, 191–210. doi: 10.1017/S0261444807004338

Vandergrift, L., Goh, C. C., Mareschal, C. J., and Tafaghodtari, M. H. (2006). The metacognitive awareness listening questionnaire: development and validation. *Lang. Learn.* 56, 431–462. doi: 10.1111/j.1467-9922.2006.00373.x

Vandergrift, L., and Tafaghodtari, M. H. (2010). Teaching L2 learners how to listen does make a difference: an empirical study. *Lang. Learn.* 60, 470–497. doi: 10.1111/j.1467-9922.2009.00559.x

Wang, W. (2016). Learning to listen: the impact of a metacognitive approach to listening instruction. *Asia-Pac. Educ. Res.* 25, 79–88. doi: 10.1007/s40299-015-0235-4

Wenden, A. (1998). Metacognitive knowledge and language learning. *Appl. Linguist.* 19, 515–537. doi: 10.1093/applin/19.4.515

Zhang, L. J., and Shen, Y. (2023). What two decades of research into L2 listening in System tells us: Looking back for looking forward. *System*. 112, 1–14. doi: 10.1016/j.system.2022.102970

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Assessing the intention to accept inquiry-based teaching pedagogy among Chinese university students: an extension of technology acceptance model

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Introduction: Due to the limitations of traditional didactic teaching, inquiry-based teaching has attracted increasing attention and has become an important content of curriculum teaching reform in college education. Nevertheless, it is vital to investigate students' subjective acceptance of inquiry-based instruction and its influencing factors before inquiry-based teaching methods are widely implemented.

Methods: In light of this, taking into account the psychological factors of students, an acceptance model of inquiry-based teaching pedagogy was established based on the extended technology acceptance model (TAM). Three additional variables, namely self-efficacy, implementation quality, and risk perception, were incorporated into the TAM. Firstly, subjective evaluation data of the influencing factors of inquiry teaching acceptance were obtained through a network questionnaire survey from university students in Guangdong, China, using snowball sampling and convenient sampling. A total of 485 valid questionnaires were retrieved, with an effective response rate of 88.2%. Then, internal consistency and reliability, convergent validity and discriminant validity of the model and its hypothesis were tested with reliability and validity tests. Finally, path analysis was used to examine key determinants of students' acceptance of inquiry teaching and moderators.

Results: Results indicated that the constructed model can explain the acceptability of inquiry teaching for college students by 88.6%; Attitude has a positive significant impact on behavioral intention; Perceived ease of use indirectly affects behavioral intention through perceived usefulness, while perceived usefulness indirectly affects behavioral intention through attitude; self-efficacy not only directly affects behavioral intention but also indirectly affects behavioral intention through implementation quality; implementation quality indirectly affects behavioral intention through perceived usefulness and attitude; students' risk perception of inquiry-based teaching has no negative impact on behavioral intention.

Conclusion: Overall, this study has implications for policymakers, teachers or learners in terms of the implementation and promotion of inquiry-based teaching in college classroom.

KEYWORDS

inquiry-based teaching pedagogy, intention to accept, technology acceptance model, influencing factors, path analysis, university students

1 Introduction

With the development of society and the progress of science and technology, universities education is increasingly paying attention to cultivating students' innovative thinking and problem-solving abilities (Justice et al., 2009). Traditional teaching methods are no longer able to meet the needs of students. Therefore, inquiry-based teaching methods have gradually gained widespread attention and have become an indispensable part of the curriculum teaching reform (Keselman, 2003; Kiernan and Lotter, 2019). Inquiry-based teaching is student-centered learning and teaching, which encourages students to actively discover, explore, collaborate, and communicate with their peers, in order to construct knowledge and promote the application of several problem-solving skills (Kogan and Laursen, 2014). Traditional teaching methods focus on "what to learn," that is, what teachers teach and what students learn; while inquiry-based teaching pedagogies emphasize "how to learn" and "learning by doing" (Benlahcene et al., 2020). Besides receiving scientific knowledge directly from teachers in the classroom, students also engage in learning through inquiry and problem-solving activities. Inquiry-based teaching tries to change the focus of the classroom from "teacher's teaching" to "student's learning," which can improve students' initiative, participation, and experience in the classroom learning process unprecedently (Justice et al., 2009; Benlahcene et al., 2020). Furthermore, it can effectively enhance students' problem-awareness, autonomous learning abilities and critical thinking skills, and teamwork spirit (Çakıroğlu and Öztürk, 2017). Inquiry-based teaching is a cutting-edge and advanced classroom teaching method vigorously advocated in the current teaching reform, and it is also an important starting point for building first-class classrooms, thus opening the "last mile" from the construction of first-class universities to the training of first-class talents. A few quantitative studies support the effectiveness of inquiry-based teaching as an instructional approach (Alfieri et al., 2011; Furtak et al., 2012; Fan and Ye, 2022).

The introduction of a new pedagogy (inquiry-based teaching) is often met with challenges and barriers within an existing program or curriculum (Justice et al., 2009). Inquiry-based teaching is a student-centered and problem-oriented teaching method that subverts traditional teaching method, and has obvious advantages in strengthening the links between teaching and research (Spronken-Smith and Walker, 2010). If the inquiry-based teaching is not accepted by students, it will be difficult to play an important role in the implementation process, and its application and popularization in college course education will also be hindered. Therefore, it is valuable to examine inquiry-based teaching acceptance from the perspective of students' cognitive characteristics further in more detail, and identify its key influencing factors in the early stage of the application of inquiry-based teaching. Specifically, discussing students' perspectives and their willingness to accept inquiry-based teaching will make some meaningful contributions to the sustainable development of learner-centered learning/teaching approaches, e.g., mixed methods, problem-oriented, competition-oriented (Ye et al., 2023a). Meanwhile, it has indescribable practical significance for improving its teaching effect and application promotion. For example, research results can help teachers use differentiated and student-centered inquiry-based teaching methods in different subjects.

Most research on inquiry-based teaching methods focuses on analyzing the quality of learning outcomes. To date, however, few empirically studies have explored the acceptance of inquiry-based teaching (Hao and Wang, 2019; Chen and Wang, 2020; Wang and Li, 2020; Hsu and Rowland-Goldsmith, 2021; Fan and Ye, 2022). They mainly investigated the intuitive feelings, acceptance willingness, and satisfaction of college students from different educational backgrounds on inquiry-based teaching methods by online surveys. These research results are all based on descriptive statistics and do not rely on any underlying theoretical models. Public acceptance is a crucial factor for successful technology implementation. Researchers often use the technology acceptance theory to explain public acceptance, such as the Technology Acceptance Model (TAM), the Theory of Planned Behavior (TPB), and the Unified Theory of Acceptance and Use of Technology (UTAUT), etc. The original TAM consists of four factors: perceived usefulness, perceived ease of use, attitude, and behavioral intention to use. More and more scholars extended the TAM model with adding new influencing factors (e.g., self-efficacy, and risk perception) or integrating multiple models to describe public acceptance to further enhance the predictability of the model (Gallego-Gómez et al., 2021; Vladova et al., 2021; Chou et al., 2023; Ohanu et al., 2023). The integrated model has a stronger explanatory power for acceptance willingness, which is widely regarded as the main model for studying public acceptance (Venkatesh et al., 2012). However, these models have not yet been applied to study the acceptance of inquiry-based teaching.

To sum up, research based on any single model has the problem of incomplete consideration of influencing factors, and the research results may be slightly different from the actual case. A model based on the integration of the original TAM and multiple external latent variables (influencing factors) is more explanatory and is a common practice in studying public acceptance (Ye et al., 2023b). Regrettably, current research mainly focuses on the acceptance of information technology teaching and blended teaching methods (Wu et al., 2010; Fathema et al., 2015; Teo et al., 2019; Long and Khoi, 2020; Gallego-Gómez et al., 2021; Ohanu et al., 2023), and research results cannot be fully applied to inquiry-based teaching methods. This is because the influencing factors and their paths (e.g., direct effect, indirect effect or mediating effect) to influence acceptance were different regarding different research objects. Moreover, the results of descriptive statistical analysis cannot reflect the influence mechanism. It is critical to quantify the direct effects and indirect effects of the observable psychological factors on behavioral intention. To fill this research gap, the present study proposes a novel inquiry-based teaching acceptance model that explains the subject acceptance and use of inquiry-based teaching, as well as its influencing factors, by extending TAM. Besides the predictors used in the original TAM (behavioral intention, attitudes, perceived usefulness, perceived ease of use; to be described later), external variables are important antecedents that influence learning experience. Through a review of the literature, self-efficacy, implementation quality, and risk perception are included as the external variables of the research model of acceptance of inquiry-based teaching. The reasons for adding three external variables are twofold: (1) From social cognitive theory, self-efficacy is believed to be the most relevant factors affecting human behavior in performing a specific behavior (Bandura, 1977; Venkatesh et al., 2003; Hong et al., 2019). (2) Learning satisfaction is essential for understanding how students feel about their learning experience (Hossain and Quaddus, 2012; Sockalingam, 2013). The degree of

satisfaction is directly influenced by perceived learning effect and expectations of the perception (denoted as implementation quality), as well as cumulative psychological response to learning contents and learning environment (denoted as risk perception) (Yao et al., 2016).

In summary, this study aims to explore the following core research questions:

> *RQ1: How do psychological factors affect students' acceptance of inquiry-based teaching?*
>
> *RQ2: What are the key determinants of students' acceptance of inquiry teaching and moderators?*

2 Research model and hypothesis development

In order to provide a better understanding to the exploration of injury-based teaching acceptance among Chinese university students, three factors "self-efficacy," "implementation quality" and "risk perception" were incorporated as external variables in the original TAM to form a new theoretical model. The proposed model (as depicted in Figure 1) was used to explore the effects of the proposed external variables on inquiry-based teaching acceptance behavior. The solid line is the path relationship of the original TAM model, and the dotted line is the path relationship of the newly added latent variable. There are two reasons for adding new latent variables: (1) Inquiry-based teaching method is an emerging teaching method that subverts traditional teaching. The perception of its teaching form, implementation quality and risk perception are key factors affecting students' willingness to accept; (2) Self-efficacy is held to be the principal cognitive determinants of individual behavior (Wu et al., 2010). That is, students who had higher self-efficacy will have higher confidence and capability to perform a specific behavior. In the next section, brief definitions and the inferences of the proposed three factors as antecedents of injury-based teaching usage and related hypotheses are presented.

2.1 Attitude and behavioral intention to use

Attitude (ATT) refers to the subjective positive or negative feelings about performing the behavior (Fishbein and Ajzen, 1975; Hong et al., 2020). Here, attitude is defined as the degree to which an individual feels positive or negative about accepting injury-based teaching. Behavioral intention to use (BIU) refers to the degree to which the public uses the thing or is willing to complete a specific behavior. According to the TAM, acceptance depends on the use intention for a particular technology (Davis et al., 1989). Those who hold a positive attitude towards new technologies often have a strong behavioral intention, which ultimately affects actual use behavior (Davis et al., 1989). Ye et al. (2023b) also stated that attitudes toward technology were found to be one of the most important factors influencing the acceptance of the technology. As such, this study makes the following hypothesis:

> *H1*: A positive attitude towards inquiry-based teaching will promote acceptance.

2.2 Perceived usefulness and perceived ease of use

In the original TAM model, perceived usefulness (PU) and perceived ease of use (PEU) are the two most fundamental factors. Perceived usefulness refers to the degree to which the public believes that use of a specific application system can improve job performance (Davis et al., 1989). Inquiry-based teaching can bring many benefits to classroom teaching, such as improving learning interest, stimulating creativity, promoting active learning and team cooperation awareness, etc. These benefits may promote students' positive attitudes and acceptance intentions towards it. Perceived ease of use refers to the degree to which the public believes that a specific application system is easy to use (Davis et al., 1989). If students are not particularly familiar with inquiry-based teaching, they need to spend more energy to adapt and learn. Likewise, if the perceived ease of use is not good, it will have a negative impact on their acceptance of this method. Thus, this study formed theses hypotheses as suggested by Davis et al.

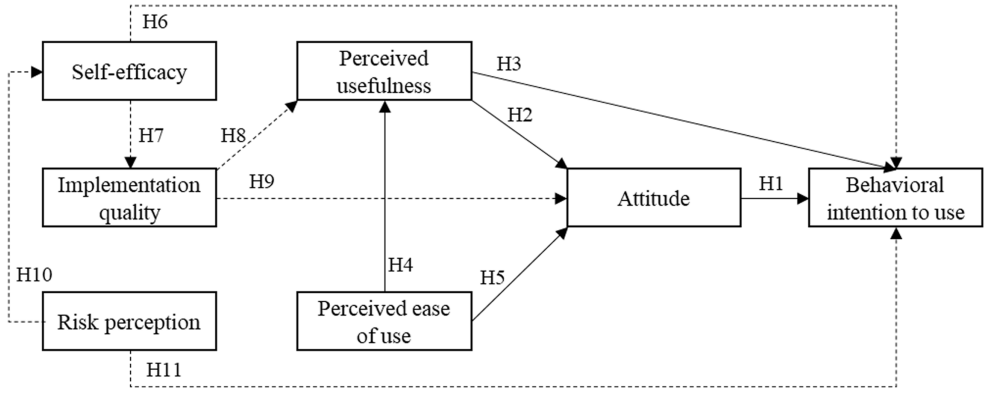

FIGURE 1
Proposed extended TAM (permission for using TAM in the current research has been obtained from the authors).

(1989), which were corroborated by previous studies (Davis et al., 1989; Chang et al., 2015):

> *H2*: Perceived usefulness will have a positive impact on the attitude towards using inquiry-based teaching.
>
> *H3*: Perceived usefulness will have a positive impact on behavioral intention to use inquiry-based teaching.
>
> *H4*: Perceived ease of use will have a positive impact on perceived usefulness of inquiry-based teaching.
>
> *H5*: Perceived ease of use will have a positive impact on attitude towards using inquiry-based teaching.

2.3 Self-efficacy

Self-efficacy refers to an individual's confidence in their ability to effectively complete a task or achieve a goal (Bandura, 1982; Jiang et al., 2021). According to the concept of self-efficacy, self-efficacy is defined as students' ability and confidence to complete various tasks and challenges in the implementation process of inquiry-based teaching. In previous studies, self-efficacy was confirmed as a decisive factor in accepting and using an application system (Venkatesh et al., 2003; Wu et al., 2010). Studies also show that the improvement of self-efficacy can enhance the initiative and persistence of individual learning, thereby improving their good expectations for implementation results and behavioral intentions (Johnston et al., 2005; Francescato et al., 2006). In addition, empirical research has found that there is a significant positive correlation between self-efficacy and students' learning attitudes and abilities (Venkatesh and Davis, 2000), that is, students with higher sense of self-efficacy are more likely to have better learning attitudes and abilities to adapt to inquiry-based teaching. They will be more recognized for its value and full of expectations for it, thereby stimulating their behavioral intentions to use this method. Following the findings of these studies, the following hypotheses were proposed:

> *H6*: Self-efficacy will have a positive impact on behavioral intention to use inquiry-based teaching.
>
> *H7*: Self-efficacy will have a positive impact on implementation quality of inquiry-based teaching.

2.4 Implementation quality

Implementation quality is defined as the degree of an individual's perception of how well the system (Venkatesh and Davis, 2000). Here, implementation quality is a measure of the quality and effectiveness of inquiry-based teaching, including teacher's process guidance, inquiry of questions, student participation and interactive atmosphere. Studies have shown that implementation quality has a significant impact on public's positive perception of things. It is believed that implementation quality affects perceived usefulness and attitude (Venkatesh and Bala, 2008). The higher the implementation quality of inquiry-based teaching methods, the better the participation experience for students, giving them better thinking inspiration and exploration space. Therefore, they can perceive its usefulness more positively and have positive behavioral attitudes towards it (Venkatesh and Bala, 2008; Fathema et al., 2015; Teo et al., 2019). Therefore, the following hypotheses are proposed:

> *H8*: Implementation quality will have a positive impact on perceived usefulness of inquiry-based teaching.
>
> *H9*: Implementation quality will have a positive impact on attitude towards accepting inquiry-based teaching.

2.5 Risk perception

Risk perception (RP) refers to individuals' risk cognition and evaluation of certain situations or behaviors, which can determine individuals' behavior to a certain extent (Dowling and Staelin, 1994). Risk perception is introduced in this paper is that because students are not particularly familiar with inquiry-based teaching, they may exhibit negative effects such as not achieving expected teaching results or perceiving this method as having great challenges and uncertainties. Risk perception is crucial for acceptance intention (Dowling and Staelin, 1994; Lo, 2013; Alalwan et al., 2016). Risk perception is a prerequisite for trust and acceptance. Only by reducing risk perception can acceptance intention be improved (Mou, 2017). In addition, research has shown that there was a close relationship between risk perception and self-efficacy. Bandura pointed out that when individuals perceive higher risks, their sense of self-efficacy decreases (Bandura et al., 1999). Because he feels that he cannot overcome these risks and cannot successfully complete tasks or achieve goals. Conversely, when a person perceives low risks, his sense of self-efficacy increases because he believes he can easily complete a task or achieve a goal. Therefore, the following hypotheses are:

> *H10*: Risk perception will have a negative impact on self-efficacy.
>
> *H11*: Risk perception will have a negative impact on the behavioral intention of using inquiry-based teaching.

3 Methods

3.1 Participants

In total, 485 undergraduate students from universities in the Guangdong region were invited to complete the online survey on a voluntary basis. The size of the sample collected was considered sufficient and was consistent with sample size recommendations from previous research that has suggested that sample sizes should be approximately 10–20 times the model's observed items (Schreiber et al., 2006; Nicolaou and Masoner, 2013). As the survey instrument used 23 observed items, a multiple of 20 was used to assure better survey reliability ($23 \times 20 = 460 < 485$). All the participants were above 18 years old. Among them, 55.7% of them were male and 44.3% were female. The summary of socio-demographic of the respondents were shown in Table 1. Of the 485 students, 35.9% were sophomore and 23.5% were junior; 53% majored in Science and Technology and

TABLE 1 Descriptive statistics of the sample.

Variable	Categorical	Percent(%)	Variable	Categorical	Percent(%)
Gender	Male	55.7	Major	Natural Science, engineering, agriculture, medicine, military	53.0
	Female	44.3		Literature, history, Philosophy	14.2
Grade	Freshman	20.4		Education, arts, science of physical culture and sports	9.5
	Sophomore	35.9		Economics, Management Science, law	22.7
	Junior	23.5		Others	0.6
	Senior	20.2	Have you been exposed to inquiry-based teaching	Never	2.5
University Rank	985 Project	5.1		Seldom	12.0
	211 Project	12.0		Occasionally	24.5
	Common	80.6		Often	46.2
	Vocational	2.3		Always	14.8

23.7% majored in Social Science and Humanities. The percentage of students who often experienced inquiry-based teaching was 46.2%, and only 14.5% were "never" or "seldom" exposed to inquiry-based teaching. Invitations to participate in this study with an online survey link or quick response (QR) code from an online platform (Questionnaire Star) were sent out to 512 currently college students.

3.2 Measurements

As latent variables cannot be directly measured, a questionnaire was designed to collect the empirical data for this study. The purpose of the questionnaire survey is to obtain basic information about the respondents and assess their perception toward inquiry-based teaching acceptance intention and behavioral intention to accept inquiry-based teaching soon. In total, there were three sections in the questionnaire. The first section is an introduction at the beginning of the questionnaire, which provided a detailed explanation of the concept and implementation process of inquiry-based teaching methods. This introduction made sure that all respondents understood the topic well, so they could give more accurate and insightful responses. The second section collected students' basic information, investigate demographic information such as student gender, grade, school, etc., and whether they often exposed to the use of inquiry teaching methods in classroom. The third section asked about respondents' perception of usefulness, ease of use, attitude, and behavioral intention to use inquiry-based teaching, as well as self-efficacy, implementation quality, risk perception. The questionnaire includes 7 latent factors and a total of 23 items of measurement, all of which are developed by modifying the verified scales presented in the existing literature (see Appendix A). At the same time, these items were also appropriately modified and adjusted based a pilot test to ensure the accuracy of the questions and the reliability of the survey. All items of latent factors were asked in the Likert scale of 1–5(1 to 5: strongly disagree, disagree, neutral, agree, and strongly agree).

4 Research results

4.1 Reliability and validity test

In the factor structure, reliability and validity test are used to test the internal consistency, reliability and validity of the measured items and latent factors. The commonly used method for testing internal consistency of the measured items in the factors is Cronbach's alpha (CA) and composite reliability (CR). When the values of CA and CR are both greater than 0.7 (Fornell and Larcker, 1981; Hatcher and O'Rourke, 2013), internal consistency and reliability are reasonable. When the values of CA and CR are both greater than 0.6 revealing poor reliability but acceptable (Huang et al., 2013; Xie et al., 2023). Factor loadings (FL) of the measured items on the factor and average variance extracted (AVE) for the factor are used to evaluate the convergent validity of the measurement model. When FL > 0.6 and AVE > 0.5 (Hair, 2009), the questionnaire results are considered to have good convergent validity. When the square root of AVE is greater than the bivariate correlation with other factors, it is considered that a factor has good discriminant validity, namely the factors in a model are empirically different from each other. The results of three tests (internal consistency, convergent validity, and discriminant validity) are shown in Tables 2, 3 respectively. All values in the tables were greater than the mentioned above criteria, indicating that the proposed measurement model have good internal consistency and reliability, convergence validity and discriminant validity.

4.2 Evaluation of the structural model and hypothesis testing

First, the goodness-of-fit between the proposed model and the obtained data were judged by the combination of several indices: chi-square test, comparative fit index (CFI), root mean square error of approximation (RMSEA), incremental fit index (IFI) and Tucker-Lewis's index (TLI). A model is considered as a good fit when CMIN/DF < 3, RMSEA <0.08, CFI > 0.9, IFI > 0.9, TLI > 0.9, GFI > 0.9, and AGFI >0.8 (Baumgartner and Homburg, 1996; Hu and Bentler, 1999; Hooper et al., 2008; Kline, 2016). The numerical values of all indices and their reference standards are shown in Table 4. All indicators are within the standard range, indicating the good fit of the model.

With acceptable goodness of fit statistics, SEM was conducted to ascertain the path of relationships between the factors based on the proposed extended TAM (as shown in Figure 1). The path coefficients (standardized coefficients) and significance of each hypothesis path were calculated to test whether the hypotheses and paths of relationships between the factors in the model were supported or not. A p-value of 0.05 and below is accepted or supported (Roberts et al., 2012). Table 5 shows that the relationship between BIU and PU was

insignificant ($p = 0.879 > 0.05$); hence, hypothesis H3, is not supported. Similarly, hypothesis H5 and H11 are also not supported.

Removing the above three invalid hypotheses H3, H5 and H11, the revised hypotheses regarding the paths of relationships between the factors were tested through SEM again and the results are presented in Table 6. All the paths of relationships hypothesized were found to be supported. At the same time, the fit of the revised model was re-tested. The fit indices of the revised model were CMIN/DF = 2.708, RMSEA = 0.059, CFI = 0.936, TLI = 0.927, IFI = 0.936, GFI = 0.904 and AGFI = 0.880, indicating that the fit of the revised model was also good. The results of SEM of revised model were presented in Figure 2.

The technology acceptance model assumes that the use of the system is determined by BIU. There are direct and indirect effects between each latent variable and BIU in the model. The direct effect refers to the path coefficient between two latent variables, and the indirect effect refers to the product of multiple coefficients on the path, and the total effect is equal to the direct effect plus the indirect effect. Table 7 details the direct and indirect effects of several factors on BIU.

As shown in Table 7, only SE and ATT have the direct effect on BIU, and SE has the larger direct effect on BIU (0.64) than ATT (0.389). SE was mediated by IQ, and the magnitude of mediation was 0.253 (indirect effect on BIU). In addition, other factors only have the indirect effect on BIU. Among these factors, IQ has the largest indirect effect on BIU (0.399). PU and ATT mediated IQ with the magnitude of 0.178 and 0.161, respectively. Note that only RP have the negative indirect effect on BIU.

TABLE 2 Internal consistency and convergent validity test.

Factor	Item	FL	CA	AVE	CR
PEU	PEU1	0.764	0.675	0.519	0.683
	PEU2	0.675			
PU	PU1	0.789	0.776	0.536	0.776
	PU2	0.697			
	PU3	0.707			
ATT	ATT1	0.777	0.852	0.593	0.854
	ATT2	0.728			
	ATT3	0.794			
	ATT4	0.780			
RP	RP1	0.737	0.891	0.625	0.892
	RP2	0.818			
	RP3	0.742			
	RP4	0.820			
	RP5	0.829			
IQ	IQ 1	0.745	0.83	0.553	0.831
	IQ 2	0.693			
	IQ 3	0.778			
	IQ 4	0.755			
SE	SE1	0.679	0.688	0.531	0.693
	SE2	0.775			
BIU	BIU1	0.791	0.808	0.583	0.808
	BIU2	0.729			
	BIU3	0.770			

5 Discussions

Self-efficacy has the largest total effect on the acceptance of inquiry teaching methods (0.894). Self-efficacy has a direct effect on BIU (0.64), and thus can directly affect students' acceptance of inquiry teaching. This outcome was similar to the findings of previous studies (Holden and Rada, 2011; Haynes et al., 2023). Self-efficacy also has an indirect effect on behavioral intentions through implementation quality (0.253). Self-efficacy has a significant positive effect on implementation quality (standardized path coefficient value 0.747) (Bonet, 2021). Improving self-efficacy is one of the most important ways to enhance students' acceptance behavior intention. Therefore, when promoting and implementing inquiry-based teaching methods, the role of the lecturer should be shifted to being a facilitator and motivator who provides direction to students to find information and knowledge needed in the

TABLE 3 Discriminant validity test.

	PEU	PU	ATT	IQ	RP	SE	BIU
PEU	**0.721**						
PU	0.390**	**0.732**					
ATT	0.417**	0.729**	**0.770**				
IQ	0.395**	0.685**	0.747**	**0.743**			
RP	−0.163**	−0.206**	−0.240**	−0.218**	**0.790**		
SE	0.460**	0.494**	0.550**	0.576**	−0.268**	**0.729**	
BIU	0.399**	0.601**	0.680**	0.670**	−0.222**	0.685**	**0.764**

**Correlation is significant at the 0.01 level.

TABLE 4 Fit indices for the tested model.

	CMIN/DF	RMSEA	CFI	IFI	TLI	GFI	AGFI
Measurement model	2.724	0.06	0.936	0.937	0.926	0.905	0.880
Recommended value	<3	<0.08	>0.9	>0.9	>0.9	>0.9	>0.8

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TABLE 5 Hypothesis testing results.

Hypothesis	Path	Standardized coefficient	Unstandardized coefficient	S.E.	C.R.	*p*	Supported?
H1	BIU ← ATT	0.366	0.377	0.132	2.858	0.004	Yes
H2	ATT ← PU	0.505	0.668	0.131	5.106	***	Yes
H3	BIU ← PU	0.018	0.025	0.165	0.152	0.879	No
H4	PU ← PEU	0.194	0.120	0.04	2.977	0.003	Yes
H5	ATT ← PEU	0.053	0.043	0.033	1.312	0.190	No
H6	BIU ← SE	0.671	0.738	0.087	8.524	***	Yes
H7	IQ ← SE	0.745	0.822	0.075	10.994	***	Yes
H8	PU ← IQ	0.82	0.601	0.047	12.723	***	Yes
H9	ATT ← IQ	0.455	0.441	0.089	4.952	***	Yes
H10	SE ← RP	−0.332	−0.228	0.039	−5.829	***	Yes
H11	BIU ← RP	0.064	0.048	0.029	1.694	0.090	No

S.E. = Standardized Estimate. C.R. = Critical Ratio.

TABLE 6 Revised hypothesis testing results.

Hypothesis	Path	Standardized coefficient	Unstandardized coefficient	S.E.	C.R.	*p*	Supported?
H1	BIU ← ATT	0.389	0.398	0.062	6.37	***	Yes
H2	ATT ← PU	0.557	0.751	0.118	6.382	***	Yes
H4	PU ← PEU	0.201	0.120	0.042	2.828	0.005	Yes
H6	BIU ← SE	0.640	0.704	0.081	8.676	***	Yes
H7	IQ ← SE	0.747	0.822	0.074	11.033	***	Yes
H8	PU ← IQ	0.821	0.595	0.047	12.683	***	Yes
H9	ATT ← IQ	0.415	0.405	0.079	5.145	***	Yes
H10	SE ← RP	−0.310	−0.214	0.038	−5.618	***	Yes

S.E. = Standardized Estimate. C.R. = Critical Ratio.

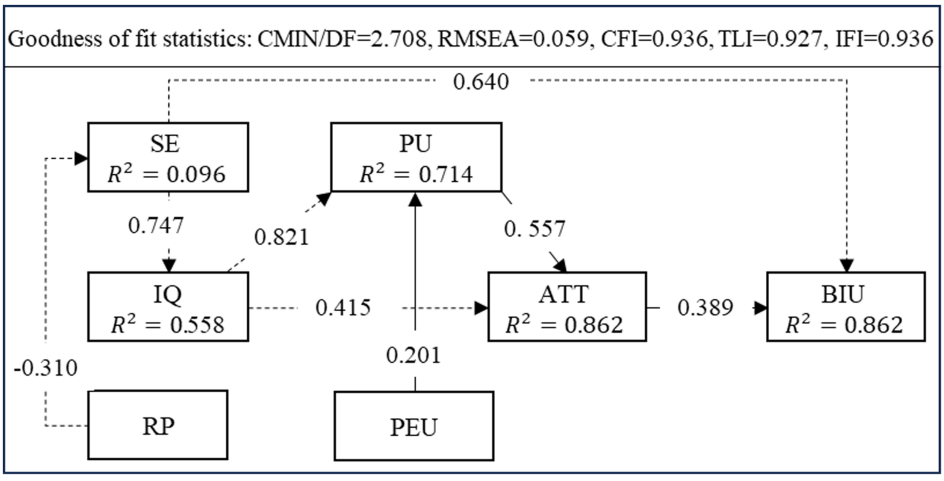

FIGURE 2
SEM results of the revised model.

learning process according to students' knowledge level, individual differences, and subject characteristics. Build and strengthen students' confidence, enhance their sense of participation, identity and achievement, and make them more interested and confident to complete inquiry activities, so as to improve their acceptance of inquiry teaching.

Attitude (0.389) is a significant secondary determinant of students' intentions to accept inquiry teaching methods. Attitude directly affects

TABLE 7 Direct and indirect effects on BIU.

Variable	PEU	RP	SE	IQ	PU	ATT
Direct effect	–	–	0.640	–	–	0.389
Total indirect effect	0.044	−0.277	0.253	0.339	0.217	–
Total effect	0.044	−0.277	0.894	0.339	0.217	0.389

behavior intention, implying that the more students develop positive attitudes toward inquiry-based teaching, the more they accept it. This result consists fairly well with the literature (Akman and Turhan, 2017; Moreno et al., 2017; Nicol et al., 2022; Ye et al., 2023b), demonstrating that attitude was a significant predictor. Therefore, in order to improve students' acceptance of inquiry-based teaching, the key lies in changing students' understanding of inquiry-based teaching to shape positive attitude. Teachers should introduce its differences and values compared with traditional teaching methods from multiple perspectives so that students have a full understanding and recognize of its role forming a positive attitude of acceptance.

The total effect of implementation quality on the acceptance of inquiry teaching is 0.339, next to attitude. Implementation quality has no direct effect on behavioral intentions. It indirectly affects behavioral intentions through perceived usefulness and attitude. Implementation quality has a significant positive effect on perceived usefulness and attitude (standardized path coefficient values are 0.821 and 0.415), which conforms well with similar studies conducted on Edmodo acceptance (Unal and Uzun, 2021). Students were likely to believe that inquiry-based teaching is one approach to improving the effectiveness and productivity for learning by moving toward more student-directed, interactive methods of learning and this might have influenced their perception of usefulness and attitude (Justice et al., 2009). Therefore, in the implementation of inquiry teaching, teachers should play the role of guide and tutor, provide necessary guidance and support to students in the exploration process; It is important to help students solve problems and answer questions to improve their sense of participation and confidence in learning on their own, and to ensure that each student can achieve the established learning objectives and improve students' perception of implementation quality. If students believe that inquiry teaching are meaningful and useful for learning, they will perceive its usefulness for learning and generating positive behavioral attitudes.

The total effect of perceived ease of use and perceived usefulness on the acceptance intention of inquiry teaching is 0.044 and 0.217, respectively. Consistent with many other research (Davis et al., 1989; Moon and Kim, 2001), this result indicates that, although ease of use is clearly important, and the usefulness of inquiry-based teaching methods is even more important and should be emphasized. It is worth noting that perceived usefulness has no direct effect on behavioral intentions but indirectly affects behavioral intentions through attitudes, which is inconsistent with prior findings. This implies that students' judgment of the usefulness of inquiry-based teaching will significantly affect their cognitive aspects of attitudes towards it and thus play an important role in their acceptance behavior. Contrary to the presupposition, perceived ease of use has no significant effect on attitude, but only indirectly affects attitude through perceived usefulness. A possible explanation is that first students evaluate how easy or difficult it is to learn with the inquiry-based teaching, then they look at the usefulness of it for them. If they find it as an 'useful' method for them then they develop a positive attitude towards it. The positive attitudes lead them to develop a positive intention to accept it. In other words, if they find it as an 'unprofitable' method for them, they may hold a negative attitude towards it.

The total effect of risk perception on the acceptance intention of inquiry teaching methods is −0.277, which is the only factor negatively correlated with behavioral intention, indicating that students with lower risk perception are more they are more likely to be motivated to accept inquiry-based teaching or vice versa. This result was in line with the literature (Zhang et al., 2019). Risk perception has no direct effect on behavioral intentions, but only indirectly affects behavioral intentions through self-efficacy. Risk perception has a significant negative impact on self-efficacy. Therefore, teachers should pay attention to process guidance, question design and inquiry atmosphere when using inquiry-based teaching method. Specifically, teachers need to give continuous guidance and guidance to students, so that students can find the right direction of inquiry; Open questions should be designed according to the content of teaching materials and teaching objectives, and each student should be guided to solve the problems through experiments, discussions, observations, etc. Some ice-breaking activities can also be used to ease the classroom atmosphere, cultivate students' interest and willingness to explore, encourage students to share and cooperate, and allow each student to complete the exploration activities and knowledge learning in a pleasant environment.

6 Conclusion and implications

6.1 Conclusion

This study assesses the acceptability of inquiry-based teaching at the subjective level of students in higher education. Theoretically, this paper constructs a complex model that helps to understand the factors influencing the acceptance of inquiry-based teaching methods. The whole extended TAM accounted for 88.6% of the variance in explaining students' behavioral intention to accept inquiry-based teaching, indicating its good applicability to understand the acceptance of inquiry teaching methods. The extended TAM was again empirically validated as a theoretical model for future research on the use of new teaching/learning methods in educational settings.

The research results showed that, all latent variables have a significant impact on the behavioral intention to accept inquiry-based teaching: Self-efficacy (0.894), Attitude (0.389), Implementation quality (0.339), Perceived Usefulness (0.217), Perceived Ease of Use (0.044), and Perceived Risk (−0.277). Self-efficacy and attitude directly influence the intention to accept, while other factors have an indirect impact. Specifically, self-efficacy had a positive impact on implementation quality and behavioral intention to use; implementation quality had a positive impact on perceived usefulness

and attitude; perceived risk had a negative impact on self-efficacy; perceived ease of use had a positive impact on perceived usefulness; perceived usefulness had a positive effect on attitude, while attitude had a positive effect on behavioral intention to use.

6.2 Practical implications

In terms of practical application, these details of the link between inquiry-based teaching and various factors provided theoretical guidance and practical support to improve the application of inquiry-based teaching in college education and the quality of inquiry-based instruction. First of all, the study results revealed that self-efficacy was the most critical and salient factor in determining users' acceptance of inquiry-based teaching. This can be achieved by reducing students' worries, anxieties and fears when they engaged in a new teaching method, given that perceived risk was found to be negatively related to students' level of self-efficacy. Therefore, it is important to inform students about the features, usefulness of it so that they can gain an in-depth understanding of the features of inquiry-based teaching method and become more confident in achieving desired tasks. At the same time, teachers should fully understand the content of the textbook, design inquiry questions around teaching goals and knowledge abilities, so that students can learn knowledge points and internalize them through the exploration and research of the problems, enhance the interaction and assistance between teachers and students and students, and stimulate every student's confidence, interest and cooperation in exploration. Secondly, students' positive attitude should be set up in the process of popularization of inquiry-based teaching, and efforts should be made to improve the implementation quality. For students who hold negative attitudes or are dissatisfied with implementation quality, lecturers should pay attention to their inner needs and value orientation in time, and focus on giving help and encouragement; Finally, teachers should improve their ability to teach, the adaption of situations and expertise and skill to the gain the student performance (Alharbi, 2022). They should have practical knowledge in multiple aspects, such as interpersonal knowledge and strategic knowledge. Teachers can design inquiry questions according to classroom teaching content and teaching materials, carefully arrange tasks, guide and supervise processes and evaluate inquiry results. The entire inquiry process is student-centered, respecting their individuality to achieve their self-growth, so that students can perceive the practical value and usefulness of inquiry-based teaching methods and thus reduce their risk perception.

6.3 Contributions

First, on the authors' knowledge, this is the first adoption of TAM to model the acceptance behavior of inquiry-based teaching methods. This is also the first time that self-efficacy was identified as the most critical antecedent in exploring determinants of students' acceptance for inquiry-based teaching methods, and directly influenced the intention to accept. This finding is not in line with previous studies, which have reported that the role of self-efficacy was supplementary or mediated by other factors (Wu et al., 2010; Unal and Uzun, 2021), probably due to limitations in the proposed models or the survey population.

The second theoretical contribution is that this study results help clarifying the conflicting results on the importance of perceived risk to BIU in the previous literature (Martins et al., 2014; Mou et al., 2015; Alalwan et al., 2016). Our results revealed that perceived risk would not directly determine students' behavioral intention towards inquiry-based teaching methods but would affect it indirectly by influencing students' level of self-efficacy.

The third theoretical contribution argues that, this study integrated the classic technology acceptance model theory, learners' cognitive theory (self-efficacy and implementation quality), and risk perception theory (perceived risk) to investigate students' acceptance of inquiry-based teaching. For inquiry-based teaching, students' role in student-centered teaching approach is significantly different from their role in teacher-centered learning approach (Hannafin and Land, 1997). Therefore, it is important to identify perceptions of students about teaching and learning processes, perceptions regarding student-centered learning contexts, and their belief in one's capability to perform certain learning tasks, which can be well identified and elucidated by these factors in the proposed model.

6.4 Limitations of this study and future work

The results of our study need to be interpreted in consideration of several limitations. One limitation is that the minority of the respondents have not actually been exposed to the inquiry-based teaching methods and have little or no understanding about it. The level of self-efficacy, attitude and perceived risk as well as their antecedents would change in the future, with students' more familiarity with the approach. Another limitation is that subjective measure of latent variables might not represent objective behaviors. Moreover, due to the limited number of questionnaires, research results cannot reflect the acceptance intention of all university students. In the future, it is possible to consider further expanding the region of investigation and sample size, especially increasing target student groups who have actual experience. Longitudinal studies are necessary to further clarify how key determinants (i.e., self-efficacy, attitude) and their role in student acceptance evolve after students have more interacting experience with inquiry-based teaching methods.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Ethics Board of the School of Civil and Transportation Engineering, Guangdong University of Technology. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written

informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

S-gH: Conceptualization, Methodology, Writing – original draft, Writing – review & editing. W-yW: Funding acquisition, Methodology, Validation, Writing – review & editing. X-XW: Conceptualization, Funding acquisition, Investigation, Supervision, Validation, Writing – review & editing. Y-MY: Investigation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Akman, I., and Turhan, C. (2017). User acceptance of social learning systems in higher education: an application of the extended technology acceptance model. *Innov. Educ. Teach. Int.* 54, 229–237. doi: 10.1080/14703297.2015.1093426

Alalwan, A. A., Dwivedi, Y. K., Rana, N. P., and Williams, M. D. (2016). Consumer adoption of mobile banking in Jordan: examining the role of usefulness, ease of use, perceived risk and self-efficacy. *J. Enterp. Inf. Manag.* 29, 118–139. doi: 10.1108/JEIM-04-2015-0035

Alfieri, L., Brooks, P. J., Aldrich, N. J., and Tenenbaum, H. R. (2011). Does discovery-based instruction enhance learning? *J. Educ. Psychol.* 103, 1–18. doi: 10.1037/a0021017

Alharbi, A. A. (2022). Is the emergency distance teaching experience different in postgraduate programs?: students' voices. *Int. J. Online Pedagog. Course Des.* 12, 1–16. doi: 10.4018/IJOPCD.302084

Bandura, A. (1977). Self-efficacy: toward a unifying theory of behavioral change. *Psychol. Rev.* 84, 191–215. doi: 10.1037/0033-295X.84.2.191

Bandura, A. (1982). Self-efficacy mechanism in human agency[J]. *Am. Psychol.* 37, 122–147. doi: 10.1037/0003-066X.37.2.122

Bandura, A., Freeman, W. H., and Lightsey, R. (1999). Self-efficacy: the exercise of control [J]. *J. Cogn. Psychother.* 13, 158–166. doi: 10.1891/0889-8391.13.2.158

Baumgartner, H., and Homburg, C. (1996). Applications of structural equation modeling in marketing and consumer research: a review. *Int. J. Res. Mark.* 13, 139–161. doi: 10.1016/0167-8116(95)00038-0

Benlahcene, A., Lashari, S. A., Lashari, T. A., Shehzad, M. W., and Deli, W. (2020). Exploring the perception of students using student-centered learning approach in a Malaysian public university. *Int. J. Higher Educ.* 9, 204–217. doi: 10.5430/ijhe.v9n1p204

Bonet, B. (2021). Exploring middle school science teachers' self-efficacy with inquiry-based learning: A case study. Doctoral dissertation, Northcentral University.

Çakıroğlu, Ü., and Öztürk, M. (2017). Flipped classroom with problem based activities: exploring self-regulated learning in a programming language course. *Int. Forum Educ. Technol. Society* 20, 337–349. doi: 10.1109/ICCCNT.2016.7568515

Chang, C. C., Hung, S. W., Cheng, M. J., and Wu, C. Y. (2015). Exploring the intention to continue using social networking sites: the case of Facebook. *Technol. Forecast. Soc. Chang.* 95, 48–56. doi: 10.1016/j.techfore.2014.03.012

Chen, Y., and Wang, Y. (2020). A study on student acceptance of inquiry-based learning approach in a blended learning environment. *J. Educ. Technol. Develop. Exchange* 13, 1–14.

Chou, S. F., Horng, J. S., Liu, C. H., Lin, J. Y., and Chen, L. (2023). Discovering the processes of undergraduate hospitality students' acceptance of facebook teaching interventions. *Educ. Inf. Technol.* 28, 15245–15265. doi: 10.1007/s10639-023-11836-z

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Q.* 13, 319–340. doi: 10.2307/249008

Davis, F. D., Bagozzi, R. P., and Warshaw, P. R. (1989). User acceptance of computer technology: a comparison of two theoretical models. *Manag. Sci.* 35, 982–1003. doi: 10.1287/mnsc.35.8.982

Dowling, G. R., and Staelin, R. (1994). A model of perceived risk and intended risk-handling activity. *J. Consum. Res.* 21, 119–134. doi: 10.1086/209386

Fan, J. Y., and Ye, J. H. (2022). The effectiveness of inquiry and practice during project design courses at a technology university. *Front. Psychol.* 13:859164. doi: 10.3389/fpsyg.2022.859164

Fathema, N., Shannon, D., and Ross, M. (2015). Expanding the technology acceptance model (TAM) to examine faculty use of learning management systems (LMSs) in higher education institutions. *J. Online Learn. Teach.* 11, 210–232. doi: 10.1080/08923647.2015.1029183

Fishbein, M., and Ajzen, I. (1975). *Belief, attitude, intension and behavior: An introduction to theory and research*, Reading, MA: Addison Wesley.

Fornell, C., and Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *J. Mark. Res.* 18, 39–50. doi: 10.1177/002224378101800104

Francescato, D., Porcelli, R., Mebane, M., Cuddetta, M., Klobas, J., and Renzi, P. (2006). Evaluation of the efficacy of collaborative learning in face-to-face and computer-supported university contexts. *Comput. Hum. Behav.* 22, 163–176. doi: 10.1016/j.chb.2005.03.001

Furtak, E. M., Seidel, T., Iverson, H., and Briggs, D. C. (2012). Experimental and quasi-experimental studies of inquiry-based science teaching: a meta-analysis. *Rev. Educ. Res.* 82, 300–329. doi: 10.3102/0034654312457206

Gallego-Gómez, C., De-Pablos-Heredero, C., and Montes-Botella, J. L. (2021). Change of processes in the COVID-19 scenario: from face-to-face to remote teaching-learning systems. *Sustainability* 13:10513. doi: 10.3390/su131910513

Hair, J. (2009). *Multivariate data analysis*. Faculty Publications. Available at: https://digitalcommons.kennesaw.edu/facpubs/2925

Hannafin, M. J., and Land, S. M. (1997). The foundations and assumptions of technology-enhanced student-centered learning environments. *Instr. Sci.* 25, 167–202. doi: 10.1023/A:1002997414652

Hao, L., and Wang, D. (2019). Exploratory learning in higher education: students' perceptions and implications for curriculum design. *Front. Psychol.* 10:2042.

Hatcher, L., and O'Rourke, N. (2013). *A step-by-step approach to using SAS for factor analysis and structural equation modeling*. Sas Institute.

Haynes, M., Brown, A., Nichols, K., and Parveen Musofer, R. (2023). Measurement of student attitudes to science and association with inquiry-based learning in regional schools. *Int. J. Sci. Educ.* 45, 593–612. doi: 10.1080/09500693.2023.2168138

Holden, H., and Rada, R. (2011). Understanding the influence of perceived usability and technology self-efficacy on teachers' technology acceptance. *J. Res. Technol. Educ.* 43, 343–367.

Hong, J. C., Chen, M. L., and Ye, J. H. (2020). Acceptance of YouTube applied to dance learning. *Int. J. Inform. Educ. Technol.* 10, 7–13. doi: 10.18178/ijiet.2020.10.1.1331

Hong, J. C., Ye, J. H., and Fan, J. Y. (2019). STEM in fashion design: the roles of creative self-efficacy and epistemic curiosity in creative performance. *Eurasia J. Mathematics Sci. Technol. Educ.* 15, 1–18. doi: 10.29333/ejmste/108455

Hooper, D., Coughlan, J., and Mullen, M. R. (2008). Structural equation modelling: Guidelines for determining model fit. *Electron. J. Bus. Res. Methods* 6, 53–60. doi: 10.21427/D7CF7R

Hossain, M. A., and Quaddus, M. (2012). Expectation–confirmation theory in information system research: a review and analysis. *Inform. Syst. Theory* 28, 441–469. doi: 10.1007/978-1-4419-6108-2_21

Hsu, J. L., and Rowland-Goldsmith, M. (2021). Student perceptions of an inquiry-based molecular biology lecture and lab following a mid-semester transition to online teaching. *Biochem. Mol. Biol. Educ.* 49, 15–25. doi: 10.1002/bmb.21478

Hu, L. T., and Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: conventional criteria versus new alternatives. *Struct. Equ. Model.* 6, 1–55. doi: 10.1080/10705519909540118

Huang, C. C., Wang, Y. M., Wu, T. W., and Wang, P. A. (2013). An empirical analysis of the antecedents and performance consequences of using the Moodle platform. *Int. J. Inform. Educ. Technol.* 3, 217–221. doi: 10.7763/IJIET.2013.V3.267

Jiang, M. Y. C., Jong, M. S. Y., Lau, W. W. F., Meng, Y. L., Chai, C. S., and Chen, M. (2021). Validating the general extended technology acceptance model for e-learning: evidence from an online English as a foreign language course amid COVID-19. *Front. Psychol.* 12:671615. doi: 10.3389/fpsyg.2021.671615

Johnston, J., Killion, J., and Oomen, J. (2005). Student satisfaction in the virtual classroom. *Internet J. Allied Health Sci. Pract.* 3:6. doi: 10.46743/1540-580X/2005.1071

Justice, C., Rice, J., Roy, D., Hudspith, B., and Jenkins, H. (2009). Inquiry-based learning in higher education: administrators' perspectives on integrating inquiry pedagogy into the curriculum. *High. Educ.* 58, 841–855. doi: 10.1007/s10734-009-9228-7

Keselman, A. (2003). Supporting inquiry learning by promoting normative understanding of multivariable causality. *J. Res. Sci. Teach.* 40, 898–921. doi: 10.1002/tea.10115

Kiernan, D. A., and Lotter, C. (2019). Inquiry-based teaching in the college classroom: the nontraditional student. *Am. Biol. Teach.* 81, 479–484. doi: 10.1525/abt.2019.81.7.479

Kline, R. B. (2016). *Principles and practice of structural equation modeling. 4th* ed. Guilford publications.

Kogan, M., and Laursen, S. L. (2014). Assessing long-term effects of inquiry-based learning: a case study from college mathematics. *Innov. High. Educ.* 39, 183–199. doi: 10.1007/s10755-013-9269-9

Lo, A. Y. (2013). The role of social norms in climate adaptation: mediating risk perception and flood insurance purchase. *Glob. Environ. Chang.* 23, 1249–1257. doi: 10.1016/j.gloenvcha.2013.07.019

Long, N., and Khoi, B. (2020). The intention to study using zoom during the SARS-CoV-2 pandemic. *Int. J. Emerg. Technol. Learn.* 15, 195–216. doi: 10.3991/ijet.v15i21.16777

Martins, C., Oliveira, T., and Popovič, A. (2014). Understanding the internet banking adoption: a unified theory of acceptance and use of technology and perceived risk application. *Int. J. Inf. Manag.* 34, 1–13. doi: 10.1016/j.ijinfomgt.2013.06.002

Mou, Y. (2017). The research of public acceptance towards nuclear power in China based on the dual-factor model of risk perception. *Energy Procedia*. 105, 975–980. doi: 10.1016/j.egypro.2017.03.367

Moon, J. W., and Kim, Y. G. (2001). Extending the TAM for a world-wide-web context. *Inf. Manag.* 38, 217–230. doi: 10.1016/S0378-7206(00)00061-6

Moreno, V., Cavazotte, F., and Alves, I. (2017). Explaining university students' effective use of e-learning platforms. *Br. J. Educ. Technol.* 48, 995–1009. doi: 10.1111/bjet.12469

Mou, J., Shin, D. H., and Cohen, J. F. (2015). Trust and risk in consumer acceptance of e-services. *Electron. Commer. Res.* 17, 255–288. doi: 10.1007/s10660-015-9205-4

Nicol, C. B., Gakuba, E., and Habinshuti, G. (2022). Effects of inquiry-based chemistry experimentation on Students' attitudes towards the teaching and learning of chemistry. *J. Balt. Sci. Educ.* 21, 663–679. doi: 10.33225/jbse/22.21.663

Nicolaou, A. I., and Masoner, M. M. (2013). Sample size requirements in structural equation models under standard conditions. *Int. J. Account. Inf. Syst.* 14, 256–274. doi: 10.1016/j.accinf.2013.11.001

Ohanu, I. B., Shodipe, T. O., Ohanu, C. M., and Anene-Okeakwa, J. E. (2023). System quality, technology acceptance model and theory of planned behaviour models: agents for adopting blended learning tools. *E Learn. Digital Media* 20, 255–281. doi: 10.1177/20427530221108031

Roberts, S. C., Ghazizadeh, M., and Lee, J. D. (2012). Warn me now or inform me later: Drivers acceptance of real-time and post-drive distraction mitigation systems. *Int. J. Hum. Comput. Stud.* 70, 967–979. doi: 10.1016/j.ijhcs.2012.08.002

Schreiber, J. B., Nora, A., Stage, F. K., Barlow, E. A., and King, J. (2006). Reporting structural equation modeling and confirmatory factor analysis results: a review. *J. Educ. Res.* 99, 323–338. doi: 10.3200/JOER.99.6.323-338

Sockalingam, N. (2013). The relation between student satisfaction and student performance in blended learning curricula. *Int. J. Learn. Annu. Rev.* 18, 121–134. doi: 10.18848/1447-9494/cgp/v18i12/47842

Spronken-Smith, R., and Walker, R. (2010). Can inquiry-based learning strengthen the links between teaching and disciplinary research? *Stud. High. Educ.* 35, 723–740. doi: 10.1080/03075070903315502

Teo, T., Zhou, M., Fan, A. C. W., and Huang, F. (2019). Factors that influence university students' intention to use Moodle: a study in Macau. *Educ. Technol. Res. Dev.* 67, 749–766. doi: 10.1007/s11423-019-09650-x

Unal, E., and Uzun, A. M. (2021). Understanding university students' behavioral intention to use Edmodo through the lens of an extended technology acceptance model. *Br. J. Educ. Technol.* 52, 619–637. doi: 10.1111/bjet.13046

Venkatesh, V., and Bala, H. (2008). Technology acceptance model 3 and a research agenda on interventions. *Decis. Sci.* 39, 273–315. doi: 10.1111/j.1540-5915.2008.00192.x

Venkatesh, V., and Davis, F. D. (2000). A theoretical extension of the technology acceptance model: four longitudinal field studies. *Manag. Sci.* 46, 186–204. doi: 10.1287/mnsc.46.2.186.11926

Venkatesh, V., Morris, M. G., Davis, G. B., and Davis, F. D. (2003). User acceptance of information technology: toward a unified view. *MIS Q.* 27, 425–478. doi: 10.2307/30036540

Venkatesh, V., Thong, J. Y., and Xu, X. (2012). Consumer acceptance and use of information technology: extending the unified theory of acceptance and use of technology. *MIS Q.* 36, 157–178. doi: 10.2307/41410412

Vladova, G., Ullrich, A., Bender, B., and Gronau, N. (2021). Students' acceptance of technology-mediated teaching-how it was influenced during the COVID-19 pandemic in 2020: a study from Germany. *Front. Psychol.* 12:636086. doi: 10.3389/fpsyg.2021.636086

Wang, B., and Li, Y. (2020). Evaluating the impact of inquiry-based learning on student engagement and learning outcomes: an online survey study. *J. Educ. Learn.* 9, 152–165.

Wu, J. H., Tennyson, R. D., and Hsia, T. L. (2010). A study of student satisfaction in a blended e-learning system environment. *Comput. Educ.* 55, 155–164. doi: 10.1016/j.compedu.2009.12.012

Xie, Q., Liu, X., Fan, L., Peng, S., and Zeng, Y. (2023). Evaluation of equivalent crack propagation length and fracture energy of two commonly used rock fracture toughness test configurations based on Bažant's size effect law. *Eng. Fract. Mech.* 281:109067. doi: 10.1016/j.engfracmech.2023.109067

Yao, J., Yang, T., Ding, X., and Chen, X. W. (2016). The concept tracing, concept definition and implication analysis of urban community sports' public service's satisfaction. *J. Xi'an Phys. Educ. University* 33, 48–56.

Ye, J. H., Chen, M. Y., and Hao, Y. W. (2023a). Editorial: teaching and learning in higher education: the role of emotion and cognition. *Front. Psychol.* 14:1230472. doi: 10.3389/fpsyg.2023.1230472

Ye, J. H., Lee, Y. S., Wang, C. L., Nong, W., Ye, J.-N., and Sun, Y. (2023b). The continuous use intention for online learning of Chinese vocational students in the post-epidemic era: the extended technology acceptance model and expectation confirmation theory. *Sustainability* 15:1819. doi: 10.3390/su15031819

Zhang, T., Tao, D., Qu, X., Zhang, X., Lin, R., and Zhang, W. (2019). The roles of initial trust and perceived risk in public's acceptance of automated vehicles. *Transport. Res. Part C* 98, 207–220. doi: 10.1016/j.trc.2018.11.018

APPENDIX A Latent factors and survey items.

Factors	Items	Description of each item	Sources (modified from)
Perceived ease of use (PEU)	PEU1	It is easy for me to conduct inquiry activities according to the questions raised by the teacher.	Davis (1989)
	PEU2	The implementation process of inquiry teaching is simple and easy to understand.	
Perceived usefulness(PU)	PU1	Inquiry-based teaching can enhance my interest and awareness of learning.	Davis (1989)
	PU2	Inquiry-based teaching can improve my learning initiative and research ability.	
	PU3	Inquiry-based teaching can deepen my understanding and application of knowledge and greatly improve my learning effect.	
Attitude (ATT)	ATT1	I think it is worthwhile to use inquiry-based teaching in classroom.	Long and Khoi (2020)
	ATT2	I hope the inquiry-based teaching will be adopted in the classroom.	
	ATT3	I find the inquiry-based teaching attractive in the classroom.	
	ATT4	I find the inquiry-based approach to classroom teaching very enjoyable.	
Implementation Quality (IQ)	IQ1	I think the teacher's guidance and enlightenment to students in the process of inquiry-based teaching is very good.	Davis (1989)
	IQ2	I think the questions raised in the inquiry-based classroom are very probing and enlightening.	
	IQ3	I think the inquiry-based teaching has had a very good participation experience in the classroom.	
	IQ4	I think the teacher-student interaction and group collaboration in the inquiry-based teaching classroom is very good.	
Risk Perceived(RP)	RP1	I am worried that the teacher's guidance is not timely, and the whole class will become loose, feeling like "shepherding sheep."	This study
	RP2	I am afraid that the questions of inquiry are too difficult for me to achieve my learning goals.	
	RP3	Interacting with teachers, discussing, and collaborating with group members makes me shy, irritable and anxious.	
	RP4	With the inquiry-based teaching, I am afraid that the knowledge received is not systematic, but fragmented and scattered	
	RP5	I am worried that I will not be able to complete the learning task of independent inquiry well because of my lack of consciousness or enthusiasm	
Self-efficacy (SE)	SE1	I can easily acquire useful knowledge for myself in inquiry teaching activities	This study
	SE2	I enjoy interacting with teachers and working collaboratively with team members to complete tasks	
Behavioral intention to use (BIU)	BIU1	I will actively recommend inquiry-based teaching courses to my classmates around me	Davis (1989)
	BIU2	I would invest more time and energy in inquiry-based classes	
	BIU3	I am willing to participate in practical tasks or experiments in the inquiry-based classroom	

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Gamification in the classroom: Kahoot! As a tool for university teaching innovation

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Objectives: The purpose of this study has been to evaluate the use of gamification in the classroom, in terms of its effects on attention, concentration, creativity, and generic capabilities, for university students enrolled in a Bachelor's degree program in Physiotherapy.

Methods: An experimental design was implemented, using three groups differentiated by their time of exposure to the game (0 min, 30 min, or 60 min per week). The sample consisted of 73 s-year students from a Bachelor's degree program in Physiotherapy. The theoretical content for each class was taught during a period of 4 months, reinforced by use of the Kahoot! Online platform. Selective attention and concentration were evaluated using the d2 Test of Attention; creative intelligence using the Creative Intelligence Test (CREA); and generic capabilities using the capabilities subscale of the Student Engagement Questionnaire (SEQ).

Results: The study's participants had a mean age of 19.51 ± 0.9 years, and it has demonstrated that use of Kahoot! For longer periods of time, i.e., more than 60 min per day, can improve essential skills in university students, such as attention, creativity, critical thinking, self-managed learning, adaptability, problem solving, and computer literacy. This study's results show that integrating Kahoot! Into the educational environment, especially with longer sessions that allow for deeper immersion in the game, produces benefits by stimulating various cognitive aspects and enhancing complex skills.

Conclusion: This study has demonstrated that use of Kahoot! Improves key skills such as attention, creativity, and critical thinking, especially when longer sessions are used. It is also suggested that its use should be balanced with other educational activities, in order to achieve comprehensive development for the students.

KEYWORDS

gamification, teaching innovation, university education, creative intelligence, concentration, attention, generic capabilities

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1 Introduction

Teaching in the 21st century requires the use of active approaches that give students a prominent role during the learning process, and their educational experiences need to be useful and broadly applicable. This means that the students should be given opportunities for interaction, cooperation, competition, etc. (Martínez, 2017), because these aspects are typically associated with improved motivation during the teaching-learning process, as demonstrated by recent studies (Rodríguez et al., 2019; Darling-Hammond et al., 2020). New educational demands require new teaching strategies that can improve the dynamics of the learning process, and one of these new strategies is known as gamification (Li et al., 2023), whose benefits in the educational environment have been widely documented (Dahalan et al., 2023).

Gamification is defined as an educational strategy that adapts elements of game playing, so that they can be applied in the learning environment, with the aim of improving the students' academic performance (Chen and Liang, 2022). Incorporating game-based elements can increase attention and engagement (Licorish et al., 2018), enhance motivation for working in groups, and in general, produce a more effective commitment to learning (Müller et al., 2015). It is an approach that can potentially enhance the learning process (Johns, 2015; Kalu and Bwalya, 2017), with an impact on the students' grades and creation of a more satisfying educational experience (Ismail and Mohammad, 2017).

Integrating gamification into the educational environment requires strategic use of the mechanics offered by the games themselves, such as rewards, competition, levels, and goals, but in contexts unrelated to those games (Arnold, 2014). This approach also requires development of creative activities that can challenge the students to complete tasks in an innovative and original way (Lee and Hammer, 2011; Calvo and López-Rodríguez, 2021). In turn, this contributes to development of social skills, as the students are confronted by the challenges and objectives presented by the educational games (Villalustre and Del Moral, 2015). According to Kapp (2012) and Zichermann and Cunningham (2011), the aim of gamification is to make use of game-like strategies and mechanics to strengthen individual engagement and increase learning and motivation, among other objectives. It has been demonstrated that gamification can provide multiple advantages, with some of the highlights being the psychological benefits of improved concentration and attention (McGonigal, 2011), promotion of deductive and spatial thinking (Miller, 2013), and stimulation of imagination and creativity (De Soto, 2018). We agree with the conclusion reached by De Soto (Uyulgan and Akkuzu, 2004), that when an activity is enjoyable, the brain is able to assimilate information better. Gamification is therefore an approach that can help optimize learning, thereby improving the acquisition of knowledge (Ortiz et al., 2018).

There are currently a variety of online applications available on the market, which allow creation of interactive tests and questionnaires for use in the classroom, with the students able to participate by using their own mobile devices (Lozada and Gómez, 2017). These are tools that make it possible to develop games, activities, and questionnaires, and this can encourage more active student participation. The introduction of innovative teaching techniques, such as competition tests, motivates the students to play a more dynamic and interactive role (Orbegoso, 2016). The games are appealing to them, and by reviewing questionnaires or encouraging discussions during the game, these activities can become exciting and attractive experiences for the students (Oliva, 2017). In addition, the use of devices such as iClickers and smartphones, along with free online tools such as Socrative, Kahoot! And Quizizz, are making evaluation of students easier by providing real-time results. They also make it possible for instructors to obtain specific feedback, regarding the level of student comprehension of the contents they are teaching in the classroom (Pintor-Díaz, 2017).

After performing some in-depth background research and exploring various options, we decided to implement a methodology based on gamification by using the Kahoot! Platform. Our belief was that this would represent an opportunity to stimulate motivation, improve group dynamics, increase attention and critical thinking, and enhance learning among the students (McLaughlin and Yan, 2017). Kahoot! Is a type of software that allows the instructor to present questions or questionnaires related to the material being taught, with the students then able to respond using their own mobile devices, such as smartphones, tablets, or notebook computers (Cerro, 2015). The students can therefore use their mobile devices to review or apply what they have learned in an entertaining way, by merging games, learning, and new technologies during the educational process (Parra-González and Segura-Robles, 2019). In Spain, Kahoot! Has become one of the most popular entertainment-based digital learning tools in recent years, with the advantages of being free, easy to use, and effective in terms of improving classroom dynamics. It was conceived in 2013 by Professor Alf Inge Wang at the Norwegian University of Science and Technology, with the aim of generating enjoyable and functional educational environments (Martínez, 2017).

Kahoot! Is therefore a tool that can be incorporated into a teaching curriculum to enhance interdisciplinary skills, while also effectively integrating digital technologies and communications as resources for learning. It can stimulate motivation among the students, while also assisting with collection of data regarding their learning process and their understanding of the contents being taught (Amores-Valencia et al., 2022). It can also make a significant contribution to increasing the students' active participation and commitment in the classroom, while fostering positive relationships among the various groups of students. In summary, all of this makes Kahoot! A valuable gamification tool for application during the educational process (Urh et al., 2015; Gokbulut, 2020; López-Belmonte et al., 2020), and it has already been used with success in a variety of university programs, to facilitate retention of complex theoretical concepts while at the same time stimulating the students' intrinsic motivation to learn (Rodríguez, 2017).

In this context, the objective of our study is to evaluate the impact of gamification in the university educational environment, specifically among students enrolled in the Bachelor's degree in Physiotherapy. We intend to determine how the integration of game elements, particularly through the Kahoot! Platform, influences attention, concentration, motivation, creativity, and the social skills of the students. We hypothesize that gamification not only improves these key dimensions of learning but also contributes to a greater overall satisfaction with the educational experience.

2 Materials and methods

2.1 Research design and participants

An experimental design was implemented using three groups, differentiated by their time of exposure to the game (0 min, 30 min,

or 60 min per week). The sample consisted of 73 students enrolled in their second year of a Bachelor's degree program in Physiotherapy. The following criteria were used to select the students eligible to participate: (i) enrollment in the second year of the Bachelor's degree program in Physiotherapy; (ii) owning a smartphone; (iii) willingness to participate and signing an informed consent form. Before the study began, all eligible participants signed an informed consent form approved by the University of the Atlántico Medio's Human Research Ethics Committee (CEI/01-007), which was designed to comply with the Declaration of Helsinki, best clinical practices, and the applicable laws and regulations. The study was conducted from September to December 2022, with registration number NCT06142812.

2.2 Intervention

The intervention carried out with Kahoot! Was meticulously planned to evaluate its effect on student learning over a four-month period. During this time, educational reinforcement sessions were organized using Kahoot! Divided into two intervention groups, differentiated by the duration of each session: one enjoyed 30-min sessions per week, while the other had 60-min sessions. A third group, which served as a control group, did not use Kahoot! For feedback, opting instead for conventional teaching methods with slide presentations.

Structured sessions with Kahoot! They were designed to consolidate the understanding of the theoretical concepts addressed in class. For this purpose, a specific questionnaire was developed in Kahoot! For each topic, composed of 15 questions, each with three answer options. These questionnaires were administered right at the end of the theoretical presentations of each unit, with the purpose of reinforcing and evaluating the students' immediate understanding of the most recently taught content.

The dynamics of the sessions with Kahoot! Encouraged active participation: students entered the game through a unique PIN, using nicknames to maintain anonymity. The questions were projected on a large screen and accompanied by four visual options, along with a countdown timer, adding an element of gamification and friendly competition to the activity. Students selected the answer they considered correct using their mobile devices connected to the Internet. Immediately after answering, they received feedback on their choice, allowing the instructor to clarify doubts and explain the reasons behind the correct and incorrect answers.

This method of immediate feedback, added to the competitive and playful structure of the sessions, not only encouraged the attention and interest of the students, but also promoted an active and participatory learning environment. At the end of each questionnaire, a leaderboard was displayed with the names of the students who had obtained the five best scores, based on accuracy and speed of response, which added an additional motivating element for the participants (Parra-González and Segura-Robles, 2019). The possibility of downloading the results of the sessions allowed the instructor to identify both the questions that had presented the most difficulties to the students and those that required additional support, thus facilitating more personalized and effective teaching. Since the Kahoot! App is free and easy to use, both instructors and students have considered it to be an essential tool for enhancing classroom dynamics (Amores-Valencia et al., 2022).

2.3 Outcomes

As part of this study, data was collected at the beginning of the research and again after the intervention period had ended. Socio-demographic data related to the participants was also compiled, such as their age, sex, income level, and any learning difficulties.

To ensure validity, the chosen measures underwent extensive review by experts in the field to assess their appropriateness for the study population and research objectives. Additionally, a pilot test was conducted to evaluate the clarity and understandability of the measures for participants. Furthermore in this study, reliability was ensured through several methods. First, standardized procedures were followed consistently during data collection to minimize measurement error and variability. This included providing clear instructions to participants, using standardized assessment tools, and conducting assessments under similar conditions for all participants.

The Spanish version of the d2 Test of Attention (Seisdedos, 2012) can be used to evaluate selective attention and concentration in a classroom context. This test asks each participant to carefully check what is written on each line, from left to right, then cross out all instances of the letter "d" that have two small lines around them (two lines above, two lines below, or one above and one below). Those elements are considered relevant, while all other combinations (the letters "d" and "p" with other combinations of lines or no lines) are included as "distractors" and should not be crossed out. The participant is given 20 s to complete each line. In addition to demonstrating convergent and divergent validity, this test has been found to have excellent reliability, with both Cronbach's alpha and test–retest reliability ranging between 0.90 and 0.97 (Pawlowski, 2020).

The Creative Intelligence Test (CREA) (Corbalán, 2006) evaluates creative intelligence by asking questions about an image. First, before the image is displayed, the participant fills in spaces using the information provided. The image is then displayed, and the participant's task is to formulate as many questions as possible. Those questions are then assessed using specific guidelines, with positive scores given to appropriate questions, and questions that do not fit the context penalized. Additional points are awarded for compound questions. The final point score is calculated by taking into account the number of questions, omissions, canceled responses, and extra points. A high score (75–99 points) indicates excellent creative skills, a medium score (26–74 points) indicates a moderate level of creativity, and a low score (1–25 points) suggests limited creative capacity.

The student capabilities subscale of the Student Engagement Questionnaire (SEQ) developed by Kember and Leung (2009) and Gargallo et al. (2018) was also used to compile data regarding the students' own reflections on their development of generic capabilities. This subscale contains 16 items that measure 8 aspects of capability: critical thinking (2 items), creative thinking (2 items), self-managed learning (2 items), adaptability (2 items), problem solving (2 items), communication skills (2 items), interpersonal skills and group work (2 items), and computer literacy (2 items). The participants' responses are recorded using a 5-point Likert scale, ranging from 5 ("strongly agree") to 1 ("strongly disagree"). The questionnaire also includes two open-ended questions to obtain comments about the best aspect and the

aspect that most needs improvement. In this study, the capabilities subscale showed high reliability, with Cronbach's alphas of 0.86 and 0.92.

2.3.1 Sample size calculation.

Our study has been based on detecting a minimum clinically relevant change in the variables used to measure attention, creative intelligence, and SEQ capabilities. Using a power analysis, we determined that a sample size of 73 participants would give us a power of 80% for detecting these changes, using a 0.05 significance level and a realistic estimation of the effects based on previous research (Chan et al., 2021).

2.3.2 Statistical analysis

An exploratory analysis was performed using the Kolmogorov–Smirnov test, to confirm the pre-training and post-training normality of the data. The results showed that the data had a normal distribution ($p > 0.05$), which justified the use of parametric tests. The pre-training and post-training values were presented as a mean and standard deviation, and a paired Student's *t*-test was used to assess the statistical significance ($p < 0.05$) of the changes observed, using a stratified analysis based on time of exposure to the game. As part of the multivariate analysis of covariation (MANCOVA), the potential confusion effect caused by the variable that recorded the students' sex was evaluated for all of the result variables, along with the interaction between the sex and time variables.

3 Results

The total sample consisted of 73 students with a mean age of 19.51 ± 0.95 years, all with attention difficulties, and with a higher proportion of male students (65.8%). Most of the students (76.7%) said that they enjoyed playing games on their mobile devices, with 39.7% reporting their daily use as between 1 and 60 min and the other 37% reporting more than 60 min of daily use (Table 1).

A variety of tests were given to the students both before and after the intervention (Table 2). For the group that had no exposure to the game, there only significant differences observed were in the scores for adaptability (difference in means 4.42; $p = 0.02$), while those who played Kahoot! For 1–60 min each day showed differences only in their scores for adaptability (difference in means 29.66; $p = 0.01$) and computer literacy (44.48; $p = 0.004$).

TABLE 1 Characteristics of the sample population.

	Mean		SD
Age	19.51		0.95
		n	%
Sex	Male	48	65.8%
	Female	25	34.2%
Like playing mobile games?	No	17	23.3%
	Yes	56	76.7%
Daily game minutes	0 min	17	23.3%
	1–60 min	29	39.7%
	> 60 min	27	37.0%

SD, Standard deviation.

Finally, the students with more than 60 min of daily game playing showed improvement in most of the tests performed, with some of the most notable results being those for attention (difference in means 91.48), total attention (difference in means 83.70), creative intelligence (difference in means 80.00), critical thinking (difference in means 6.47), creative thinking (difference in means 4.70) self-managed learning (difference in means 8.57), adaptability (difference in mean 6.94), problem solving (difference in means 8.18), and computer literacy (difference in means 5.41), with these differences all significant ($p < 0.001$). However, there were no differences observed in relation to communication skills ($p = 0.59$) or interpersonal relationships and group work ($p = 0.658$). Furthermore, it is important to consider that, although students who played for more than 60 min daily showed significant improvements in a wide range of cognitive skills, we cannot disregard the influence of other external factors that may have contributed to these results. For instance, students' personal commitment level to the game, their intrinsic motivation to participate, and their familiarity with the Kahoot! Platform could have influenced the magnitude and direction of the observed improvements. Likewise, students' socio-economic and cultural background, as well as their prior educational level, might have played a role in their response to the game and in the acquisition of cognitive skills. Therefore, conducting more detailed analyses that take into account these potential confounding variables is essential for a comprehensive understanding of the effects of gaming on students' cognitive development.

The multivariate analysis confirmed the significance of the differences seen when evaluating the group with the most game time exposure. The sex variable was discarded to eliminate any confusion effect, and the interaction between the game minutes and sex variables was also discarded, which indicates that regardless of a student's sex, more than 60 min of game time can produce significant, beneficial differences, with the highest levels of impact on attention, creative thinking, adaptability, problem solving, and computer literacy (Wilks' lambda = 1.99, $p = 0.010$) (Table 3).

4 Discussion

The purpose of this research has been to evaluate the effects that use of the Kahoot! App on mobile devices may have on attention, creative intelligence, and the SEQ student capacities subscale, for students enrolled in their second year of the Bachelor's degree program in Physiotherapy at the University of Jaén.

In our increasingly digital world, the use of digital tools in education has generated debates regarding their impact on student development (Martínez, 2017). Therefore, to help understand the potential role of technology in contemporary education, the present study has used differentiated groups of university students to address the question of whether regular use of the Kahoot! Platform, for more than 60 min per day, can improve essential skills such as attention, creativity, critical thinking, self-managed learning, adaptability, problem solving, and computer literacy.

In agreement with previous studies (Ismail and Mohammad, 2017; Licorish et al., 2018), our results support the conclusion that integrating platforms such as Kahoot! Into the educational process can produce multiple benefits. However, we should emphasize that the differences observed in our study are primarily seen in the group with the most time spent using that app (> 60 min per day), which would

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TABLE 2 Pre- and post-intervention comparison for each form of evaluation, stratified by game time.

Variables evaluated	0 min					1–60 min					> 60 min				
	PRE		POST			PRE		POST			PRE		POST		
	Mean	SD	Mean	SD	*p*	Mean	SD	Mean	SD	*p*	Mean	SD	Mean	SD	*p*
d2	60.41	14.26	60.88	14.30	0.77	62.66	17.652	63.59	15.80	0.46	64.56	15.26	73.70	14.60	< 0.001
d2 Total	66.71	14.24	69.76	15.80	0.06	65.69	15.609	67.72	13.85	0.12	66.19	15.76	74.56	14.14	< 0.001
Creativity	57.88	18.30	56.88	18.43	0.55	58.83	21.899	57.76	22.46	0.46	56.48	18.44	64.48	17.19	< 0.001
Critical thinking	2.78	1.28	2.89	1.17	0.65	3.47	1.070	3.47	1.14	0.98	2.92	1.18	3.56	1.01	< 0.001
Creative thinking	2.84	960	2.74	963	0.70	2.87	0.995	2.76	0.84	0.54	2.88	1.12	3.35	1.05	< 0.001
Self-managed learning	3.55	955	3.33	760	0.39	3.39	0.809	21.82	97.36	0.32	3.40	0.95	4.26	0.67	< 0.001
Adaptability	3.19	789	3.63	838	0.02	3.45	0.806	3.75	0.84	0.01	3.60	0.74	4.30	0.65	< 0.001
Problem solving	2.94	1.07	3.25	1.03	0.19	3.11	0.872	3.43	0.97	0.06	3.20	1.12	04.02	0.80	< 0.001
Communication skills	3.30	951	3.19	1.08	0.51	03.09	0.783	3.14	0.92	0.68	3.17	1.13	3.12	1.06	0.589
Interpersonal skills and group work	3.22	937	3.13	970	0.58	03.09	0.914	2.95	0.96	0.22	3.00	1.17	2.95	1.14	0.658
Computer literacy	3.22	1.18	03.07	1.10	0.35	3.12	1.058	3.57	1.03	0.04	3.33	0.99	3.87	0.91	< 0.001

support the conclusion that the duration of use of such platforms may have a notable influence on the skills developed, because of various factors that may affect their impact. Use in the classroom for longer time periods allows deeper immersion in the dynamics of the game, which leads to development of a wider range of skills. By dedicating more time to use of the app, the students are faced with a greater diversity of challenges and situations that can stimulate various cognitive aspects (Rodríguez, 2017).

The complexity and variety of the challenges presented during longer usage sessions provide fertile ground for strengthening critical thinking and problem-solving skills. This is supported by previous research results demonstrating that additional usage time allows a more diverse set of problems to be incorporated, which in turn promotes development of more complex and sophisticated skills, and that prolonged use also allows for better adaptation to the game's format and specific dynamics (Chacon and Janssen, 2020). In addition, longer periods of immersion may improve the students' ability to adapt to other similar platforms and engage effectively with similar digital environments. Ongoing exposure to the Kahoot! Interface and mechanics during longer sessions may also increase computer literacy, which is supported by the observation that as students become more familiar with a platform's features and characteristics, their competencies related to digital environments also improve (Wang and Thair, 2020).

With regard to specific skills, it has been demonstrated that in our modern context saturated with digital distractions, where attention has itself become an essential capability, the use of tools such as Kahoot! Can help students maintain their attention levels during longer sessions. This may be due to the fact that the platform's interactive and competitive format encourages sustained concentration during educational tasks, offering an effective alternative to the distractions commonly existing in the digital environment (Aivaz and Teodorescu, 2022), and also the fact that prolonged engagement with challenging activities, such as interactive games, enhances attention (Fatima et al., 2019). In relation to this, the game's interactive and challenging dynamics help improve concentration, mental resilience, and absorption of information, which are all important aspects of paying attention to details and increasing cognitive performance (Martinez et al., 2023).

Creative intelligence, as another essential aspect of student development, is stimulated by the entertaining nature of the Kahoot! Platform, because answering questions quickly, or creating questionnaires, inspires innovative thought in the participants and helps them generate original ideas. These effects have also been reported by Calvo and López-Rodríguez (2021), who found that spending longer time periods with activities such as those offered by Kahoot! Encourages exploration of diverse ideas and inspires creativity. In addition, the improvement seen in critical thinking skills may be due to the need to confront challenges presented in real time, because analyzing information, making quick decisions, and evaluating options contributes to the development of skills that are applicable not only in the academic world, but also in everyday life (Jin and Ji, 2021).

In addition, the results observed in this study regarding self-managed learning associated with the use of Kahoot! Can be attributed to the fact that it allows the players to advance at their own pace. This is also in agreement with previous research results that have emphasized independence as a driver of self-regulation and time management, which leads to continual improvement in terms of

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TABLE 3 MANCOVA analysis adjusted for the daily game minutes variable and its interaction with the sex variable.

		F	*p*
Daily Minutes	Wilks' lambda	1.99	00.10
	Dependent Variable	*F*	*p*
Daily minutes	d2	4.8292	0.011
	d2 Total	1.6176	0.206
	Creativity	1.0962	0.340
	Critical thinking	2.1384	0.125
	Creative thinking	3.3977	0.039
	Self-managed learning	7.417	0.480
	Adaptability	5.0949	0.001
	Problem solving	4.4251	0.015
	Communication skills	212	0.979
	Interpersonal skills and group work	2.089	0.812
	Computer literacy	3.3649	0.040
Sex	d2	5.304	0.469
	d2 Total	2.106	0.648
	Creativity	1.0335	0.313
	Critical thinking	0.550	0.815
	Creative thinking	4.918	0.486
	Self-managed learning	5.136	0.476
	Adaptability	0.680	0.795
	Problem solving	2.0778	0.154
	Communication skills	2.5373	0.116
	Interpersonal skills and group work	1.2383	0.270
	Computer literacy	2.1795	0.145
Daily minutes ✻ Sex	d2	2.1864	0.120
	d2 Total	6.082	0.547
	Creativity	2.0182	0.141
	Critical thinking	2.0488	0.137
	Creative thinking	1.6505	0.200
	Self-managed learning	3.710	0.691
	Adaptability	0.987	0.906
	Problem solving	3.232	0.725
	Communication skills	1.409	0.869
	Interpersonal skills and group work	1.3104	0.277
	Computer literacy	2.538	0.777

interaction with the contents being taught (Grabner-Hagen and Kingsley, 2023).

With regard to adaptability, our study indicates a clear association between exposure to the Kahoot! Platform and significant improvement in this skill among the students. This improvement was observed in all groups exposed to use of the game, although it was more pronounced among the students who used Kahoot! For more than 60 min each day. Given the critical importance of adapting to new contexts, both in the educational and work environments, prolonged immersion in Kahoot! Seems to facilitate better adjustment to the challenges presented during the game. This factor has potentially influenced the notable improvement seen in this skill, and has also been previously reported in the literature (Schmidt et al., 2011).

Problem solving is enhanced by the wide diversity of challenges presented when using Kahoot! The variety of situations and questions stimulates the students' ability to quickly adapt to changing environments, and to find effective solutions in shorter periods of time (Kalleny, 2020). When the students dedicate more time to the game, they are able to experiment with different approaches to solving problems, which significantly contributes to their development of this skill. The game presents a wide range of situations that require adaptation to changing environments, and generation of effective answers in contexts where time is limited (Vlachopoulos and Makri, 2017). In addition, other researchers have reported that prolonged exposure facilitates experimentation with multiple strategies when solving problems, which also strengthens this skill (Donkin and Rasmussen, 2021; Teunisse et al., 2022).

With regard to self-managed learning, our study demonstrates that prolonged exposure to the game can be beneficial (Primack et al., 2012). This could be explained by the fact that the independence offered by Kahoot! Allows the players to advance at their own pace (Nieto-Escamez and Roldán-Tapia, 2021). The other studies included in a systematic review indicate that this independence facilitates more personalized interaction with the contents being taught, which has probably helped contribute to the improvement observed, and this can in turn stimulate self-regulation and time management (Edisherashvili et al., 2022).

Finally, computer literacy is strengthened by regular use of Kahoot! (Neureiter et al., 2020). Familiarity with digital interfaces and technological tools, and the ability to navigate smoothly through their contents, are important competencies in our increasingly digital world (Cortellazzo et al., 2019), and these are skills that can be strengthened through a deeper understanding of the platform's features and characteristics. In contrast to previously reported results, however, we found that shorter sessions (from 1 to 60 min) tend to have effects focused on more immediate skills, such as adaptability and computer literacy. These shorter periods of interaction may not be sufficient to allow deeper exposure to more complex aspects involving critical thinking or creativity, which require more time and ongoing practice. It is also worth emphasizing that this study's results did not show differences in communication skills or interpersonal relationships, regardless of the exposure time, which contrasts with the results reported by Chan et al. (2021), where the authors found differences in communication skills ($p = 0.04$) at the end of the course.

Another relevant limitation lies in the sample population, which is restricted to university students of a specific course at a particular institution. This limitation may restrict the generalizability of the findings to other student populations or educational contexts. Furthermore, the study design may not fully address the complexity of the effects of Kahoot use, as the specific learning context and individual characteristics of participants that could influence the results were not considered.

To address these limitations and advance the field of gamification in education, it is suggested to conduct more specific and targeted research.

For example, future studies could consider including multiple educational institutions and educational levels to evaluate the transferability of the effects of Kahoot use in different contexts. Additionally, it would be beneficial to incorporate more detailed measures of individual participant characteristics, such as cognitive ability level, learning styles, and prior experience with technology, to better understand the factors that may modulate the developmental impact of Kahoot. Of skills. Likewise, it is suggested to explore the optimal duration and frequency of use of Kahoot to maximize educational benefits and avoid possible adverse effects, such as cognitive fatigue or loss of interest. These investigations could contribute significantly to the understanding of the role of gamification in education and provide guidance for effective and evidence-based educational practices.

In summary, ongoing use of Kahoot! During longer sessions could serve as a catalyst for development of critical skills in university students. However, it is essential to maintain a balance between the use of technology and other educational activities, to ensure comprehensive and diversified student development. In addition, the amount of time dedicated to technology-based activities may be a critical factor for allowing deeper, better consolidated development. This is because longer periods of use provide opportunities for more significant improvement, by giving students more time for in-depth exploration, reflection, and perfection of their capabilities.

5 Conclusion

The research reported here has demonstrated that use of the Kahoot! Platform for more than 60 min per day can produce significant results in terms of improving specific skills. This use for longer periods of time has revealed notable benefits in terms of attention, creativity, critical thinking, adaptability, problem solving, and computer literacy, therefore supporting integration of Kahoot! Into the educational process at universities. Our data suggest that inclusion of these digital activities for longer time periods promotes development of complex skills, and represents an effective means of cognitive enhancement and acquisition of essential skills. However, it is also worth emphasizing the need for a suitable balance between the use of technology and other educational activities, to ensure comprehensive and diversified student development. Ongoing use of these platforms provides opportunities for deeper, more exhaustive improvement of cognitive skills, which highlights the importance of dedicating sufficient time to activities of this type, to allow full development of the students' capabilities.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by the Research Ethics Committee of the University of the Atlántico Medio (CEI/01-007). The studies were conducted in accordance with local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

AA-A: Conceptualization, Methodology, Writing – original draft. YC-C: Conceptualization, Supervision, Writing – review & editing. MC-F: Methodology, Supervision, Writing – original draft. YR-C: Formal analysis, Writing – review & editing. AG-M: Formal analysis, Supervision, Writing – review & editing.

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The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Aivaz, K. A., and Teodorescu, D. (2022). College Students' distractions from learning caused by multitasking in online vs. face-to-face classes: a case study at a public University in Romania. *Int. J. Environ. Res. Public Health* 19:11188. doi: 10.3390/ijerph191811188

Amores-Valencia, A., Burgos, D., and Branch-Bedoya, J. W. (2022). Influence of motivation and academic performance in the use of augmented reality in education. A systematic review. *Front. Psychol.* 13:1011409. Published 2022 Oct 11. doi: 10.3389/fpsyg.2022.1011409

Arnold, B. J. *Gamification in education*. American Society of Business. Las Vegas, NV. (2014).

Calvo, V., and López-Rodríguez, M. I. (2021). University classroom gamification: a "reverse escape room" experience. *Rev. Docencia Univ.* 19, 47–74. doi: 10.4995/redu.2021.15666

Cerro, G. D.. Aprender jugando, resolviendo: diseñando experiencias positivas de aprendizaje. XII Jornadas Internacionales de Innovación Universitaria Educar para transformar: Aprendizaje experiencial. (2015). Available at: https://goo.gl/x6Z70t.

Chacon, J. A., and Janssen, H. (2020). Teaching critical thinking and problem-solving skills to healthcare professionals. *Med. Sci. Educ.* 31, 235–239. doi: 10.1007/s40670-020-01128-3

Chan, C. W. H., Tang, F. W. K., Chow, K. M., and Wong, C. L. (2021). Enhancing generic capabilities and metacognitive awareness of first-year nursing students using active learning strategy. *BMC Nurs.* 20:81. doi: 10.1186/s12912-021-00601-7

Chen, J., and Liang, M. (2022). Play hard, study hard? The influence of gamification on students' study engagement. *Front. Psychol.* 13:994700. doi: 10.3389/fpsyg.2022.994700

Corbalán, F. J.. *Crea, inteligencia creativa: una medida cognitiva de la creatividad*. Madrid: TEA Ediciones. (2006).

Cortellazzo, L., Bruni, E., and Zampieri, R. (2019). The role of leadership in a digitalized world: a review. *Front. Psychol.* 10:1938. doi: 10.3389/fpsyg.2019.01938

Dahalan, F., Alias, N., and Shaharom, M. S. N. (2023). Gamification and game based learning for vocational education and training: a systematic literature review. *Educ. Inf. Technol.* 29, 1279–1317. doi: 10.1007/s10639-022-11548-w

Darling-Hammond, L., Flook, L., Cook-Harvey, C., Barron, B., and Osher, D. (2020). Implications for educational practice of the science of learning and development. *Appl. Dev. Sci.* 24, 97–140. doi: 10.1080/10888691.2018.1537791

De Soto, I. S. (2018). Gamification tools for learning earth sciences. *Edutec. Rev. Electr. Tecnol. Edu.* 65, 29–39. doi: 10.21556/edutec.2018.65.1143

Donkin, R., and Rasmussen, R. (2021). Student perception and the effectiveness of Kahoot!: a scoping review in histology, anatomy, and medical education. *Anat. Sci. Educ.* 14, 572–585. doi: 10.1002/ase.2094

Edisherashvili, N., Saks, K., Pedaste, M., and Leijen, Ä. (2022). Supporting self-regulated learning in distance learning contexts at higher education level: systematic literature review. *Front. Psychol.* 12:792422. doi: 10.3389/fpsyg.2021.792422

Fatima, S. S., Ghias, K., Jabeen, K., and Sabzwari, S. (2019). Enhancing cognitive engagement of pre-clinical undergraduate medical students via video cases and interactive quizzes in problem-based learning. *Cureus* 11:e3832. doi: 10.7759/cureus.3832

Gargallo, B., Suárez-Rodríguez, J. M., Almerich, G., Verde, I., and Cebrià i Iranzo, M. A. (2018). The dimensional validation of the student engagement questionnaire (SEQ) with a Spanish university population. Students' capabilities and the teaching-learning environment. *An. Psicol.* 34, 519–530. doi: 10.6018/analesps.34.3.299041

Gokbulut, B. (2020). The effect of Mentimeter and Kahoot applications on university students'e-learning. *World J. Educ. Technol.* 12, 107–116. doi: 10.18844/wjet.v12i2.4814

Grabner-Hagen, M. M., and Kingsley, T. (2023). From badges to boss challenges: gamification through need-supporting scaffolded design to instruct and motivate elementary learners. *Comput. Educ.* 4:100131. doi: 10.1016/j.caeo.2023.100131

Ismail, M. A. A., and Mohammad, J. A. M. (2017). Kahoot: a promising tool for formative assessment in medical education. *Educ. Med. J.* 9, 19–26. doi: 10.21315/eimj2017.9.2.2

Jin, M., and Ji, C. (2021). The correlation of metacognitive ability, self-directed learning ability and critical thinking in nursing students: a cross-sectional study. *Nurs. Open* 8, 936–945. doi: 10.1002/nop2.702

Johns, K. (2015). Engaging and assessing students with technology: a review of Kahoot! *Delta Kappa gamma bull.* 5, 89–91.

Kalleny, N. K. (2020). Advantages of Kahoot! Game-based formative assessments along with methods of its use and application during the COVID-19 pandemic in various live learning sessions. *J. Microsc. Ultrastruct.* 8, 175–185. doi: 10.4103/JMAU.JMAU_61_20

Kalu, F. A., and Bwalya, J. C. (2017). What makes qualitative research good research? An exploratory analysis of critical elements. *Int. J. Soc. Sci. Res.* 5, 43–56. doi: 10.5296/ijssr.v5i2.10711

Kapp, K. M.. *The gamification of learning and instruction: game-based methods and strategies for training and education*. Wiley. Hoboken. (2012).

Kember, D., and Leung, D. Y. P. (2009). Development of a questionnaire for assessing students' perceptions of the teaching and learning environment and its use in quality assurance. *Learn. Environ. Res.* 12, 15–29. doi: 10.1007/s10984-008-9050-7

Lee, J. J., and Hammer, J. (2011). Gamification in education: what, how, why bother? *Acad. Exch. Q.* 15, 1–5.

Li, Q., Yin, X., Yin, W., Dong, X., and Li, Q. (2023). Evaluation of gamification techniques in learning abilities for higher school students using FAHP and EDAS methods. *Soft. Comput.* 18:9. doi: 10.1007/s00500-023-08179-9

Licorish, S. A., Owen, H. E., Daniel, B., and George, J. L. (2018). Students' perception of Kahoot!'s influence on teaching and learning. *RPTEL* 13:9. doi: 10.1186/s41039-018-0078-8

López-Belmonte, J., Segura-Robles, A., Fuentes-Cabrera, A., and Parra-González, M. E. (2020). Evaluating activation and absence of negative effect: gamification and escape rooms for learning. *Int. J. Environ. Res. Public Health* 17:2224. doi: 10.3390/ijerph17072224

Lozada, C., and Gómez, S. B. (2017). La gamificación en la Educación Superior: una revisión sistemática. *Rev. Ingen. Univ. Medel.* 16, 97–124. doi: 10.22395/rium.v16n31a5

Martínez, N. G. *Tecnologías y nuevas tendencias en educación: aprender jugando* (2017). Universidad Complutense de Madrid. Spain

Martinez, L., Gimenes, M., and Lambert, E. (2023). Video games and board games: effects of playing practice on cognition. *PLoS One* 18:e0283654. doi: 10.1371/journal.pone.0283654

McGonigal, J. *Reality is broken: Why games make us better and how they can change the world*. London: Penguin Press. (2011).

McLaughlin, T., and Yan, Z. (2017). Diverse delivery methods and strong psychological benefits: a review of online formative assessment. *J. Comput. Assist. Learn.* 33, 562–574. doi: 10.1111/jcal.12200

Miller, C. (2013). The gamification of education. *Dev. Bus. Simul. Exp. Learn.* 40, 196–200. doi: 10.1007/978-1-4302-3594-1_3

Müller, B. C., Reise, C., and Seliger, G. (2015). Gamification in factory management education – a case study with Lego Mindstorms. *Procedia CIRP* 26, 121–126. doi: 10.1016/j.procir.2014.07.056

Neureiter, D., Klieser, E., Neumayer, B., Winkelmann, P., Urbas, R., and Kiesslich, T. (2020). Feasibility of Kahoot! As a real-time assessment tool in (Histo-) pathology classroom teaching. *Adv. Med. Educ. Pract.* 11, 695–705. doi: 10.2147/AMEP.S264821

Nieto-Escamez, F. A., and Roldán-Tapia, M. D. (2021). Gamification as online teaching strategy during COVID-19: a Mini-review. *Front. Psychol.* 12:648552. doi: 10.3389/fpsyg.2021.648552

Oliva, H. (2017). The gamification as a methodological strategy in the university educational context. *Real. Reflex.* 44, 29–47. doi: 10.5377/ryr.v44i0.3563

Orbegoso, G. A. (2016). La motivación intrínseca según Ryan & Deci y algunas recomendaciones para maestros. *Lumen Educare* 2, 75–93. doi: 10.19141/2447-5432/lumen.v2.n1.p.75-93

Ortiz, A. M., Jordán, J., and Agredal, M. (2018). Gamificación en educación: una panorámica sobre el estado de la cuestión. *Educ. Pesqui.* 44:3773. doi: 10.1590/S1678-4634201844173773

Parra-González, M. E., and Segura-Robles, A. (2019). Traducción y validación de la escala de evaluación de experiencias gamificadas (GAMEX). *Bordón* 71, 87–99. doi: 10.13042/Bordon.2019.70783

Pawlowski, J. (2020). The d2 test of attention: internal consistency, temporal stability and evidence of validity. *Rev. Costar. Psico.* 39, 145–165. doi: 10.22544/rcps.v39i02.02

Pintor-Díaz, P. (2017). Gamificando con Kahoot en Evaluación Formativa. *Educ. Aprend.* 3, 112–117. doi: 10.22370/ieya.2017.3.2.709

Primack, B. A., Carroll, M. V., McNamara, M., Klem, M. L., King, B., Rich, M., et al. (2012). Role of video games in improving health-related outcomes: a systematic review. *Am. J. Prev. Med.* 42, 630–638. doi: 10.1016/j.amepre.2012.02.023

Rodríguez, L. (2017). Smartphones y aprendizaje: El uso de Kahoot en el aula universitaria. *Revi. Mediter. Comun.* 8, 181–190. doi: 10.14198/MEdCoM2017.8.1.13

Rodríguez, M., Díaz, I., González, E. J., and González-Miquel, M. (2019). Motivational active learning: an integrated approach to teaching and learning process control. *Educ. Chem. Eng.* 26:2. doi: 10.1016/j.ece.2019.01.002

Schmidt, H. G., Rotgans, J. I., and Yew, E. H. (2011). The process of problem-based learning: what works and why. *Med. Educ.* 45, 792–806. doi: 10.1111/j.1365-2923.2011.04035.x

Seisdedos, N. A.. *Española D2, Test de Atención de Brickenkamp*. TEA Ediciones: Madrid, Spain (2012).

Teunisse, A. K., Pembroke, L., O'Gradey-Lee, M., Sy, M., Rapee, R. M., Wuthrich, V. M., et al. (2022). A scoping review investigating the use of exposure for the treatment and targeted prevention of anxiety and related disorders in young people. *JCPP Adv.* 2:e12080. doi: 10.1002/jcv2.12080

Urh, M., Vukovic, G., and Jereb, E. (2015). The model for introduction of gamification into e-learning in higher education. *Procedia Soc. Behav. Sci.* 197, 388–397. doi: 10.1016/j.sbspro.2015.07.154

Uyulgan, M. A., and Akkuzu, N. (2004). An overview of student teachers' academic intrinsic motivation. *Educ. Sci.* 14, 24–32. doi: 10.12738/estp.2014.1.2013

Villalustre, L., and Del Moral, M. E. (2015). Gamificación: Estrategia para optimizar el proceso de aprendizaje y la adquisición de competencias en contextos universitarios. *Dig. Edu. Rev.* 27, 13–31. doi: 10.1344/der.2015.27.13-31

Vlachopoulos, D., and Makri, A. (2017). The effect of games and simulations on higher education: a systematic literature review. *Int. J. Educ. Technol. High. Educ.* 14:22. doi: 10.1186/s41239-017-0062-1

Wang, A. I., and Thair, R. (2020). The effect of using Kahoot! For learning – a literature review. *Comput. Educ.* 149:103818. doi: 10.1016/j.compedu.2020.103818

Zichermann, G., and Cunningham, C.. *Gamification by design: implementing game mechanics in web and mobile apps*. Sebastopol, CA: O'Reilly Media. (2011).

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Educators as agents of breadth-biased learning: using social reconstructionism as rationale for embracing media multitasking and enhancing teaching practices in higher education

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This perspective article contends that media multitasking has significant implications on cognitive control processes, particularly in how information is processed and utilized. Contrary to viewing media multitasking as inherently negative, the article argues that it contributes to the evolving nature of cognitive processing, without necessarily improving or degrading it. The discussion draws on theoretical frameworks from contemporary cognitive neuroscience to contextualize these arguments. The article provides a nuanced perspective on media multitasking, acknowledging its enduring presence and exploring its influence on cognitive processes, while also proposing strategies for educators to navigate its implications in educational settings.

KEYWORDS

media multitasking, cognitive flexibility, breadth-biased learning, mindfulness practices, higher education, learning and teaching, pedagogical approaches

Introduction

The philosophy of social reconstructionism challenges the status quo of education and invites educators to take agency of societal change. This prestigious agency is granted to educators based on the notion that every educated member of society is a product of schools, and as such, should be equipped with the right skills and resources to bring about lasting solutions to social problems. In this perspective piece, I use the philosophy of social reconstructionism to critically evaluate the popular notion that, as media multitasking becomes part of everyday life, infiltrating both living, learning, and working spaces, it is bringing with it negative consequences such as superficial mode of acquiring information and knowledge, as well as reducing accuracy and performance of cognitive tasks (Schuur et al., 2015). The article aims to provide a rationale for embracing the here-to-stay nature of media multitasking and endorsing the argument that it in fact influences the evolving nature of cognitive control processes, in that it alters the way information is received and utilized, without necessarily making it better or worse. Theoretical frameworks from recent and current practices in cognitive neuroscience and computational modeling are discussed to provide contextual basis for the key arguments in the article. Primary focus is given to a critical discussion on cognitive processes involved in media multitasking, their direct implications on learning and education, and practical solutions for educators to enhance teaching practices in the new media age.

Social reconstructionism

Social reconstructionism is a philosophy of education founded by Brameld (1977) who advocated for empowering teachers with the tools and resources they need to bring about enduring solutions to fundamental problems at the school level in particular and the societal level in general (Liston and Zeichner, 1991). The theory aims to understand the historical foundations of social issues and encourages educators to take the lead in reforming the ways in which schools provide education and produce effective generations of leaders. In so doing, social reconstructionism empowers educators to oppose perpetuating the status quo and instead become agents of social change (Parks, 2006; Ong'ondo, 2017). At the core of social reconstructionism is the belief that the classroom is where educators and students identify social priorities and continuously work toward finding implementable solutions for them. Identifying current day media multitasking as a societal priority and one that is particularly impacting students in higher education, this article encourages institutions to adapt to the way the brain processes information and find congruency between the way educators deliver their teaching and the manner students receive it.

Chronic media-multitasking

Chronic media multitasking is causing structural changes in the brain (May and Elder, 2018). Given the age we live in, there is a growing body of research on media multitasking and its effect on the way the brain processes information (Coulacoglou and Saklofske, 2017; Firth et al., 2019; Korte, 2020). As a relatively new area of research, media multitasking is motivating researchers to explore the possible novel ways that the cognitive system is encoding, processing, and utilizing information. Studies have found varying levels of media use across different age groups, where young adults are found to be the heaviest media multitaskers (Carrier et al., 2009; Courage et al., 2015; Uncapher et al., 2017). They are also the focus of studies due to developmental research showing the brain's malleability and susceptibility to environmental stimuli during this key developmental stage (Arnett, 2000). It is argued that by virtue of neuroplasticity, emerging adults are at an advantage for increased environmental adaptability; and accordingly, extensive and chronic media use as experienced by this age group may have an association with developmental neuroplasticity, the brain's capacity to rewire and form new neural pathways (Firth et al., 2019; Korte, 2020).

Breadth-biased information processing

There is growing interest in how chronic media multitasking might be altering the way the brain processes information, from a linear and in-depth cognitive processing to a more breadth-biased one (Foerde et al., 2006; Poldrack and Foerde, 2007; Lin, 2009; Ophir et al., 2009; Uncapher et al., 2017). Contrary to the former, breadth-biased processing is characterized by engaging the brain in multiple activities and paying attention to several sources of information simultaneously (Lin and Parsons, 2018). Studies have found that heavy media multitaskers process information in a breadth-biased manner (Karpinski et al., 2013; Poplawska et al., 2021), which is quite distinct from the linear and in-depth style. This shift is attributed to chronic media consumption, which is increasingly becoming part of current day learning practices. Breadth-biased cognitive control involves information processing that is characterized by superficial and scattered attention toward several sources of information simultaneously, without focusing deeply on one single task. Ophir et al. (2009) argued that heavy media multitaskers are inclined to pay attention to a wider scope of information instead of focusing on a particular single piece. This may not necessarily mean inefficient use of cognitive resources, but rather a shift in cognitive control processes as chronic media consumption becomes part of everyday life.

Furthermore, in neuro-ergonomics, functional MRI studies have shown changes that occur in active parts of the brain during multitasking. Studies by Poldrack and Foerde (2007) and Foerde et al. (2013) found that the medial temporal lobe region of the brain, associated with declarative memory, is activated when selective and focused single task learning takes place; whereas the striatum, which is associated with procedural memory is activated when breadth-biased dual task learning takes place. In addition, the same studies showed increased activity around the dorsolateral pre-frontal cortex region when dual tasks were performed, which is a functional structure of the brain associated with media multitasking involving working memory capacity, cognitive flexibility, and abstract reasoning. The authors explain how in the presence of a distraction - in this particular case a secondary task - the results indicate that accuracy of performance is not affected; however, a shift occurs in the way the brain acquires learning, corresponding with the argument that multitasking might be altering the way the brain processes information.

Of the types of cognitive processes implicated in learning and the education environment, attention, working memory, cognitive control, and executive functioning are the notable ones (Clark and Harrelson, 2002). Studies have shown that these same processes are influenced by media multitasking, and alterations in brain regions such as the prefrontal cortex, the anterior cingulate cortex, and the dorsolateral prefrontal cortex have been observed using neuroimaging techniques (Loh and Kanai, 2014; Verghese et al., 2016; Cao et al., 2022; Luo et al., 2022). While these studies indicate that heavy media multitaskers engaged in specific learning-related cognitive activities showed significantly worse executive function than their counterparts, they had greater prefrontal activation and did not perform significantly worse on cognitive tasks (Luo et al., 2022). Moreover, experimental studies focused on training in multitasking activities indicate significant training-induced performance improvements in the left prefrontal cortex and the dorsolateral prefrontal cortex, particularly in sensitivity to multitasking demands and heightened neural activity when performing single tasks regardless of variations in input/output modalities (Verghese et al., 2016). These findings have direct educational implications on higher learning where educators could embrace novel ways of teaching practices that extend beyond the traditional mode of teaching delivery.

Mindfulness

Mindfulness experts argue that chronic media use is a defining characteristic of the modern digital world, hence inescapable, and scientific studies should instead focus on possible ways of enabling the cognitive system to cope with media use in an efficient and conducive manner through the practice of mindfulness (Brown and Ryan, 2003; Case and King, 2003; Carrier et al., 2009; Chiesa et al., 2011; Ie et al., 2013). Whilst trait mindfulness is a dispositional state of being, studies show that it can be enhanced and strengthened through various instructional intervention techniques. This, they argue, could foster cognitive flexibility and creative thinking, which are critical to learning in higher education (Langer and Moldoveanu, 2000; Sternberg, 2000; Hart et al., 2013; Rogaten and Moneta, 2016; Kercook et al., 2017). Moreover, the use of technology to deliver and access education has become increasingly mainstream and students are increasingly engaged in media multitasking to navigate through their education. Studies show that young adults who are also heavy media multitaskers could benefit from short-term mindfulness interventions whereby their attentional abilities are increased (Gorman and Green, 2016). Experimental research findings (Ie et al., 2013; Seddon et al., 2021) measuring cognitive performance on media multitasking activities found heavy media multitaskers who also had mindfulness as a dispositional trait performed significantly better. Arguably, this could be due to frequent media multitasking, resulting in significant improvement in cognitive flexibility.

Cognitive flexibility

Cognitive flexibility is defined as the brain's ability to remain flexible in the face of a constantly changing environment (Cools, 2015; Feng et al., 2020). Advocates of mindfulness suggest that through frequent engagement in mindfulness practices, it is possible to alter the structures of the brain responsible for executive functioning and consequently develop more efficiency in cognitive capacity while engaging in multitasking activities (Moore and Malinowski, 2009; Ie et al., 2013; Seddon et al., 2021). Researchers are increasingly recommending ways of fostering mindfulness practices to increase cognitive flexibility and enhance multitasking abilities, both of which could benefit students' learning and academic performance (Coulacoglou and Saklofske, 2017).

In recent years, studies have focused on investigating the relationship between trait mindfulness and its effects on attention, working memory, and other cognitive functions (Corti and Gelati, 2020; Nassif et al., 2023). Functional Magnetic Resonance Imaging (fMRI) studies on emerging adults show dramatic maturity of the dorsolateral prefrontal cortex region of the brain, associated with cognitive control (Jaeger et al., 2012; Tymofiyeva and Gaschler, 2020). There is also greater functional connectivity of this region with the right hippocampus, posterior and anterior cingulate, and two areas of the prefrontal cortex, suggesting maturity in working memory capacity and cognitive control of emerging adults. What such findings reveal is not only the structural changes this particular age group undergoes developmentally, but also possibly the functional ways in which thinking, learning, and general acquisition of information are being altered in the face of external environmental stimuli, such as chronic media usage.

General discussion and recommendations for educators

In the context of higher education, the discussion around media multitasking is essential due to its pervasive influence on students' learning approaches and the need for enhanced and evidence-based pedagogical practices. Firstly, educators could benefit from learning about the cognitive and neural mechanisms underlying media multitasking and its effects on the brain. Understanding the concepts discussed in this article, including breadth-biased processing, mindfulness, and cognitive flexibility is crucial for devising effective pedagogical strategies that take into account the effects of media multitasking on learning and cognition. Secondly, aligning pedagogical practices to the neural expectations brought on by media multitasking can play a vital role in enhancing cognitive flexibility and other desirable cognitive processes that aid learning. Educators can implement practical pedagogical strategies that promote engagement and enhance cognitive flexibility, including the following.

1. Provide mindfulness resources: Offer resources such as guided meditation recordings and mindfulness applications that students can access independently. Longitudinal studies have shown the positive and transformative impact of accessing mindfulness resources in higher education (Oberski et al., 2015; Barker et al., 2021; Ergas and Hadar, 2023).
2. Metacognitive strategies: Teach metacognitive strategies such as self-reflection, goal-setting, and strategic planning to help students develop awareness of their own thinking processes and learning strategies. Doing so has been found to enhance the ability to organize and integrate a large body of information, such as what is found when media multitasking, which in turn fosters creativity and cognitive flexibility (Meltzer, 2013).
3. Foster reflective practices and self-regulated learning: Encourage students to reflect on their learning experiences and identify instances in their learning journey where mindfulness practices could be beneficial. Teaching self-regulation strategies such as setting intentions and monitoring attentional focus has been found to augment cognitive flexibility and cognitive control among students (Marcovitch et al., 2008; Orakçi, 2021; Daggöl, 2023).
4. Promote problem-based learning: Implement problem-based learning (PBL) approaches where students work collaboratively to solve complex, real-world problems. PBL encourages students to explore multiple perspectives, consider alternative solutions, and adapt their thinking based on new information, fostering lateral and critical thinking skills (Tursynkulova et al., 2023).
5. Encourage Socratic questioning: Use Socratic questioning techniques to encourage students to critically analyze and evaluate ideas, arguments, and assumptions. By posing thought-provoking questions that challenge students' assumptions and encourage deeper exploration of topics,

educators can promote meaningful learning and intellectual growth (Tursynkulova et al., 2023).

6. Provide experiential learning opportunities: This would help engage students in authentic, real-world experiences. Experiential learning encourages students to apply theoretical knowledge in practical contexts, adapt to novel situations, and learn from failure and iteration, which are at the heart of cognitive flexibility (Durak, 2023).
7. Assign problem-based media tasks: Present students with problem-based tasks that require them to navigate and evaluate information from multiple media sources to solve real-world challenges. For instance, students could analyze conflicting news reports on a current event, assess the credibility of online sources, and synthesize their findings to form evidence-based conclusions. This cultivates cognitive flexibility by challenging students to critically evaluate and integrate information from diverse media sources, mirroring the cognitive demands of media multitasking (DeHaan, 2009; Fjaellingsdal et al., 2021; Green and Rathgeb-Schnierer, 2023).

Conclusion

In conclusion, media multitasking may have an effect on the evolving nature of cognitive control processes. Congruent with the theory of cognitive flexibility within the mindfulness literature, such concepts lend credence to the notion that media multitasking may be promoting a breadth-biased style of information processing. The philosophy of social reconstructionism grants educators the agency for social change, and institutions in higher education carry the responsibility to ensure that teaching methodologies are aligned with the most efficient ways that students can receive and process information. Experimental research findings (Corti and Gelati, 2020; Nassif et al., 2023) show that mindfulness practices and other teachable strategies can be developed without necessarily having prior experiences. The overarching argument here is that fostering mindfulness, and by extension, cognitive flexibility, will enhance breadth-biased learning, which will have a knock-on effect on students overall learning experiences and academic achievements in today's media-saturated world.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

SK: Conceptualization, Methodology, Project administration, Resources, Visualization, Writing – original draft, Writing – review & editing.

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The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Arnett, J. J. (2000). Emerging adulthood: a theory of development from the late teens through the twenties. *Am. Psychol.* 55, 469–480. doi: 10.1037/0003-066X.55.5.469

Barker, R. K., Tuominen, L. P., Larson, M. R., Lee-Nichols, M. E., Eslinger, G., Patterson, K. L., et al. (2021). Enhancing mindfulness and well-being in higher education. *Int. J Commun. Well-Being* 4, 625–646. doi: 10.1007/s42413-021-00118-6

Brameld, T. (1977). Reconstructionism as radical philosophy of education: a reappraisal. *Educ. Forum* 42, 67–76. doi: 10.1080/00131727709338153

Brown, K. W., and Ryan, R. M. (2003). The benefits of being present: mindfulness and its role in psychological well-being. *J. Pers. Soc. Psychol.* 84, 822–848. doi: 10.1037/0022-3514.84.4.822

Cao, N., Pi, Y., Qiu, F., Wang, Y., Xia, X., Liu, Y., et al. (2022). Plasticity changes in dorsolateral prefrontal cortex associated with procedural sequence learning are hemisphere-specific. *NeuroImage* 259:119406. doi: 10.1016/j.neuroimage.2022.119406

Carrier, L. M., Cheever, N. A., Rosen, L. D., Benitez, S., and Chang, J. (2009). Multitasking across generations: multitasking choices and difficulty ratings in three generations of Americans. *Comput. Hum. Behav.* 25, 483–489. doi: 10.1016/j.chb.2008.10.012

Case, C. J., and King, D. I. (2003). Are undergraduates using the internet productively? *Issues Inf. Syst.* 5, 45–51.

Chiesa, A., Calati, R., and Serretti, A. (2011). Does mindfulness training improve cognitive abilities? A Systematic review of neuropsychological findings. *Clin. Psychol. Rev.* 31, 449–464. doi: 10.1016/j.cpr.2010.11.003

Clark, R., and Harrelson, G. L. (2002). Designing instruction that supports cognitive learning processes. *J. Athletic Train.* 37, S152–S159.

Cools, R. (2015). Neuropsychopharmacology of cognitive flexibility. *Brain Mapping: An Encyclopedic Reference* 3, 349–353. doi: 10.1016/B978-0-12-397025-1.00253-0

Corti, L., and Gelati, C. (2020). Mindfulness and coaching to improve learning abilities in university students: a pilot study. *Int. J. Environ. Res. Pub. Health* 17:1935. doi: 10.3390/ijerph17061935

Coulacoglou, C., and Saklofske, D. H. (2017). *Executive Function, Theory of Mind, and Adaptive Behavior. Psychometrics and Psychological Assessment*. Ontario: Academic Press.

Courage, M. L., Bakhtiar, A., Fitzpatrick, C., Kenny, S., and Brandeau, K. (2015). Growing up multitasking: the costs and benefits for cognitive development. *Dev. Rev.* 35, 5–41. doi: 10.1016/j.dr.2014.12.002

Daggöl, G. D. (2023). Online self-regulated learning and cognitive flexibility through the eyes of English-major students. *Acta Educ. Generalis* 13, 107–132. doi: 10.2478/atd-2023-0006

DeHaan, R. L. (2009). Teaching creativity and inventive problem solving in science. *CBE—Life Sci. Educ.* 8, 172–181. doi: 10.1187/cbe.08-12-0081

Durak, H. Y. (2023). Examining various variables related to authentic learning self-efficacy of university students in educational online social networks: creative self-efficacy, rational experiential thinking, and cognitive flexibility. *Curr. Psychol.* 42, 22093–22102. doi: 10.1007/s12144-022-03211-x

Ergas, O., and Hadar, L. L. (2023). Does mindfulness belong in higher education? An eight year research of students' experiences. *Pedagogy Culture Soc.* 31, 359–377. doi: 10.1080/14681366.2021.1906307

Feng, X., Perceval, G. J., Feng, W., and Feng, C. (2020). High cognitive flexibility learners perform better in probabilistic rule learning. *Front. Psychol.* 11:415. doi: 10.3389/fpsyg.2020.00415

Firth, J., Torous, J., Stubbs, B., Firth, J. A., Steiner, G. Z., Smith, L., et al. (2019). The "online brain": how the internet may be changing our changing. *World Psychiatry* 18, 119–129. doi: 10.1002/wps.20617

Fjaellingsdal, T. G., Vesper, C., Fusaroli, R., and Tylén, K. (2021). *Diversity Promotes Abstraction and Cognitive Flexibility in Collective Problem Solving*. Available online at: osf.io/umhf6

Foerde, K., Knowlton, B. J., and Poldrack, R. A. (2006). Modulation of competing memory systems by distraction. *Proc. Nat. Acad. Sci. U. S. A.* 103, 11778–11783. doi: 10.1073/pnas.0602659103

Foerde, K., Race, E., Verfaellie, M., and Shohamy, D. (2013). A role for the medial temporal lobe in feedback-driven learning: evidence from amnesia. *J. Neurosci.* 33, 5698–5704. doi: 10.1523/JNEUROSCI.5217-12.2013

Gorman, T. E., and Green, C. S. (2016). Short-term mindfulness intervention reduces the negative attentional effects associated with heavy media multitasking. *Sci. Rep.* 6:24542. doi: 10.1038/srep24542

Green, M., and Rathgeb-Schnierer, E. (2023). Summing up: cognitive flexibility and mental arithmetic. *J. Mathematics Educ.* 13, 1–17. doi: 10.26711/0075771527900

Hart, R., Ivtzan, I., and Hart, D. (2013). Mind the gap in mindfulness research: a comparative account of the leading schools of thought. *Rev. Gen. Psychol.* 17, 453–466. doi: 10.1037/a0035212

Ie, A., Haller, C. S., Langer, E. J., and Courvoisier, D. (2013). Mindful multitasking: the relationship between mindful flexibility and media multitasking. *Comput. Hum. Behav.* 28, 1526–1532. doi: 10.1016/j.chb.2012.03.022

Jaeger, A., Selmeczy, D., O'Connor, A. R., Diaz, M., and Dobbins, I. G. (2012). Prefrontal cortex contributions to controlled memory judgment: fMRI evidence from adolescents and young adults. *Neuropsychologia* 50, 3745–3756. doi: 10.1016/j.neuropsychologia.2012.10.022

Karpinski, A. C., Kirschner, P. A., Ozer, I., Mellot, J. A., and Ochwo, P. (2013). An exploration of social networking site use, multitasking, and academic performance among United States and European university students. *Comput. Hum. Behav.* 29, 1182–1192. doi: 10.1016/j.chb.2012.10.011

Kercook, S., Lineweaver, T. T., Frank, C. C., and Fromm, E. D. (2017). Cognitive flexibility and its relationship to academic achievement and career choice of college students with and without attention deficit hyperactivity disorder. *J. Postsecondary Educ. Disability* 30, 327–342.

Korte, M. (2020). The impact of the digital revolution on human brain and behavior: where do we stand? Dialogues Clin. *Neurosci.* 22, 101–111. doi: 10.31887/DCNS.2020.22.2/mkorte

Langer, E. J., and Moldoveanu, M. (2000). The construct of mindfulness. *J. Soc. Issues* 56, 1–9. doi: 10.1111/0022-4537.00148

Lin, L. (2009). Breadth-biased versus focused cognitive control in media multitasking behaviors. *Proc. Nat. Acad. Sci. U. S. A.* 106, 15521–15522. doi: 10.1073/pnas.0908642106

Lin, L., and Parsons, T. D. (2018). Ecologically valid assessments of attention and learning engagement in media multitaskers. *TechTrends* 62, 518–524. doi: 10.1007/s11528-018-0311-8

Liston, D., and Zeichner, K. (1991). *Teacher Education and the Social Conditions of Schooling*. New York, NY: Routledge.

Loh, K. K., and Kanai, R. (2014). Higher media multi-tasking activity is associated with smaller gray-matter density in the anterior cingulate cortex. *PloS ONE* 9:e106698. doi: 10.1371/journal.pone.0106698

Luo, B., Li, J., Liu, J., Li, F., Gu, M., Xiao, H., et al. (2022). Frequency-dependent plasticity in the temporal association cortex originates from the primary auditory cortex, and is modified by the secondary auditory cortex and the medial geniculate body. *J. Neurosci.* 42, 5254–5267. doi: 10.1523/JNEUROSCI.1481-21.2022

Marcovitch, S., Jacques, S., Boseovski, J. J., and Zelazo, P. D. (2008). Self-reflection and the cognitive control of behavior: Implications for learning. *Mind Brain Educ.* 2, 136–141. doi: 10.1111/j.1751-228X.2008.00044.x

May, K. E., and Elder, A. D. (2018). Efficient, helpful, or distracting? A literature review of media multitasking in relation to academic performance. *Int. J. Educ. Technol. Higher Educ.* 15, 1–15. doi: 10.1186/s41239-018-0096-z

Meltzer, L. (2013). *Teaching Executive Functioning Processes: Promoting Metacognition, Strategy Use, and Effort. Handbook of Executive Functioning*. New York, NY: Springer New York.

Moore, A., and Malinowski, P. (2009). Meditation, mindfulness and cognitive flexibility. *Consciousness Cognit.* 18, 176–186. doi: 10.1016/j.concog.2008.12.008

Nassif, T. H., Adrian, A. L., Gutierrez, I. A., Dixon, A. C., Rogers, S. L., Jha, A., and Adler, A. B. (2023). Optimizing performance and mental skills with mindfulness-based attention training: two field studies with operational units. *Military Med.* 188, e761–e770. doi: 10.1093/milmed/usab380

Oberski, I., Murray, S., Goldblatt, J., and DePlacido, C. (2015). Contemplation and mindfulness in higher education. *Global Innov. Teaching Learn. Higher Educ. Transg. Boundaries* 12, 317–340. doi: 10.1007/978-3-319-10482-9_19

Ong'ondo, C. O. (2017). Teacher education as an agent of social change: analysis of the Kenyan case. *J. Educ. Soc. Policy* 4, 147–155.

Ophir, E., Nass, C., and Wagner, A. D. (2009). Cognitive control in media multitaskers. *Proc. Nat. Acad. Sci. U. S. A.* 106, 15583–15587. doi: 10.1073/pnas.0903620106

Orakçi, S. (2021). Exploring the relationships between cognitive flexibility, learner autonomy, and reflective thinking. *Thinking Skills Creativity* 41:100838. doi: 10.1016/j.tsc.2021.100838

Parks, M. W. (2006). I am from a very small town: social reconstructionism and multicultural education. *Multic. Persp.* 8, 46–50. doi: 10.1207/s15327892mcp0802_8

Poldrack, R. A., and Foerde, K. (2007). Category learning and the memory systems debate. *Neurosci. Biobehav. Rev.* 32, 197–205. doi: 10.1016/j.neubiorev.2007.07.007

Poplawska, A., Szumowska, E., and Kus, J. (2021). Why do we need media multitasking? A self-regulatory perspective. *Front. Psychol.* 12:624649. doi: 10.3389/fpsyg.2021.624649

Rogaten, J., and Moneta, G. B. (eds.). (2016). "Creativity in higher education: the use of creative cognition in studying," in *Psychology of Creativity: Cognitive, Emotional, and Social Processes* (Hauppauge, NY: Nova Science Pub Inc.), 3–20. Available online at: https://www.novapublishers.com/catalog/product_inf...

Schuur, W. A., Baumgartner, S. E., Sumter, S. R., and Valkenburg, P. M. (2015). The Consequences of media multitasking for youth: a review. *Comput. Hum. Behav.* 53, 204–215. doi: 10.1016/j.chb.2015.06.035

Seddon, A. L., Law, A. S., Adams, A. M., and Simmons, F. R. (2021). Individual differences in media multitasking ability: the importance of cognitive flexibility. *Comput. Hum. Behav. Rep.* 3:100068. doi: 10.1016/j.chbr.2021.100068

Sternberg, R. J. (2000). Images of mindfulness. *J. Soc. Issues* 56, 11–27. doi: 10.1111/0022-4537.00149

Tursynkulova, E., Madiyarov, N., Turlybek, S., and Peruza, D. (2023). The effect of problem-based learning on cognitive skills in solving geometric construction problems: a case study in Kazakhstan. *Front. Educ.* 8:1284305. doi: 10.3389/feduc.2023.1284305

Tymofiyeva, O., and Gaschler, R. (2020). Training-induced neural plasticity in youth: a systematic review of structural and functional MRI studies. *Front. Hum. Neurosci.* 12:497245. doi: 10.3389/fnhum.2020.497245

Uncapher, M., Lin, L., Rosen, L., Kirkorian, H., Baron, N., Bailey, K., et al. (2017). Media multitasking is associated with cognitive, psychological, neural, and learning differences. *Pediatrics: Off. J. Am. Acad. Pediatrics* 22, s62–s66. doi: 10.1542/peds.2016-1758D

Verghese, A., Garner, K. G., Mattingley, J. B., and Dux, P. E. (2016). Prefrontal cortex structure predicts training-induced improvements in multitasking performance. *J. Neurosci.* 36, 2638–2645. doi: 10.1523/JNEUROSCI.3410-15.2016

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Shaping the future of creative education: the transformative power of VR in art and design learning

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Addressing a critical gap in the understanding of virtual reality (VR) in education, this study develops and validates a predictive model to elucidate the influence of usability and spatial ability on learning satisfaction among art and design undergraduates. Utilizing structural equation modeling on data from 105 art and design students in Mexico, we demonstrate that enhanced usability and spatial ability in VR significantly predicts increased learning satisfaction, which in turn, positively affects motivation, cognitive benefits, reflective thinking, and perceived learning. Our findings reveal a direct correlation between VR environment design and educational outcomes, suggesting that meticulous attention to usability and spatial navigation can substantially elevate the learning experience in art and design students. This research contributes to educational technology by offering empirical evidence on optimizing VR for higher education, with implications for curriculum design and pedagogical strategies in creative disciplines.

KEYWORDS

virtual reality, learning, design education, learning experience, education in art and design

1 Introduction

The advent of virtual reality (VR) technology has revolutionized educational methodologies over the past few decades, offering novel tools that significantly enrich learning experiences (Marougkas et al., 2023). Notably, VR stands out for its ability to immerse students in interactive and stimulating environments, thereby fostering deeper and more meaningful learning processes. This technology is particularly beneficial in art and design education, where sensory experience and spatial perception are crucial to the learning journey (Kerr and Lawson, 2020; Guerra-Tamez, 2023).

Drawing from a constructivist theory, which posits learning as an active process wherein students construct new ideas or concepts based on their current knowledge and experiences (Pande and Bharathi, 2020), VR environments serve as an ideal platform for implementing these principles (Soliman et al., 2021). The immersive and interactive nature of VR allows art and design students not only to observe but also to actively engage in their educational process, thus facilitating more effective and personalized knowledge construction (Guerra-Tamez, 2023).

This study aims to develop and validate a predictive model using structural equations to explore how usability and spatial ability in VR environments influence undergraduate art and design students' satisfaction. Student satisfaction, viewed as an indicator of the quality and effectiveness of the educational experience, is hypothesized to be a key predictor of learning success. Furthermore, the study examines how this satisfaction impacts essential aspects of learning, including motivation, cognitive benefits, reflective thinking, and perceived learning.

Investigating these relationships is crucial for understanding how emerging technologies like VR can be optimized to enhance education. As VR becomes a more accessible and prevalent educational tool, identifying and addressing factors that influence the quality of students' learning experiences is paramount. This research contributes to the existing literature by providing a detailed analysis of how usability and spatial ability in VR affect satisfaction and, consequently, learning outcomes in specific educational contexts.

2 Literature review

2.1 Virtual reality in education

VR has emerged as a transformative catalyst in education, offering interactive virtual environments that support immersion and active engagement (Won et al., 2023). Studies have shown that VR facilitates deeper understanding and knowledge retention by promoting hands-on learning experiences, which are crucial in disciplines where direct experience and object manipulation play key roles (Di Natale et al., 2020; Hamilton et al., 2021). Specifically, art and design education benefits significantly from the implementation of VR, as it enhances sensory experiences and spatial perception, essential elements for skill development in these areas (Guerra-Tamez, 2023). The specific literature in this field indicates that VR not only improves students' design skills and visual perception but also provides an unparalleled medium for creative and technical exploration in an environment free from the physical limitations of the real world (Bourgeois-Bougrine et al., 2020). This enriched approach promises to revolutionize pedagogy in art and design, preparing students for the challenges of today's professional landscape through a more dynamic and interactive education.

2.2 Constructivist theory and virtual reality

Integrating VR into educational paradigms dovetails seamlessly with the principles of constructivist theory, which champions active learner engagement and the construction of knowledge within one's learning environment. Constructivism suggests that meaningful learning transpires as students interact with their surroundings, engaging in exploration, experimentation, and reflection (Pande and Bharathi, 2020). This educational philosophy underscores the significance of learner-centric experiences, positing that students forge new understandings from their pre-existing knowledge and experiences (Du Plessis, 2020). VR, with its immersive and interactive capacities, offers a quintessential platform for facilitating such constructivist learning modalities. This is particularly pertinent in disciplines such as art and design, where sensory experiences and spatial awareness are paramount (Kerr and Lawson, 2020).

The immersive attributes of VR in art and design education allow students to delve deeply into content, affording them the opportunity to directly manipulate design elements and spatial configurations. This hands-on methodology bolsters the application of theoretical concepts in practical scenarios, thereby engendering a more profound comprehension of intricate spatial relationships and design principles (Guerra-Tamez, 2023). This segues into the significance of usability and spatial ability in VR underpins the seamless integration of technology and pedagogy.

2.3 Usability and spatial ability in virtual reality

Delving deeper into the nexus between technology and pedagogy within VR learning environments, the paramount importance of usability and spatial ability becomes evident. Usability, defined in terms of user interface design and navigational ease within VR platforms, plays a critical role in mediating the learning experience (Huang and Lee, 2022). Empirical research has consistently demonstrated that a high degree of usability significantly mitigates cognitive overload and user frustration (Makransky and Petersen, 2019; Birt and Vasilevski, 2021; Hammady et al., 2021). This, in turn, facilitates a more efficient navigation and exploration of the virtual space, thereby allowing learners to allocate their cognitive resources more effectively toward the assimilation of new knowledge (Kuo et al., 2023). Such an environment is particularly conducive to disciplines that demand a nuanced manipulation of visual and spatial elements, underscoring the necessity for VR interfaces that are both intuitive and responsive (Wee et al., 2021).

In parallel, the enhancement of spatial ability through engagement with VR technologies emerges as a critical factor in the success of learners in design-oriented fields (Wu et al., 2020; Hamilton et al., 2021). Spatial ability, crucial for tasks requiring the visualization and manipulation of three-dimensional objects and spaces, is substantially bolstered by immersive experiences in VR (Starrett et al., 2021). Quantitative studies have validated the direct correlation between augmented spatial skills and improvements in student performance and satisfaction levels (Sun et al., 2019; Makransky et al., 2020). This correlation evidences the instrumental role of VR in not only facilitating a deeper understanding of spatial relationships but also in significantly advancing learners' competencies in design and artistic endeavors (Ho et al., 2019; Obeid and Demirkan, 2023). Consequently, the integration of VR into educational frameworks, when executed with a focus on optimizing usability and leveraging the potential for spatial skill development, presents a compelling avenue for enhancing educational outcomes across visually intensive disciplines.

2.4 Student satisfaction and learning outcomes

Transitioning from the critical analysis of usability and spatial ability within VR learning environments, the discourse naturally extends to the realm of student satisfaction and its consequential impact on learning outcomes (Hamutoglu et al., 2020). Student

satisfaction serves as a pivotal metric for assessing the quality and efficacy of the educational experience, encapsulating the learner's overall contentment and engagement with the instructional process (Bahati et al., 2019). Empirical evidence robustly supports the assertion that heightened levels of student satisfaction are inextricably linked to a plethora of positive educational outcomes (Alqurashi, 2019; Choe et al., 2019; Zhonggen et al., 2019). These include enhanced motivation (Yu et al., 2021), augmented cognitive benefits (Zhonggen et al., 2019), refined reflective thinking abilities (Chen et al., 2019), and perceived learning (Alqurashi, 2019). Specifically, within the context of VR-enhanced education, where the sensory and interactive dimensions of learning are amplified, satisfaction emerges not merely as a byproduct but as a fundamental catalyst for educational engagement and achievement.

Delving deeper into the dynamics of student satisfaction within VR settings, it becomes apparent that satisfaction acts as a mediator, fostering a conducive learning environment that encourages active participation and deep engagement. This mediation is particularly salient in VR-enhanced learning, where the immersive nature of the technology can significantly influence a student's enthusiasm and willingness to explore complex concepts (Lee and Hwang, 2022). The correlation between student satisfaction and improved learning outcomes is supported by a body of research indicating that satisfaction with the learning environment contributes to a more positive attitude toward learning, increased motivation, and a propensity to undertake challenging tasks (Ames and Archer, 1988; Liaw and Huang, 2013; Tratnik et al., 2019). Consequently, the role of VR in enhancing student satisfaction cannot be understated, as it provides a unique and compelling platform for experiential learning, thereby facilitating a deeper connection with the subject matter and fostering a more profound understanding of academic content (Wu, 2024).

3 Conceptual model

3.1 Usability in virtual reality and student satisfaction

The connection between usability in VR environments and student satisfaction has been explored in various empirical studies, establishing a direct relationship between these two variables. For instance, studies by Violante and Vezzetti (2015); AlGerafi et al. (2023) in the field of educational technology provide empirical evidence that user-friendly and intuitive VR interfaces markedly elevate learners' satisfaction. These enhancements stem from offering more straightforward access to educational content and diminishing cognitive load during learning activities.

One seminal study by Norman and Nielsen (2010) highlighted the critical role of usability in determining the overall effectiveness of digital learning environments. Although not exclusively focused on VR, their findings suggest that principles of good design and usability are essential for engaging students and enhancing their learning experience. Applying these principles to VR, we can infer that environments designed with a focus on usability are likely to increase student satisfaction.

Furthermore, Huang and Lee (2022) conducted a study specifically focusing on 3D model learning within VR environments, finding that usability factors such as intuitive navigation, clear instructions, and responsive interaction were positively correlated with students' satisfaction levels. Their research supports the notion that well-designed VR interfaces can lead to higher levels of engagement and satisfaction among students, particularly in disciplines that heavily rely on visual and interactive content, such as art and design. Building on these empirical findings, the proposed study aims to examine the relationship between usability in VR environments designed for art and design education and the satisfaction of undergraduate students. Given the established positive impact of usability on user satisfaction in general digital contexts and the specific findings related to VR learning environments, the following hypothesis is proposed:

> *Hypothesis* 1: Usability in virtual reality environments positively impacts satisfaction in art and design students.

3.2 Spatial ability in virtual reality and student satisfaction

Spatial ability, defined as the aptitude to discern and manipulate patterns within both two and three-dimensional frameworks, is crucial across various educational domains, especially in art and design. Within the realm of VR, where users engage with a digitally simulated, spatial environment, the cultivation and application of this skill are critical (Papanastasiou et al., 2019).

Research by Checa and Bustillo (2020) elucidates that student interaction with VR modules crafted to enhance spatial reasoning not only bolsters their capacity for visualizing and manipulating spatial constructs but concurrently amplifies their satisfaction with the educational process. Similarly, Drigas et al. (2022) delves into the ramifications of VR-assisted spatial training on design competencies, revealing that such training in immersive VR environments leads to not just advancements in design acumen but also to elevated satisfaction levels, attributable to VR's immersive and interactive essence, resonant with constructivist pedagogy's active learning tenets.

The consolidation of these findings indicates that spatial ability within VR transcends mere cognitive skill, evolving into a comprehensive competency with marked effects on learner satisfaction. Acknowledging the significant influence of spatial skill enhancement in VR on student contentment, the following is proposed:

> *Hypothesis* 2: Spatial ability in art and design students in virtual reality environments positively impacts their learning satisfaction.

3.3 Student satisfaction and motivation

The interrelationship between student satisfaction with VR experiences and their levels of motivation constitutes a significant area of inquiry in educational technology. A study by Jensen and Konradsen (2018) revealed that the immersive attributes of VR substantially bolster student satisfaction, which, in turn, exerts a positive influence on their learning motivation. Their findings imply that the enthralling aspects of VR foster a compelling learning environment, prompting students to immerse more deeply in educational content.

Further exploration by Makransky et al. (2021) established that the sense of presence elicited by VR—embodied by the sensation of existing within a simulated milieu—directly enhances student satisfaction and, subsequently, motivation. Complementing this, Radianti et al. (2020) research elucidated how VR experiences, when customized to align with learners' preferences and styles, can elevate satisfaction levels, thereby serving as crucial determinants of student motivation. Such individualized VR experiences, by resonating with diverse learning modalities, can significantly amplify satisfaction and motivation. Collectively, these studies substantiate the premise of the following hypothesis:

> *Hypothesis* 3: Satisfaction in virtual reality environments positively impacts motivation in art and design students.

3.4 Student satisfaction and cognitive benefits

The nexus between student satisfaction in VR environments and cognitive advantages has been substantiated by several studies. Radianti et al. (2020) found a positive correlation between satisfaction and improved memory recall and understanding, indicating that fulfilling VR experiences bolster cognitive engagement and retention.

Hmoud et al. (2023) expanded on these findings by showing that satisfaction with VR simulations in STEM enhances problem-solving abilities and scientific reasoning, pointing to the active learning potential of immersive VR environments.

Complementing this, a recent study by Guerra-Tamez (2023) reported that art and design students who expressed satisfaction with VR experiences demonstrated increased creativity and spatial awareness, essential cognitive benefits for their field. These studies collectively affirm the following hypothesis.

> *Hypothesis* 4: Satisfaction in virtual reality environments positively impacts cognitive benefits in art and design students.

3.5 Student satisfaction and reflective thinking

The connection between student satisfaction in VR learning environments and the enhancement of reflective thinking has garnered significant academic interest. Ye et al. (2022) demonstrated that satisfaction within VR settings precipitates a reflective process among learners, facilitating a more profound engagement with their learning experiences. This engagement is crucial for the development of critical thinking capabilities, which are fundamental to comprehensive student growth and academic achievement.

Further investigation by Lin and Wang (2021) corroborated these insights, revealing that students with higher levels of satisfaction were more likely to engage in critical self-evaluation of their learning journeys. This critical self-evaluation is a hallmark of reflective thinking, pivotal for augmenting learning efficiency.

Supporting Hypothesis H5, these studies collectively affirm that student satisfaction in VR environments acts as a catalyst for reflective thinking. This body of evidence accentuates the importance of designing VR learning experiences that not only fulfill educational goals but also encourage students to adopt a reflective and critical stance toward their learning, thereby equipping them with essential skills for complex problem-solving.

> *Hypothesis* 5: Satisfaction in virtual reality environments positively impacts reflective thinking in art and design students.

3.6 Student satisfaction and perceived learning

The interrelation between student satisfaction in VR environments and enhanced perceived learning has been extensively explored in educational research. Çakıroğlu et al. (2021) discovered that positive experiences in VR could significantly boost students' confidence in their learning abilities. Their study highlights how immersive VR experiences contribute to students' belief in their capability to understand and retain new information, reinforcing the link between satisfaction and perceived learning.

In a similar vein, Makransky and Lilleholt (2018) reported that students who were satisfied with their VR experiences expressed a higher perception of their learning outcomes. The study suggests that satisfaction with VR not only impacts students' enjoyment but also their self-assessment of knowledge acquisition and comprehension.

Additionally, Liu et al. (2020) provided evidence that satisfaction derived from VR learning environments correlates with students' self-reported improvements in learning performance. Their research underscores the role of VR in enhancing students' perception of learning effectiveness, pointing to a direct relationship between the quality of the VR experience and students' confidence in their learning progress.

These studies collectively substantiate Hypothesis H6, positing that satisfaction with VR experiences positively influences students' perceived learning. The findings emphasize the importance of high-quality VR learning environments in fostering not only satisfaction but also a stronger sense of learning achievement among students, highlighting VR's potential to augment self-efficacy and perceived learning in educational settings.

> *Hypothesis* 6: Satisfaction in virtual reality environments positively impacts perceived learning in art and design students.

The relationships formulated in this study are shown in Figure 1.

4 Research method

To explore the impact of VR technology on learning outcomes within art and design education, our research employed a quantitative methodology. This approach was specifically selected for its ability to rigorously analyze cause-and-effect relationships among variables. At the forefront of our investigation was the assessment of how VR technology affects crucial educational metrics such as motivation,

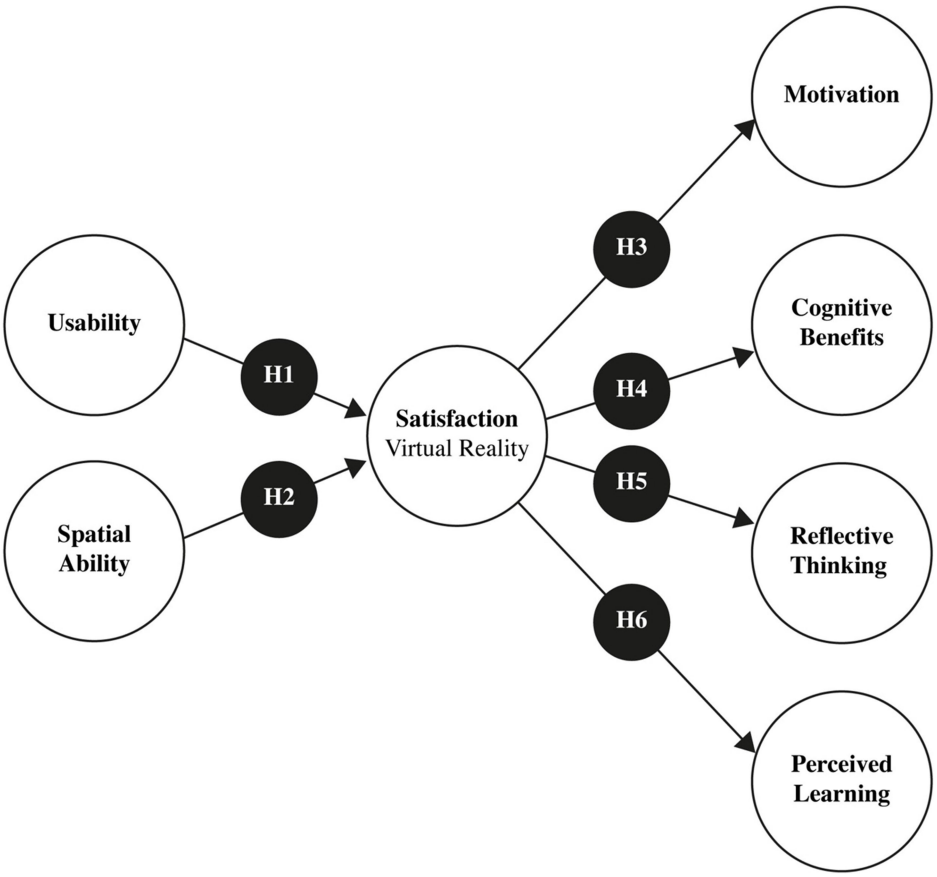

FIGURE 1
Conceptual model.

cognitive benefits, reflective thinking, perceived learning, and student satisfaction. A total of 105 valid surveys were collected from art and design students enrolled at the Centro Roberto Garza Sada (CRGS) of the University of Monterrey, Mexico (Table 1). To ensure a representative analysis, the participant selection was conducted through a randomization process across the student body, thereby capturing the heterogeneity of the CRGS student population.

TABLE 1 Technical information.

Scope	Description
Universe	Mexican art and design university students
Course	Bottom-Up
Method	Questionnaire survey
Sample size	105 valid surveys
Data fieldwork	From November 2023 to January 2024
Statistics	Collinearity statistics, CFA, PLS—SEM
Measures (7-point likert)	Satisfaction (Guerra-Tamez, 2023) Virtual Reality
	Usability (Brooke, 1986)
	Spatial Ability (Blajenkova et al., 2006; Park et al., 2011)
	Motivation (Rovai et al., 2009)
	Cognitive benefits (Makransky et al., 2019)
	Reflective thinking (Lackey et al., 2016)
	Perceived learning (Rovai et al., 2009)
Statistic software	IBM SPSS Statistics and Smart PLS 4

4.1 Preparatory phase

Before commencing the VR activity, students participated in a preparatory phase aimed at equipping them with the necessary knowledge and skills for the task. This phase began with a 15-min in-person presentation on the bottom-up design methodology, where detailed explanations were provided on how students should apply this approach in the upcoming VR activity. Immediately following this presentation, an introduction to the Shapes platform lasting between 5 and 8 min was conducted to familiarize students with the specific tools and functionalities of the application (Figure 2).

After the introduction to Shapes, students were given a period of free exploration within the platform to complement the introductory session, allowing them to dive into and experiment with the VR interface for an additional time, totaling approximately 30 min altogether. This structured approach ensured that students were adequately prepared to undertake the design task with a solid understanding of both the bottom-up methodology and the virtual environment they would be working in.

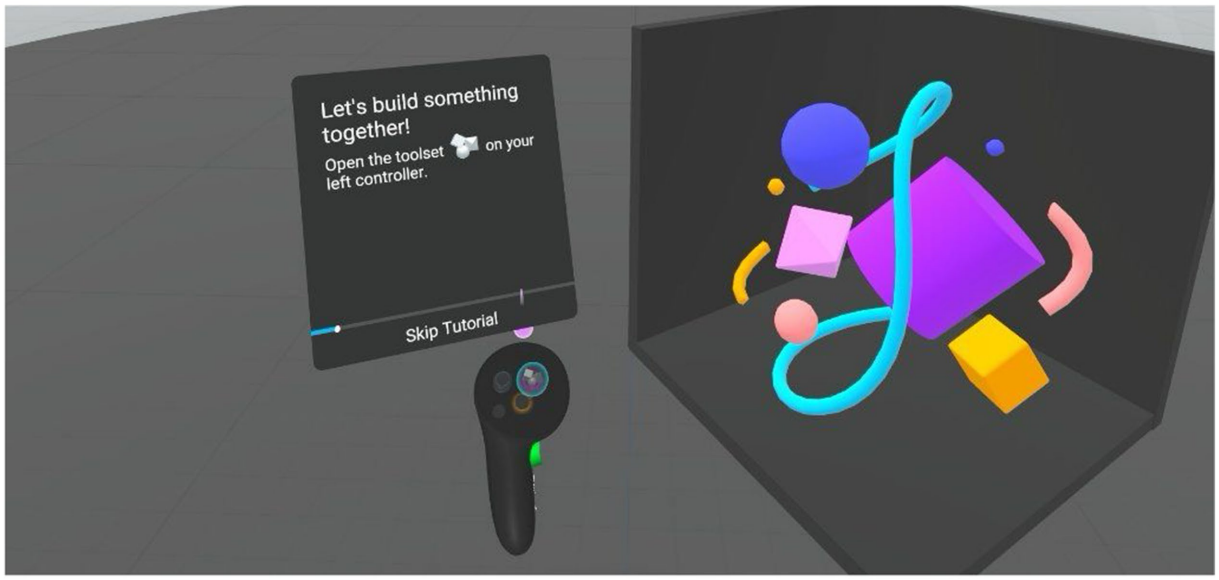

FIGURE 2
Introductory course on the shapes platform.

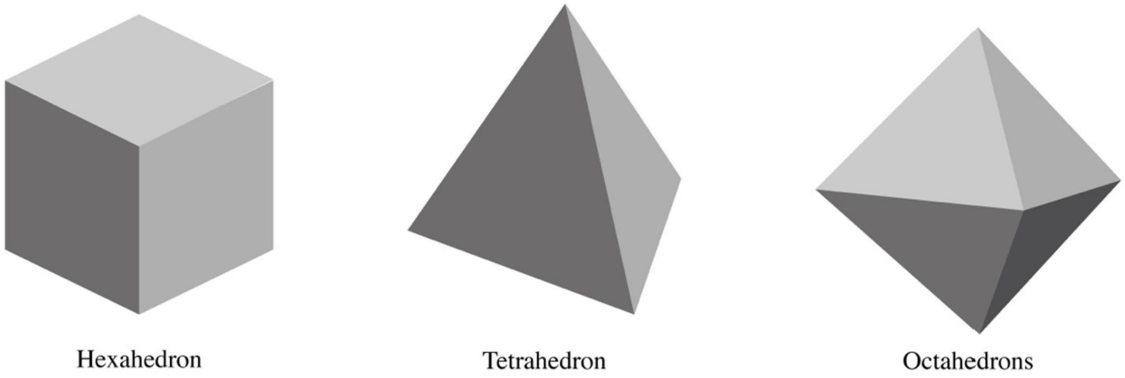

FIGURE 3
Geometric shapes available for selection during the activity.

4.2 Experimental design and activity duration

Following the preparatory phase, students moved on to the main activity, applying the bottom-up design methodology to create structures from 20 geometric choosing from hexahedrons, tetrahedrons, or octahedrons (Figure 3), within a virtual space designed to mimic CRGS classrooms (Figure 4A) on the Shapes platform (Figure 4B). Students were provided up to an hour to complete this design task, with an observed average completion time noted in the study.

4.3 Data collection

Upon completion of the activity, students' perceptions of their learning experience were gathered through digital surveys from November 2023 to January 2024. These surveys, accessible via QR codes located within the university premises, facilitated student participation, and provided immediate feedback. The collected data spanned various dimensions, including learning experience, motivation, cognitive benefits, reflective thinking, and the perceived value of the VR-based design activity. This timeframe for data collection ensured a comprehensive capture of students' experiences and reflections over the course of the study.

4.4 Data collection tool

This study utilizes a structured questionnaire to explore the educational impact of virtual reality (VR) technology. Designed based on relevant theories and previous research, the questionnaire captures diverse aspects of learners' experiences with VR, including their satisfaction, usability perceptions, spatial abilities, motivation,

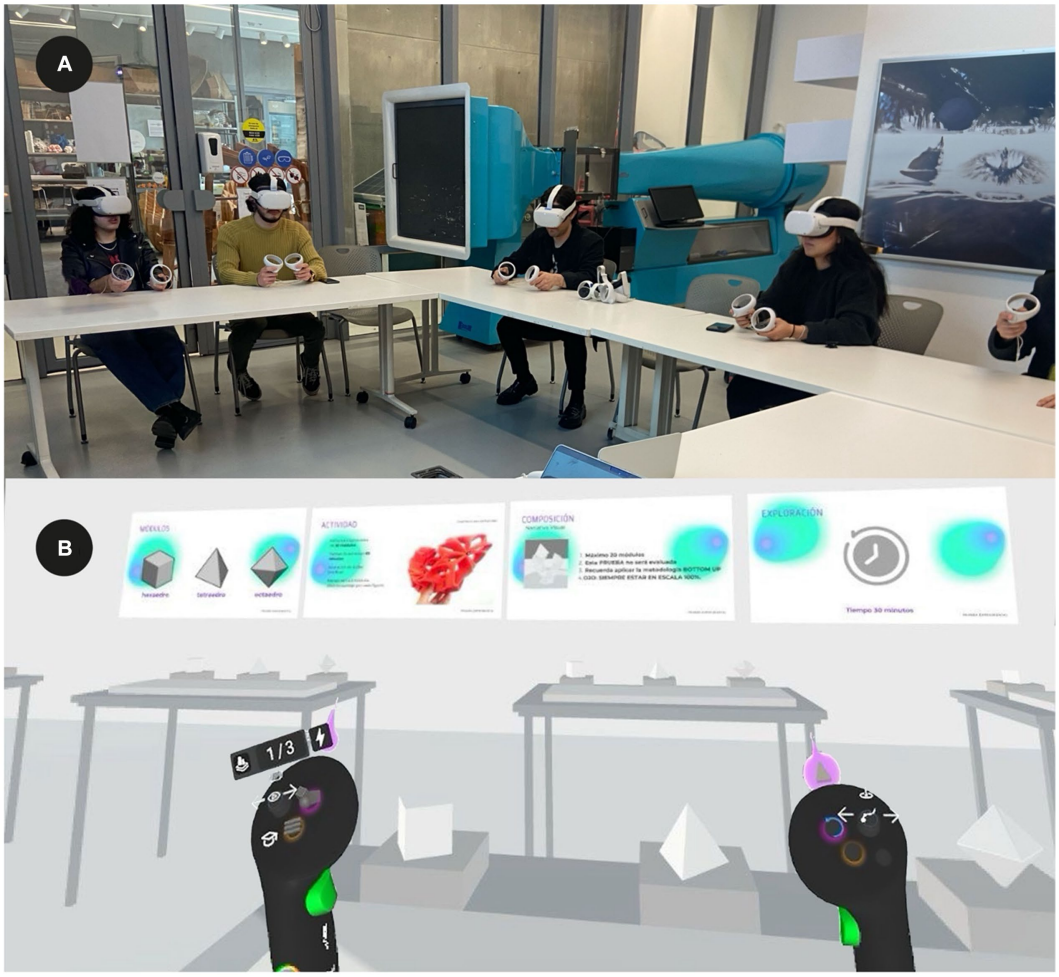

FIGURE 4
(A) Physical setting. **(B)** Virtual space replicating the physical environment.

cognitive benefits, reflective thinking, and perceived learning outcomes.

The instrument is segmented into specific dimensions, each aimed at investigating distinct facets of the VR learning experience—from the immediate user satisfaction and system usability to deeper educational impacts like enhanced cognitive functions and the development of reflective thinking.

Below is detailed Table 2 of the questionnaire, presenting each dimension alongside its subdimensions, items, and meaning.

5 Results

The data analysis for this study was systematically organized into several distinct stages, each designed to rigorously examine the impact of VR on learning satisfaction among art and design undergraduates, focusing specifically on the roles of usability and spatial ability.

1 Descriptive statistics provided a detailed overview of the participant demographics, setting the stage for a deeper investigation into the VR learning experience.
2 A confirmatory factor analysis (CFA) was employed to ensure the reliability and validity of the instruments used to measure usability, spatial ability, learning satisfaction, motivation, cognitive benefits, reflective thinking, and perceived learning, thus confirming the integrity of the data collected.
3 Structural equation modeling (SEM) was utilized to explore the complex relationships between usability and spatial ability in VR and their subsequent influence on learning satisfaction. This analysis was pivotal in uncovering how enhanced usability and spatial ability are significant predictors of increased learning satisfaction, which, according to our model, further influences motivation, cognitive benefits, reflective thinking, and perceived learning among art and design undergraduates.
4 Validation of the Measuring Instrument was rigorously tested using the Fornell-Larcker criterion, ensuring that each construct within our study was distinct and accurately measured.
5 Comprehensive goodness-of-fit assessment to verify the model's accuracy in representing the real-world phenomenon of VR's impact on educational outcomes.

TABLE 2 Instrument.

Dimension	Subdimension	Item	Meaning
Satisfaction	General Satisfaction	SVR1: Enjoy experience through VR technology.	Measures the overall enjoyment and satisfaction derived from the VR experience.
		SVR2: I found the VR experience gratifying.	Reflects on the rewarding nature of the VR experience, emphasizing satisfaction.
		SVR3: This class through VR technology exceeds my expectations.	Assesses the extent to which the VR class surpassed initial expectations, indicating high satisfaction.
Usability	Ease of Use	U1: I think I would like to use this system frequently.	Indicates user's inclination toward frequent use, suggesting the system is user-friendly.
	System Complexity	U2: I found the system unnecessarily complex.	Highlights perceived complexity, which might detract from usability.
	Integration of System Functions	U3: I found the system functions were well integrated.	Suggests that the system's features and functions are cohesively designed, enhancing usability.
	Learnability	U4: I imagine that most people would learn to use this system very quickly.	Reflects on the system's ease of learning, implying it is accessible to new users.
	Learning Requirement	U5: I needed to learn a lot of things before I could get going with this system.	Points to a significant initial learning curve, which may affect the ease of adoption.
Spatial Ability	Spatial Visualization	SA1: Using virtual reality improved my spatial ability.	Indicates an enhancement in the ability to understand and navigate three-dimensional spaces through VR.
	Mental Rotation	SA2: I can easily imagine and mentally rotate the geometric figures during the activity.	Reflects improvement in mentally visualizing and manipulating objects in space.
	Spatial Perception	SA3: I found it easy to envision exactly how the geometric figures looked when rotated during the activity.	Emphasizes enhanced ability to perceive spatial relationships and transformations.
	Skill Acquisition	SA4: I believe I acquired new skills in 3D geometry through this activity with virtual reality.	Highlights the learning of specific spatial skills, especially in understanding 3D geometry.
	Spatial Improvement	SA5: Using virtual reality has made me improve in the use of three-dimensional geometry.	Confirms overall improvement in handling and understanding 3D geometrical concepts due to VR engagement.
Motivation	Interest	M1: It is interesting to use virtual reality technology in this activity.	Reflects the intrinsic interest and excitement generated by using VR, which can boost motivation.
	Self-assessment	M2: My performance was good using virtual reality technology in this activity.	Indicates a positive self-assessment of performance when using VR, linking to increased motivation.
	Competence	M3: After using virtual reality technology for a while, I felt competent.	Suggests a growing sense of skill and mastery over time, contributing to overall motivation.
	Relaxation	M4: I felt very relaxed while using virtual reality technology in this activity.	Highlights the comfort and ease experienced during VR use, affecting motivation positively.
	Skill Confidence	M5: I am skilled at using virtual reality technology in this activity.	Confirms the participant's belief in their own proficiency with VR technology, underlining a motivational boost.
Cognitive Benefits	Understanding	CB1: Using virtual reality facilitates my understanding in this activity.	Highlights how VR aids in concrete understanding of the activity's subject matter.
	Memory	CB2: Using virtual reality facilitates my memorization.	Emphasizes VR's role in enhancing the ability to remember information.
	Application	CB3: Using virtual reality helps me apply my knowledge and skills more effectively.	Underlines the practical application of learned skills and knowledge, facilitated by VR.
	Analysis	CB4: Using virtual reality helps me analyze problems better in this activity.	Focuses on the improvement of problem-solving skills through VR usage.
	Overview	CB5: Using virtual reality helps me gain a better overview of this activity.	Highlights the contribution of VR to achieving a holistic understanding of the activity.

(Continued)

TABLE 2 (Continued)

Dimension	Subdimension	Item	Meaning
Reflective Thinking	Learning Reflection	RT1: Using virtual reality technology in this activity, I was able to reflect on how I learn.	Pertains to meta-cognitive reflection on the learning process itself, facilitated by the immersive experience of VR.
	Knowledge Integration	RT2: By using virtual reality in this activity, I was able to link new knowledge with my previous knowledge and experiences.	Emphasizes the reflective process of integrating new information with existing knowledge and experiences.
	Student Improvement	RT3: By using virtual reality in this activity, I could become a better student.	Suggests that reflective thinking about learning experiences contributes to overall improvement as a student.
	Understanding Reflection	RT4: By using virtual reality in this activity, I was able to reflect on my understanding.	Indicates a deeper, reflective understanding of the material, beyond immediate comprehension.
Perceived Learning	Skill Applicability	SPL1: I can use the skills learned in this course outside of class.	Indicates the applicability of learned skills in real-world contexts, beyond the classroom.
	Attitude Change	PL2: I have changed my attitudes about the course subject as a result of this activity.	Reflects on the transformative impact of the activity on students' perceptions and attitudes toward the course subject.
	Self-sufficiency	PL3: I feel more self-sufficient as a result of the content learned in this activity.	Highlights increased independence and self-reliance through the acquisition of knowledge and skills.
	Skill Demonstration	PL4: I can demonstrate to others the skills learned in this activity.	Suggests a level of mastery that enables the student to teach or demonstrate the acquired skills to others.
	Skill Acquisition	PL5: I feel that I have new skills as a result of this activity.	Confirms the acquisition of new skills, indicating effective learning outcomes from the activity.

5.1 Descriptive statistics

The sample size consisted of 105 valid surveys, collected from participants predominantly female (66%), followed by males (30%), and a small proportion identified as other or preferring not to say (4%). Most participants were between 18 and 21 years old (72%), reflecting a concentration in the university-aged youth. Regarding education level, a vast majority were pursuing university studies (72%), with a lesser representation in high school (5%) and postgraduate (23%). Familiarity with technology showed that most of the participants had a medium level (63%), while a significant segment reported a high level (32%), and only a small percentage indicated a low level (5%). This analysis suggests a study population that is young and educated, with moderate to high technological competence.

5.2 Confirmatory factor analysis

The model underwent validation through confirmatory factor analysis (CFA) across the full sample, employing the PLS Algorithm within the Smart PLS 4.0 software. The primary outcomes of this analysis, alongside the descriptive statistics for the constructs within the model, are detailed in Table 3 [For the questionnaire, refer to Appendix A (Table A1), which lists the indicators used in the measurement tool].

The standardized loadings (β) exceeded 0.872, indicating an ideal scenario. Utilizing Smart PLS 4.0 and IBM SPSS, the Cronbach's alpha coefficients ranged from 0.877 to 0.967, which are deemed acceptable according to existing literature. The constructs' composite reliability surpassed 0.942, and the Average Variance Extracted (AVE) for each construct was above 0.809, affirming the reliability of the constructs within the research model for the entire sample. Furthermore, the model's fit was within expected parameters, evidenced by a Normed Fit Index (NFI) exceeding 0.9 at 0.940 and a Standardized Root Mean Square Residual (SRMR) below 0.08 at 0.079.

5.3 Structure equation model

In the analytical process, the theorized linkages within the conceptual structure, as depicted by Hypotheses 1 through 6, were scrutinized. The assessment was facilitated by the application of bootstrapping procedures within the Smart PLS 4.0 environment. The detailed outcomes of this analysis, including the impact of usability and spatial ability on satisfaction with VR (H1 and H2), as well as the subsequent influence of VR satisfaction on motivation, cognitive benefits, reflective thinking, and perceived learning (H3 to H6), are delineated in Table 4 and illustrated in Figure 5. The structural equation modeling confirmed that each of the hypothesized pathways within our conceptual model stood up to empirical scrutiny.

5.4 Validation of the measuring instrument

Discriminant validity was evaluated using the Fornell-Larcker criterion, which involved comparing the square roots of the AVE values (located on the diagonal) with the correlation coefficients between constructs. Table 5 demonstrates that each construct's AVE

TABLE 3 Loadings, Cronbach's alpha, composite reliability, and AVE values.

Construct	Item	Loadings	Cronbach's alpha	Composite reliability (CR)	Average variance extracted (AVE)
Satisfaction Virtual Reality	SVR1	0.945	0.877	0.942	0.890
	SVR2	0.942			
	SVR3	0.924			
Usability	U1	0.919	0.955	0.966	0.849
	U2	0.911			
	U3	0.899			
	U4	0.939			
	U5	0.938			
Spatial Ability	SA1	0.943	0.957	0.967	0.853
	SA2	0.929			
	SA3	0.903			
	SA4	0.935			
	SA5	0.908			
Motivation	M1	0.877	0.954	0.965	0.845
	M2	0.937			
	M3	0.917			
	M4	0.904			
	M5	0.958			
Cognitive Benefits	CB1	0.892	0.941	0.955	0.809
	CB2	0.919			
	CB3	0.907			
	CB4	0.872			
	CB5	0.905			
Reflective Thinking	RT1	0.949	0.941	0.958	0.850
	RT2	0.918			
	RT3	0.911			
	RT4	0.910			
Perceived Learning	PL1	0.932	0.95	0.961	0.833
	PL 2	0.888			
	PL 3	0.909			
	PL 4	0.951			
	PL 5	0.881			

Chi-square (χ^2) = 1098.3; NFI = 0.940; SRMR = 0.079.

square root surpasses its inter-construct correlations, thereby satisfying the Fornell-Larcker standard for discriminant validity.

The collinearity diagnostics, as measured by the Variance Inflation Factor (VIF), were assessed, confirming the absence of collinearity issues within the partial least squares estimates, as illustrated in Table 6.

5.5 Goodness-of-fit diagnosis

To evaluate the adequacy of our model, we implemented the Global Goodness-of-Fit (GoF) index, which is designed to encompass the veracity of both the measurement and the structural aspects of the model. This holistic measure, conceptualized by Tenenhaus et al., rests on the principle that a cogent model should resonate closely with the observed data (Tenenhaus et al., 2004). The GoF is determined through the geometric mean of two pivotal components: the reliability of the constructs, gauged by the Average Variance Extracted (AVE), and the model's explanatory power, indicated by the squared R values. The GoF is thus defined by the equation:

$$GoF = \sqrt[2]{\overline{AVE} * \overline{R^2}}$$

$$GoF = \sqrt[2]{\overline{0.847} * \overline{0.843}}$$

$$GoF = 0.84$$

In our study, the GoF attained a value of 0.84, surpassing the recommended benchmark of 0.36 as proposed by Wetzels et al. (2009). This exceeds the standard threshold, validating the predictive capability of our structural model and confirming the measurement reliability. Such a level of fit not only satisfies but also bolsters the empirical robustness of our model, providing a solid foundation for the study's conclusions.

6 Discussion

The empirical findings of this study elucidate the pivotal role of VR in enhancing learning outcomes within art and design education, highlighting a nuanced interplay between usability, spatial ability, and student satisfaction. Notably, our analysis corroborates the hypothesis that usability in VR environments significantly contributes to learning satisfaction, aligning with previous research that emphasizes the importance of intuitive and user-friendly interfaces in educational technology (Violante and Vezzetti, 2015; AlGerafi et al., 2023). This relationship underscores the need for meticulously designed VR platforms that cater to the unique requirements of art and design pedagogy, suggesting a potential shift in how educational content is delivered and experienced.

Furthermore, the study's findings on spatial ability reinforce the criticality of this dimension in art and design disciplines, where the manipulation and understanding of space are fundamental skills. The significant impact of VR-enhanced spatial ability on learning satisfaction and subsequent educational outcomes echoes the work of Checa and Bustillo (2020) and Drigas et al. (2022), who found similar enhancements in spatial reasoning and satisfaction among students engaged with VR. This underscores VR's capacity to serve as a potent tool for spatial skill development, offering immersive experiences that traditional educational methodologies might not fully provide.

The direct correlation observed between student satisfaction in VR settings and increased motivation, cognitive benefits, and reflective thinking presents a compelling case for the integration of VR in

TABLE 4 Results of the structural model.

H	Description	β	t value	p value	Decision
H1	Usability→ Satisfaction VR	0.402	2.443	0.015	Supported
H2	Spatial Ability→ Satisfaction VR	0.547	3.525	0.000	Supported
H3	Satisfaction VR → Motivation	0.922	11.732	0.000	Supported
H4	Satisfaction VR → Cognitive Benefits	0.918	12.052	0.000	Supported
H5	Satisfaction VR → Reflective Thinking	0.902	11.769	0.000	Supported
H6	Satisfaction VR → Perceived Learning	0.919	12.689	0.000	Supported
	Constructs	R2			
	Satisfaction VR	0.884			
	Motivation	0.850			
	Cognitive Benefits	0.842			
	Reflective Thinking	0.813			
	Perceived Learning	0.844			

TABLE 5 Discriminant validity—Fornell-Larcker criterion.

	Perceived learning	Cognitive benefits	Spatial ability	Motivation	Reflective thinking	Satisfaction VR	Usability
Perceived learning	**0.913**						
Cognitive benefits	0.810	**0.899**					
Spatial ability	0.830	0.838	**0.924**				
Motivation	0.807	0.820	0.821	**0.919**			
Reflective thinking	0.817	0.834	0.839	0.806	**0.922**		
Satisfaction VR	0.825	0.830	0.838	0.828	0.812	**0.944**	
Usability	0.814	0.825	0.825	0.798	0.806	0.834	**0.921**

The diagonal elements, highlighted in bold, represent the square roots of the Average Variance Extracted (AVE), which indicate the amount of variance captured by a construct in relation to the variance due to measurement error. The off-diagonal elements are the inter-construct correlations. According to Fornell and Larcker's criterion for establishing discriminant validity, the square root of the AVE for each construct should exceed the correlations between that construct and any other in the model.

TABLE 6 Variance inflation factor (VIF) values for the structural model.

	Perceived learning	Cognitive benefits	Motivation	Reflective thinking	Satisfaction VR	Usability	Spatial ability
Perceived learning							
Cognitive benefits							
Motivation							
Reflective thinking							
Satisfaction VR	1.315	1.257	1.389	1.145			
Usability					2.467		
Spatial ability					2.098		

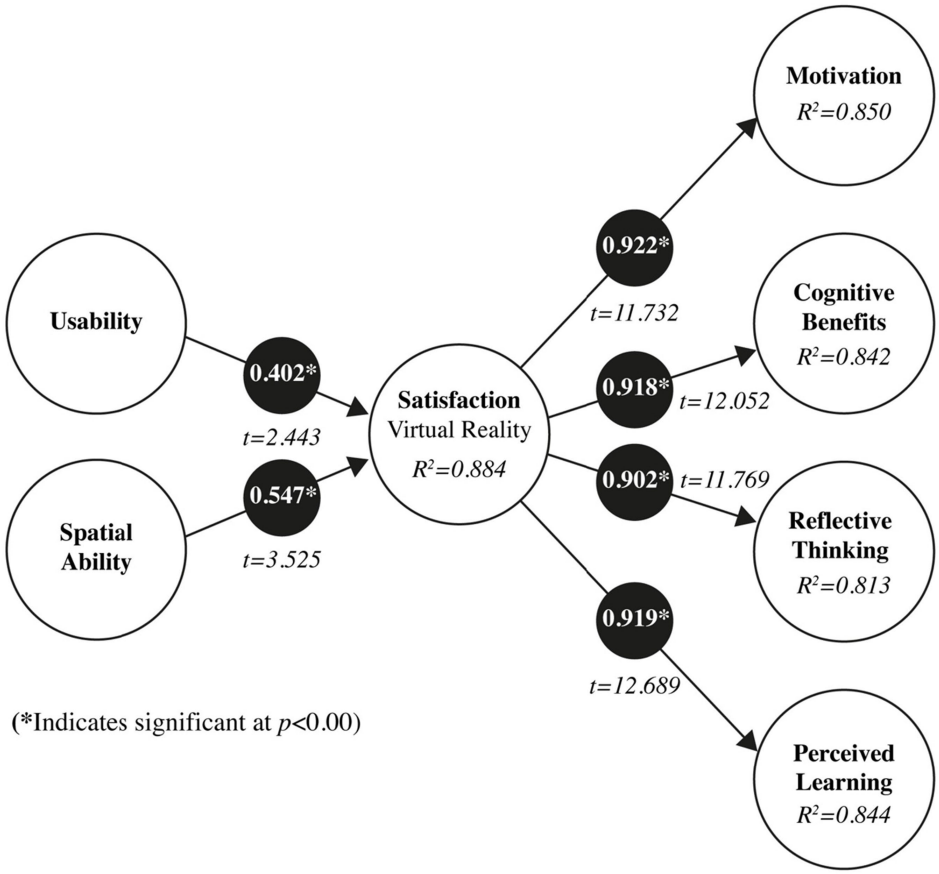

FIGURE 5
Results of the conceptual model. *indicates significant at $p < 0.00$.

educational curricula. These findings resonate with Jensen and Konradsen (2018) and Makransky et al. (2019), highlighting how immersive learning environments can foster a deeper engagement with content, thereby enhancing motivational levels and cognitive gains. This suggests that satisfaction with VR learning experiences can catalyze a virtuous cycle of engagement and achievement, emphasizing the broader educational potential of VR beyond mere technological novelty.

Building on this notion, the adaptability of VR to support personalized learning experiences further accentuates its value in education. Personalized learning, which tailors educational content to meet individual students' needs, preferences, and learning paces, is facilitated by VR's immersive and interactive nature. This approach not only amplifies motivation and self-efficacy by allowing students to engage in learning pathways that are most relevant to them but also aligns with the constructivist principles of active and meaningful learning. Such personalized engagement through VR can significantly enhance students' satisfaction, thereby fostering a more inclusive and effective

learning environment that caters to the diverse needs of learners within the art and design disciplines.

Moreover, the positive association between satisfaction derived from VR experiences and perceived learning highlights the transformative potential of VR in shaping students' perceptions of their educational journey. This aligns with the findings of Çakıroğlu et al. (2021) and Makransky and Lilleholt (2018), who noted improvements in students' confidence in their learning abilities following VR interventions. The implication here is profound, suggesting that VR not only augments the actual acquisition of knowledge and skills but also enhances students' self-efficacy and belief in their learning capabilities.

In conclusion, this study contributes to the burgeoning field of VR in education by offering empirical evidence of the multifaceted benefits of VR in art and design education. By demonstrating the significant roles of usability and spatial ability in enhancing student satisfaction and, by extension, motivation, cognitive benefits, reflective thinking, and perceived learning, it underscores the necessity of incorporating VR technologies into educational frameworks. These findings beckon educational stakeholders to embrace VR as a pivotal component of contemporary pedagogical strategies, heralding a new era of immersive and interactive learning that can profoundly enrich the educational landscape.

7 Implications of results

This study significantly enhances our comprehension of VR in educational settings, particularly within creative disciplines like art and design. The findings suggest that improved usability and spatial ability within VR environments are closely linked to increased learning satisfaction, which, in turn, elevates student motivation, cognitive benefits, reflective thinking, and perceived learning among undergraduates.

Theoretically, these findings underscore the importance of designing VR environments that are not only technically sophisticated but also intuitive and navigable for students. By demonstrating the direct influence of usability and spatial skills on educational outcomes, this study supports and expands current theories on technology-mediated learning and provides an empirical framework for future research in this domain.

Practically, the insights from this work suggest that curriculum designers and pedagogical strategists should carefully consider the integration of VR in the classroom, with particular emphasis on user experience. Investment in the development of user-friendly VR interfaces and spatial training may result in more effective and satisfying learning experiences, which is especially pertinent for disciplines heavily reliant on visualization and spatial manipulation.

Furthermore, this study holds significant implications for educational policy development and resource allocation. The results advocate for the inclusion of VR as a valuable educational tool, encouraging institutions to invest in this technology as a means to enhance learning and teaching quality.

8 Limitations

The scope and generalizability of the present study are inherently tied to its contextual framework, which focuses on a specific cohort of art and design undergraduates in Mexico. While the findings yield substantive insights into the impact of VR on various facets of the learning process, they are bounded by the cultural and educational milieu from which the data were drawn. Consequently, the application and extension of these results to dissimilar cultural or academic environments necessitate a cautious approach.

Expanding upon these limitations, it is important to acknowledge that student interactions with VR technology and their resulting learning outcomes may be influenced by cultural nuances, access to technology, individual learning styles, and the specific curriculum of art and design programs. These factors collectively play a pivotal role in shaping the effectiveness of VR as an educational tool. Thus, while the study presents a strong case for the benefits of VR in enhancing usability, spatial ability, and overall learning satisfaction, these benefits may manifest differently in diverse educational contexts.

To address these potential disparities and to fortify the robustness of the study's conclusions, it is recommended that similar research endeavors be undertaken in a variety of educational settings. Such replications could include different geographical regions, a range of academic disciplines beyond art and design, and varied levels of technological proficiency among participants.

Furthermore, extending this research could involve longitudinal studies to assess the long-term retention of knowledge and skills acquired through VR, as well as its impact on students' academic progression and career preparedness.

Adding to these considerations, practical challenges specific to the deployment of VR glasses in educational contexts must be highlighted. These include the prohibitive costs and the necessity for specialized hardware, which may limit accessibility for certain institutions or learners. Additionally, the potential side effects of VR usage, such as dizziness or discomfort, present concerns regarding the inclusivity of VR-based learning experiences. The limited availability of high-quality, educational VR content and the logistical complexities of managing VR hardware within academic settings further complicate the integration of this technology into existing curricula. These logistical and financial constraints underscore the need for innovative solutions to overcome barriers to VR adoption and utilization in education, ensuring that its benefits can be widely accessed and effectively leveraged across diverse learning environments.

9 Future research

The future research agenda emerging from this study should adopt a holistic lens, with the aim of broadening the understanding of VR's role in education. A comprehensive approach would encompass investigating VR's cross-cultural efficacy, its adaptability across various academic disciplines, and its impact on long-term learning outcomes.

Further inquiry might consider the nuanced effects of VR on cognitive processes and how these translate into academic and professional success. Such work should also prioritize the development of pedagogical frameworks for VR integration, ensuring that its deployment in educational settings is both methodologically sound and ethically responsible.

Moreover, a concerted effort to address VR accessibility will be crucial in democratizing educational technology and ensuring that the benefits of VR-enhanced learning are available to all students, regardless of background or ability.

By advancing a research paradigm that is integrative and globally conscious, future studies can pave the way for VR to become a cornerstone of innovative, inclusive, and effective education.

10 Conclusion

In synthesizing the outcomes of this study, practical applications emerge from the validation that usability and spatial ability significantly impact satisfaction in VR learning environments. These insights suggest actionable strategies for educators and technologists aiming to optimize VR as an educational tool. By prioritizing the design of user-friendly and spatially intuitive VR interfaces, there is an opportunity to significantly enhance learner engagement and satisfaction. This entails the development of VR content that is not only academically rigorous but also accessible and engaging, leveraging the immersive potential of VR to create compelling learning experiences.

The findings advocate for a transformative approach to curriculum development, where VR is seamlessly integrated into educational frameworks to foster immersive and interactive learning opportunities. For instance, the creation of VR-based lab simulations in science education or virtual art studios in design education can provide students with hands-on, experiential learning that transcends traditional classroom boundaries.

Moreover, the research underscores the importance of incorporating feedback mechanisms within VR applications to continuously refine usability and spatial navigation features. This iterative design process, informed by direct user feedback, can ensure that VR learning environments remain aligned with the evolving needs and preferences of students.

In conclusion, the study highlights the critical role of VR in redefining educational paradigms, advocating for an educational ecosystem that embraces technological advancements to enrich learning experiences. By focusing on the design and implementation of VR technologies that cater to the specific needs of learners, educators can unlock new possibilities for engagement, motivation, and cognitive development. This proactive embrace of VR in education holds the promise of fostering a more dynamic, interactive, and satisfying learning environment for students across disciplines.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by the study was conducted in accordance with the Declaration of Helsinki, and approved by the Universidad de Monterrey. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual (s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

GS-M: Conceptualization, Formal analysis, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing, Visualization. CG-T: Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing, Validation, Funding acquisition, Project administration, Resources, Software, Supervision.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

AlGerafi, M. A. M., Zhou, Y., Oubibi, M., and Wijaya, T. T. (2023). Unlocking the potential: a comprehensive evaluation of augmented reality and virtual reality in education. *Electronics (Basel)* 12:3953. doi: 10.3390/electronics12183953

Alqurashi, E. (2019). Predicting student satisfaction and perceived learning within online learning environments. *Distance Educ.* 40, 133–148. doi: 10.1080/01587919.2018.1553562

Ames, C., and Archer, J. (1988). Achievement goals in the classroom: students' learning strategies and motivation processes. *J. Educ. Psychol.* 80, 260–267. doi: 10.1037/0022-0663.80.3.260

Bahati, B., Fors, U., Hansen, P., Nouri, J., and Mukama, E. (2019). Measuring learner satisfaction with formative e-assessment strategies. *Int. J. Emerg. Technol. Learn.* 14, 61–79. doi: 10.3991/ijet.v14i07.9120

Birt, J., and Vasilevski, N. (2021). Comparison of single and multiuser immersive mobile virtual reality usability in construction education. *Educ. Technol. Soc.* 24, 93–106. doi: 10.3389/frvir.2021.713718

Blajenkova, O., Kozhevnikov, M., and Motes, M. A. (2006). Object-spatial imagery: a new self-report imagery questionnaire. *App. Cogn. Psychol.: Official J. Society for App. Res. Memory and Cogn.* 20, 239–263. doi: 10.1002/acp.1182

Bourgeois-Bougrine, S., Richard, P., Burkhardt, J.-M., Frantz, B., and Lubart, T. (2020). The expression of users' creative potential in virtual and real environments: an exploratory study. *Creat. Res. J.* 32, 55–65. doi: 10.1080/10400419.2020.1712162

Brooke, J. (1986). System usability scale (SUS): a quick-and-dirty method of system evaluation user information. *Reading, UK: Digital equipment co ltd* 43, 1–7.

Çakıroğlu, Ü., Aydın, M., Özkan, A., Turan, Ş., and Cihan, A. (2021). Perceived learning in virtual reality and animation-based learning environments: a case of the understanding our body topic. *Educ Inf Technol (Dordr)* 26, 5109–5126. doi: 10.1007/s10639-021-10522-2

Checa, D., and Bustillo, A. (2020). Advantages and limits of virtual reality in learning processes: Briviesca in the fifteenth century. *Virtual Reality* 24, 151–161. doi: 10.1007/s10055-019-00389-7

Chen, M. A., Hwang, G., and Chang, Y. (2019). A reflective thinking-promoting approach to enhancing graduate students' flipped learning engagement, participation behaviors, reflective thinking and project learning outcomes. *Br. J. Educ. Technol.* 50, 2288–2307. doi: 10.1111/bjet.12823

Choe, R. C., Scuric, Z., Eshkol, E., Cruser, S., Arndt, A., Cox, R., et al. (2019). Student satisfaction and learning outcomes in asynchronous online lecture videos, CBE—life sciences. *Education* 18:ar55. doi: 10.1187/cbe.18-08-0171

Di Natale, A. F., Repetto, C., Riva, G., and Villani, D. (2020). Immersive virtual reality in K-12 and higher education: a 10-year systematic review of empirical research. *Br. J. Educ. Technol.* 51, 2006–2033. doi: 10.1111/bjet.13030

Drigas, A., Mitsea, E., and Skianis, C. (2022). Virtual reality and metacognition training techniques for learning disabilities. *Sustain. For.* 14:10170. doi: 10.3390/su141610170

Du Plessis, E. (2020). Student teachers' perceptions, experiences, and challenges regarding learner-centred teaching. *S. Afr. J. Educ.* 40, 1–10. doi: 10.15700/saje.v40n1a1631

Guerra-Tamez, C. R. (2023). The impact of immersion through virtual reality in the learning experiences of art and design students: the mediating effect of the flow experience. *Educ Sci (Basel)* 13:185. doi: 10.3390/educsci13020185

Hamilton, D., McKechnie, J., Edgerton, E., and Wilson, C. (2021). Immersive virtual reality as a pedagogical tool in education: a systematic literature review of quantitative learning outcomes and experimental design. *J. Comput. Educ.* 8, 1–32. doi: 10.1007/s40692-020-00169-2

Hammady, R., Ma, M., Al-Kalha, Z., and Strathearn, C. (2021). A framework for constructing and evaluating the role of MR as a holographic virtual guide in museums. *Virtual Reality* 25, 895–918. doi: 10.1007/s10055-020-00497-9

Hamutoglu, N. B., Gemikonakli, O., Duman, I., Kirksekiz, A., and Kiyici, M. (2020). Evaluating students experiences using a virtual learning environment: satisfaction and preferences. *Educ. Technol. Res. Dev.* 68, 437–462. doi: 10.1007/s11423-019-09705-z

Hmoud, M., Swaity, H., Karram, O., Shibli, H., Swaity, S., and Daher, W. (2023). High school students' engagement in biology in the context of XR technology. *IEEE Access* 11, 137053–137066. doi: 10.1109/ACCESS.2023.3338176

Ho, L.-H., Sun, H., and Tsai, T.-H. (2019). Research on 3D painting in virtual reality to improve students' motivation of 3D animation learning. *Sustain. For.* 11:1605. doi: 10.3390/su11061605

Huang, H., and Lee, C.-F. (2022). Factors affecting usability of 3D model learning in a virtual reality environment. *Interact. Learn. Environ.* 30, 848–861. doi: 10.1080/10494820.2019.1691605

Jensen, L., and Konradsen, F. (2018). A review of the use of virtual reality head-mounted displays in education and training. *Educ Inf Technol (Dordr)* 23, 1515–1529. doi: 10.1007/s10639-017-9676-0

Kerr, J., and Lawson, G. (2020). Augmented reality in design education: landscape architecture studies as AR experience. *Int. J. Art & Design Educ.* 39, 6–21. doi: 10.1111/jade.12227

Kuo, Y.-T., Garcia Bravo, E., Whittinghill, D. M., and Kuo, Y.-C. (2023). Walking into a modern painting: the impacts of using virtual reality on student learning performance and experiences in art appreciation. *Int. J. Hum. Comput. Interact.* 2023, 1–22. doi: 10.1080/10447318.2023.2278929

Lackey, S. J., Salcedo, J. N., Szalma, J. L., and Hancock, P. A. (2016). The stress and workload of virtual reality training: the effects of presence, immersion and flow. *Ergonomics* 59, 1060–1072. doi: 10.1080/00140139.2015.1122234

Lee, H., and Hwang, Y. (2022). Technology-enhanced education through VR-making and metaverse-linking to foster teacher readiness and sustainable learning. *Sustain. For.* 14:4786. doi: 10.3390/su14084786

Liaw, S.-S., and Huang, H.-M. (2013). Perceived satisfaction, perceived usefulness and interactive learning environments as predictors to self-regulation in e-learning environments. *Comput. Educ.* 60, 14–24. doi: 10.1016/j.compedu.2012.07.015

Lin, Y.-J., and Wang, H. (2021). Using virtual reality to facilitate learners' creative self-efficacy and intrinsic motivation in an EFL classroom. *Educ Inf Technol (Dordr)* 26, 4487–4505. doi: 10.1007/s10639-021-10472-9

Liu, R., Wang, L., Lei, J., Wang, Q., and Ren, Y. (2020). Effects of an immersive virtual reality-based classroom on students' learning performance in science lessons. *Br. J. Educ. Technol.* 51, 2034–2049. doi: 10.1111/bjet.13028

Makransky, G., Andreasen, N. K., Baceviciute, S., and Mayer, R. E. (2021). Immersive virtual reality increases liking but not learning with a science simulation and generative learning strategies promote learning in immersive virtual reality. *J. Educ. Psychol.* 113, 719–735. doi: 10.1037/edu0000473

Makransky, G., Borre-Gude, S., and Mayer, R. E. (2019). Motivational and cognitive benefits of training in immersive virtual reality based on multiple assessments. *J. Comput. Assist. Learn.* 35, 691–707. doi: 10.1111/jcal.12375

Makransky, G., and Lilleholt, L. (2018). A structural equation modeling investigation of the emotional value of immersive virtual reality in education. *Educ. Technol. Res. Dev.* 66, 1141–1164. doi: 10.1007/s11423-018-9581-2

Makransky, G., and Petersen, G. B. (2019). Investigating the process of learning with desktop virtual reality: a structural equation modeling approach. *Comput. Educ.* 134, 15–30. doi: 10.1016/j.compedu.2019.02.002

Makransky, G., Petersen, G. B., and Klingenberg, S. (2020). Can an immersive virtual reality simulation increase students' interest and career aspirations in science? *Br. J. Educ. Technol.* 51, 2079–2097. doi: 10.1111/bjet.12954

Marougkas, A., Troussas, C., Krouska, A., and Sgouropoulou, C. (2023). Virtual reality in education: a review of learning theories, approaches and methodologies for the last decade. *Electronics (Basel)* 12:2832. doi: 10.3390/electronics12132832

Norman, D. A., and Nielsen, J. (2010). Gestural interfaces: a step backward in usability. *Interactions* 17, 46–49. doi: 10.1145/1836216.1836228

Obeid, S., and Demirkan, H. (2023). The influence of virtual reality on design process creativity in basic design studios. *Interact. Learn. Environ.* 31, 1841–1859. doi: 10.1080/10494820.2020.1858116

Pande, M., and Bharathi, S. V. (2020). Theoretical foundations of design thinking–a constructivism learning approach to design thinking. *Think. Skills Creat.* 36:100637. doi: 10.1016/j.tsc.2020.100637

Papanastasiou, G., Drigas, A., Skianis, C., Lytras, M., and Papanastasiou, E. (2019). Virtual and augmented reality effects on K-12, higher and tertiary education students' twenty-first century skills. *Virtual Reality* 23, 425–436. doi: 10.1007/s10055-018-0363-2

Park, J., Kim, D.-E., and Sohn, M. (2011). 3D simulation technology as an effective instructional tool for enhancing spatial visualization skills in apparel design. *Int. J. Technol. Des. Educ.* 21, 505–517. doi: 10.1007/s10798-010-9127-3

Radianti, J., Majchrzak, T. A., Fromm, J., and Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: design elements, lessons learned, and research agenda. *Comput. Educ.* 147:103778. doi: 10.1016/j.compedu.2019.103778

Rovai, A. P., Wighting, M. J., Baker, J. D., and Grooms, L. D. (2009). Development of an instrument to measure perceived cognitive, affective, and psychomotor learning in traditional and virtual classroom higher education settings. *Internet High. Educ.* 12, 7–13. doi: 10.1016/j.iheduc.2008.10.002

Soliman, M., Pesyridis, A., Dalaymani-Zad, D., Gronfula, M., and Kourmpetis, M. (2021). The application of virtual reality in engineering education. *Appl. Sci.* 11:2879. doi: 10.3390/app11062879

Starrett, M. J., McAvan, A. S., Huffman, D. J., Stokes, J. D., Kyle, C. T., Smuda, D. N., et al. (2021). Landmarks: a solution for spatial navigation and memory experiments in virtual reality. *Behav. Res. Methods* 53, 1046–1059. doi: 10.3758/s13428-020-01481-6

Sun, R., Wu, Y. J., and Cai, Q. (2019). The effect of a virtual reality learning environment on learners' spatial ability. *Virtual Reality* 23, 385–398. doi: 10.1007/s10055-018-0355-2

Tenenhaus, M., Amato, S., and Esposito Vinzi, V. (2004). "A global goodness-of-fit index for PLS structural equation modelling," in *Proceedings of the XLII SIS scientific meeting.* 1, 739–742.

Tratnik, A., Urh, M., and Jereb, E. (2019). Student satisfaction with an online and a face-to-face business English course in a higher education context. *Innov. Educ. Teach. Int.* 56, 36–45. doi: 10.1080/14703297.2017.1374875

Violante, M. G., and Vezzetti, E. (2015). Virtual interactive e-learning application: an evaluation of the student satisfaction. *Comput. Appl. Eng. Educ.* 23, 72–91. doi: 10.1002/cae.21580

Wee, C., Yap, K. M., and Lim, W. N. (2021). Haptic interfaces for virtual reality: challenges and research directions. *IEEE Access* 9, 112145–112162. doi: 10.1109/ACCESS.2021.3103598

Wetzels, M., Odekerken-Schröder, G., and Van Oppen, C. (2009). Using PLS path modeling for assessing hierarchical construct models: guidelines and empirical illustration. *MIS Q.* 33, 177–195. doi: 10.2307/20650284

Won, M., Ungu, D. A. K., Matovu, H., Treagust, D. F., Tsai, C. C., Park, J., et al. (2023). Diverse approaches to learning with immersive virtual reality identified from a systematic review. *Comput. Educ.* 195:104701. doi: 10.1016/j.compedu.2022.104701

Wu, X.-Y. (2024). Exploring the effects of digital technology on deep learning: a meta-analysis. *Educ Inf Technol (Dordr)* 29, 425–458. doi: 10.1007/s10639-023-12307-1

Wu, B., Yu, X., and Gu, X. (2020). Effectiveness of immersive virtual reality using head-mounted displays on learning performance: a meta-analysis. *Br. J. Educ. Technol.* 51, 1991–2005. doi: 10.1111/bjet.13023

Ye, Q., Zhou, R., Anwar, M. A., Siddiquei, A. N., Hussain, S., and Asmi, F. (2022). Virtual reality-based learning through the lens of eudaemonic factors: reflective thinking as a game changer. *Think. Skills Creat.* 45:101103. doi: 10.1016/j.tsc.2022.101103

Yu, Z., Gao, M., and Wang, L. (2021). The effect of educational games on learning outcomes, student motivation, engagement and satisfaction. *J. Educ. Comput. Res.* 59, 522–546. doi: 10.1177/0735633120969214

Zhonggen, Y., Ying, Z., Zhichun, Y., and Wentao, C. (2019). Student satisfaction, learning outcomes, and cognitive loads with a mobile learning platform. *Comput. Assist. Lang. Learn.* 32, 323–341. doi: 10.1080/09588221.2018.1517093

Appendix A

Table A1. Indicators in the measuring instrument.

Construct	Construct	
Satisfaction virtual reality	SVR1	Enjoy experience through VR technology.
	SVR2	I found the gratifying VR experience.
	SVR3	This class through VR technology exceeds my expectations.
Usability	U1	I think I would like to use this system frequently.
	U2	I found the system unnecessarily complex.
	U3	I found the system functions were well integrated.
	U4	I imagine that most people would learn to use this system very quickly.
	U5	I needed to learn a lot of things before I could get going with this system.
Spatial ability	SA1	Using virtual reality improved my spatial ability (the capacity to form a mental geometric representation of the world).
	SA2	I can easily imagine and mentally rotate the geometric figures during the activity.
	SA3	I found it easy to envision exactly how the geometric figures looked when rotated during the activity.
	SA4	I believe I acquired new skills in 3D geometry through this activity with virtual reality.
	SA5	Using virtual reality has made me improve in the use of three-dimensional geometry.
Motivation	M1	It is interesting to use virtual reality technology in this activity.
	M2	My performance was good using virtual reality technology in this activity.
	M3	After using virtual reality technology for a while, I felt competent.
	M4	I felt very relaxed while using virtual reality technology in this activity.
	M5	I am skilled at using virtual reality technology in this activity.
Cognitive benefits	CB1	Using virtual reality facilitates my understanding in this activity.
	CB2	Using virtual reality facilitates my memorization.
	CB3	Using virtual reality helps me apply my knowledge and skills more effectively.
	CB4	Using virtual reality helps me analyze problems better in this activity.
	CB5	Using virtual reality helps me gain a better overview of this activity.
Reflective thinking	RT1	Using virtual reality technology in this activity, I was able to reflect on how I learn.
	RT2	By using virtual reality in this activity, I was able to link new knowledge with my previous knowledge and experiences.
	RT3	By using virtual reality in this activity, I could become a better student.
	RT4	By using virtual reality in this activity, I was able to reflect on my understanding.
Perceived learning	SPL1	I can use the skills learned in this course outside of class.
	PL2	I have changed my attitudes about the course subject as a result of this activity.
	PL3	I feel more self-sufficient as a result of the content learned in this activity.
	PL4	I can demonstrate to others the skills learned in this activity.
	PL5	I feel that I have new skills as a result of this activity.

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Immersive virtual reality for learning about ecosystems: effect of two signaling levels and feedback on action decisions

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Introduction: The goal of the present study was to test the effect of signaling associated with feed-back in learning forest ecosystems in the context of realistic living forest simulator, in IVR conditions for students in agriculture. Two signaling modalities, corresponding to two signaling levels, were investigated: visual *flashing* of forest elements (tree species, plants, flowers, fungi, wet-areas etc.) and *marker-stones*, both with text in pop-up windows, in a 2x2 experimental plan.

Methods: Ninety-three pupils of an agricultural technological high school had to explore (including physically), interrogate (search for) and select (using the joysticks) relevant elements of the forest in three living forest areas (visually delimited inside of a broader forest area) in order to choose (and justify) the best area, among the three, in which an equipped public-tourist reception site (picnic, resting, reception site) could be built. The chosen site must have the least possible negative impact on the ecosystem of the forest and its development over time. After their decision (and justification) they were provided a feed-back with a series of VR desktop multimedia slides showing the effect of this choice on the ecosystem of the chosen area. After the feed-back they had to decide and justify again whether they would change or maintain their first decision. Finally, subjective scales were also used in order to investigate presence, cognitive complexity, sickness and overall enjoyment.

Results and discussion: Results showed significant positive effects of both signaling levels, and of the feed-back on the correct decision answers. Further, the combination, and interaction, between signaling and feedback seemed to enhance, the activation and retrieval from memory, of the task-relevant concepts. In addition, the results indicated a significant positive effect (medium size) of presence on decision performances, a finding which is consistent with the immersion principle.

KEYWORDS

learning, virtual reality, visual signaling, feedback, cognitive processes, action decision making, presence, climate change education

1 Introduction and goal

In a context of major environmental change, the use of immersive virtual reality (IVR) for the learning of complex ecosystems such as those found in forests could be a promising avenue to explore in the light of the ongoing changes in the training of students of agricultural forestry. "Seeing" the visible and non-visible forest elements and their interrelations in a 3D environment, visually observing, via IVR simulation of forest development, the potential "real" short-to-medium and long-term effect of human actions and forestry management decisions on tree species and the development of wildlife ecosystems could enhance learning and interest and improve professional decision-making (Figure 1). For example, a typical learning or training task performed by forest management students consists in identifying, understanding and building a mental model (diagnosis) of the ecosystems specific to various forest parcels in order to evaluate the impact of action decisions, such as cutting down trees (for forest thinning) or setting up public reception facilities etc., on the preservation of these ecosystems. The overarching goal of the present research is to contribute to the construction of such models.

The volume of research into IVR-assisted learning is currently growing apace, see for example the very recent studies by Makransky and Petersen, 2019; Makransky et al., 2020b,c; Stenberdt and Makransky (2023), Albus et al. (2021), Petersen et al. (2022), and Makransky and Mayer (2022) among many other articles and see also below.

Despite the popularity of IVR, which allows a high level of perceived presence, user-control and agency [see the CAMIL by Makransky and Petersen (2021), and below], a number of recent studies have revealed that IVR does not always have positive effects on learning compared to conventional desktop multimedia or video presentations (Parong and Mayer, 2018; Makransky et al., 2019a,b, 2020a; Makransky, 2022; Mayer et al., 2022). As stated in the title of the article by Makransky et al. (2019b), *"Adding immersive virtual reality… causes more presence but less learning."* In a recent review, Mayer et al. (2022) showed that out of 13 studies comparing IVR with more conventional media (or computer-screen VR) such as desktop, slideshow or video, seven indicated that students learnt better with conventional media than in IVR environments.

Only five studies showed a positive effect of IVR, with most of them revealing a small effect size (Cohen' *d* from 0.10 to 0.29). In their meta-analysis, Wu et al. (2020) found a small advantage of IVR over more conventional technologies. In their own meta-analysis, Coban et al. (2022), considered fourteen previous meta-analyses and 105 independent ESs (Effect Sizes) from 48 primary studies: They found an overall ES of g = 0.38, which corresponds to a small to medium positive effect. Araiza-Alba et al. (2020a,b) arrived at a similar conclusion concerning the use of desktop VR and IVR with children.

The high degree of realism, the enriched nature of the visual information, the potentially overwhelming effect of an immersive visual field with perceptual saliency effects, the number of elements, the user-control and agency factors may lead not only to attentional distraction and disorientation but also to an increase in both extraneous and germane cognitive load (Sweller et al., 2011; Albus and Seufert, 2022; Mayer et al., 2022). According to Makransky (2022), *"The immersion principle in multimedia learning is that immersive virtual environments promote better learning when they incorporate*

FIGURE 1
Snapshots of the VR simulation environment, from left to right and top to bottom: access path to the forest parcels, inside the parcels, view of the trees when the learner looks up toward the sky.

multimedia design principles. In short, immersive media do not necessarily improve learning but effective instructional methods within immersive virtual environments do improve learning" (page 296).

In this way, one recent line of research has consisted in "systematically" testing the potential benefits and effectiveness of making use of multimedia principles and features in IVR learning environments (Albus et al., 2021; Albus and Seufert, 2022; Mayer et al., 2022). Features that have proven their effectiveness in multimedia learning (Mayer and Fiorella, 2022) include, for example, the principles of instructional design and generative activities. The review by Parong (2022), reported a positive significant added value of features such as modality, personalization, pre-training summarizing, answering, enacting, and gender matching on learning performances in 9 out of 12 studies. Recently, Stenberdt and Makransky (2023) tested the feedback principle in IVR-based material promoting pro-environmental waste-sorting behavior.

The present study tested another instructional design feature, namely the effect of visual signaling associated with feedback for teaching agriculture students about forest ecosystems using a realistic living forest simulator in IVR conditions. To the best of our knowledge, there are to date only very few published studies that report results and have investigated verbal signaling in IVR, Albus et al. (2021) and Zhang et al. (2023), while another recent study (Decker and Merkt, 2023) has focused on the effect of signaling cues in desktop VR and IVR environments.

1.1 Learning in IVR

A second line of research, conducted within the theoretical framework of the CAMIL (Makransky and Petersen, 2021), has consisted in investigating the effect of the two main immersive affordances, namely presence and agency, on cognitive and affective factors, i.e., enjoyment, interest, self-efficacy, self-regulation, embodiment, cognitive load (extraneous, germane and intrinsic), and the effect of these factors on learning outcomes. In addition, new and interesting analytical methods, such as structural equation models (SEM) and mediation techniques, have been used to investigate whether cognitive and affective factors could mediate a hypothesized effect of IVR on learning performances (immediate and/or delayed retention and comprehension post-tests, as well as transfer post-tests etc.). For example, Makransky and Mayer (2022) investigated the benefits of taking an IVR-based climate-change-related virtual trip by comparing two groups of students (13 to 16 years old), one taking the virtual trip to Greenland via a head mounted display (HMD) and the other using 2D video. The results showed that the HMD group outperformed the 2D video group on presence, enjoyment, interest and retention in both the immediate and delayed post-test. The SEM analysis showed that enjoyment mediated the pathway from instructional design to immediate post-test performances, while interest mediated the pathway from instructional design to delayed post-test performances. Recent studies conducted within the same framework have demonstrated a positive effect of IVR and interactivity on enjoyment, interest, self-efficacy, expected outcomes, perceived embodiment, spatial presence, motivation and behavioral intention changes compared to the same content presented using 2D desktop or conventional multimedia technologies, and have done so in very different fields and subject areas (Ahn et al., 2022; Andersen et al., 2022; Makransky and Klingenberg, 2022; Makransky and Mayer, 2022; Petersen et al., 2022; Vandeweerdt et al., 2022; Plechatà et al., 2022a,b; Bagher et al., 2023; Stenberdt and Makransky, 2023). A similar pattern of results was found with young children asked to perform tasks such as remembering and recalling a story and the related emotions (Araiza-Alba et al., 2020a), understanding and recalling seaside safety instructions (Araiza-Alba et al., 2021b) and problem solving (Araiza-Alba et al., 2021a).

However, while these studies have often shown an effect of IVR on mostly perceived cognitive and affective factors, they have not always consistently demonstrated an effect on learning performance (see also Makransky, 2022), even when moderating factors have also been taken into account. Further, and as expected by the CAMIL, studies have revealed that IVR-based learning results in an increased cognitive load, and especially extraneous and germane cognitive load. This could account for the lack of effect observed on learning performances and outcomes. Cognitive load has been measured using direct brain measures (EEG) and subjective scales (Makransky et al., 2019b; Breves and Stein, 2022). The effect on cognitive load was significant in several studies. For example, Baceviciute et al. (2021) found that it was cognitively more demanding (EEG measures) and less time-efficient to read one and the same text in an IVR environment compared to real physical reading. Furthermore, in studies testing the modality effect, Baceviciute et al. (2020) revealed that reading was superior to listening for the learning outcomes of retention, self-efficacy, and extraneous attention. Reading text from a virtual book was reported to be less cognitively demanding than reading from an overlay interface. EEG analyses showed significantly lower theta and higher alpha activation in the audio condition.

The results of these previous studies led to the first line of research mentioned above, which tested the potential benefit of including multimedia principles in IVR learning environments. So far, only a few studies have been conducted (but their number is growing) and the initial results seem mixed: for some principles, the IVR results were similar to those obtained with multimedia 2D documents, whereas for others, they appear to be different (Mayer et al., 2022). This is, for example, the case for the modality principle, Baceviciute et al. (2020). Recently, Albus and Seufert (2022) also identified a reverse modality effect in VR: learning performances were better in the visual-only than the audio-visual condition as measured on recall, comprehension and transfer, with extraneous cognitive load being similar in the two conditions. Furthermore, Klingenberg et al. (2022) found that compared to a control condition, adding segmentation or summarizing activities to an IVR science lesson resulted in better transfer in seventh grade students but not in more factual knowledge. Combining segmentation and summarization did not improve learning. The body of research on IVR learning also reports many differences across studies on factors such as the type of task and contents (science lessons, architecture, biology, history, science lab environment), declarative or procedural knowledge [see the meta-analysis by Coban et al. (2022)], participants' age and activities, the task requirements and also the type of technical implementation: HMD IVR, 360° video, 2D on-screen VR, and also the level of rendering of the VR technique used. Such factors could account for at least some of the heterogeneity among the observed results. It is also necessary to address the question of signaling techniques and this issue will be addressed in Section 1.3 below after the theoretical background to IVR learning has been presented.

1.2 Theoretical background: "The great forgotten factor," visual perception?

In visually rich IVR environments displayed in 3D, we might hypothesize that the distribution of priorities between text and pictures changes. In "conventional" multimedia documents, which often include a limited number of pictures that are sometimes "poorly" designed compared to IVR or full HD videos, text is dominant, and previous studies have shown (see, for example, Schmidt-Weigand et al., 2009) that learners spend much more time on the text than on the pictures. The reverse may be true of IVR presentations because the 3D and presence effect emphasize the pictures. The cognitive guidance and strategies used by the learner should therefore rely less exclusively on the text. The feeling of the *visual completeness* of the environment due to the 3D space and the presence feeling that results from effects of perceptual salience and immersion may make the visual channel much more dominant than the phonological channel, meaning that the visual sketchpad would become the priority processing mechanism and representational system, taking precedence over the phonological and word representation system. This hypothetical explanation could partly account for the reverse modality effect observed in the study by Albus and Seufert (2022).

The present study follows on from research assessing the use of multimedia principles relating to visual signaling/cueing in IVR environments conducted within the framework of the CAMIL (Makransky and Petersen, 2021) and the CTML (Mayer and Fiorella, 2022) models.

However, because of the potential dominance of perceptual visual and pictorial processing in IVR, which could impose a visual load (rarely or never measured *per se*, Skulmowski, 2023), another complementary processing model may be of interest: The Animation Processing Model, APM (Lowe and Boucheix, 2008, 2016). IVR environments dominated by pictures frequently involve complex 3D spatial information and also dynamic, e.g., transient, information. On the one hand, the spatial information not only includes depth views, e.g., depth perception, but also front, back, side, top and bottom views of the display. On the other hand, a transience effect may arise from the possible dynamics of the objects, the context and the learner's body movements in the scene when exploring these rich environments. As postulated by the APM (Lowe and Boucheix, 2008), understanding and building mental models from such complex pictorial environments involve (i) pre-attentive (gestalt theory principles) and (ii) perceptual processes, which are the bases ("raw material") for the (iii) cognitive processing of concepts, causal relations, knowledge building and memorization. Perceptual processes lead to the required spatial and temporal partitioning of the content elements in the IVR display. The efficiency or relevance of partitioning the scene/content may depend on (i) the achievement of an optimal alignment of the perceptual salience of the (dynamic) pictorial information, (ii) top-down application of the learner's prior knowledge (iii) the learner's visuo-spatial abilities. Perceptual partitioning seems to be necessary in order to allow effective cognitive processing when selecting, organizing and structuring the relevant visual information (Mayer and Fiorella, 2022). In line with the foregoing, the APM proposes a five-stage model of the processing of dynamic visuospatial information, involving both the decomposition and composition of the visual information (Lowe and Boucheix, 2008; Boucheix et al., 2013; Lowe and Boucheix, 2016; Lowe et al., 2022).

Stage 1. *Localized perceptual exploration*. After a very short holistic processing, the continuous flow of spatiotemporal information is perceptually parsed into small groups of neighboring graphic entities in order to identify event units. This takes place through both pre-attentive and attentive exploratory processing. Stage 2. *Regional structure formation*. Event units, as well as spatiotemporal entities, begin to link up locally to form regional structures representing various parts of the display. General causal relations begin to form between these regional event units. This processing leads to the formation of dynamic micro-chunks (and micro-chunks of entities), which can be considered as individual *islands of activity and islands of comprehension* that correspond to what is happening in different regions spread across the display area. Stage 3. *Global characterization*. During this phase, the learner develops a more global internal characterization of the dynamics of and relations between spatiotemporal micro-chunks. The islands of activity are linked into broader coherent structures, such as domain-general causal chains. Stage 4. *Functional differentiation*. The relational structure is characterized in a domain-specific way. Actions are propagated along causal chains and/or bigger visual chunks. Events are interpreted in terms of the referent's central objective and the different subsystems are considered as contributing to the overall functioning of the system. This processing identifies functional episodes. Stage 5. *Mental model consolidation*. Mental models are thought to facilitate the understanding of a system's behavior, not merely in a single situation but also in a variety of circumstances and across varied operational requirements. Furthermore, the model should make it possible to adapt to different task requirements and performances. This processing results in a flexible mental model.

We assume that several features of the APM could be applicable to other forms of complex and rich visual displays, such as IVR. For example, the decomposition phase, involving the parsing of the relevant spatiotemporal entities of the displays at different locations in the immersive environment (which can be distant from each other), and the composition phase, in which relational systems are created between spatiotemporal entities and levels (macro and micro), may be also involved in IVR learning. How is it possible to help learners process such a complex visual environment?

1.3 The potential benefit of signaling in IVR

Because of the dominance of spatiotemporal and pictorial information in IVR, and based on the APM model, adding visual signaling related to task-relevant information in IVR could help learners direct their attention to relevant information, thus enabling them to select, organize, structure and integrate visual information at the right location at the right time (Mayer and Fiorella, 2022; Van Gog, 2022). Such cueing could reduce visual load, assist in the inhibition of irrelevant information and create relations between relevant information (chunks, causal chains, etc.). In the context of recognizing forest flora and fauna, for example, cueing may help learners navigating in the IVR forest environment to select tree, flower or plant species and choose soil types that promote biodiversity and forest preservation.

1.3.1 Signaling in conventional multimedia learning

The signaling principle holds that people learn better when signals/cues (verbal and/or visual) are added, not to give more

information but to highlight the relevant information and the organization of the multimedia presentation (text and/or pictures). Verbal signals include, for example, adding pointer words, numbering etc. Visual signals include highlighting, spotlighting, zooming, color coding and graphic organization (Fiorella and Mayer, 2022; Van Gog, 2022). Cueing usually introduces and increases the visual contrast between the signaled information and the other parts of the display. In this way, cueing directs learners' attention toward the relevant information and cuts search times and the extraneous load related to the search activity.

The results of numerous previous research studies have reported a positive effect of signaling on multimedia learning (for example de Koning et al., 2007, 2009, 2010a,b; Boucheix and Lowe, 2010; de Koning et al., 2011; Boucheix et al., 2013). Three main meta-analyses have reported that signaling improves learning effectiveness, with effect sizes ranging from small to medium being observed. Richter et al. (2016) analyzed the efficiency of signals that highlight correspondences between text and pictures and found a small positive effect size ($r = 0.17$) in favor of signaled multimedia for transfer and comprehension. Schneider et al. (2018) used a larger variety of multimedia material that included standalone dynamic visualizations and revealed a small-to-medium positive effect size of cues on retention ($g+ = 0.53$) and transfer ($g+ = 0.33$). Finally, Alpizar et al.'s (2020) meta-analysis showed a small-to-medium effect size in favor of signaling ($d = 0.38$). However, eye-movement data has also indicated that even if signaling is successful in directing the learner's attention to the specific relevant information, it does not always guarantee a significant improvement in comprehension and transfer performance (de Koning et al., 2010a; Lowe and Boucheix, 2011). In the case of dynamic presentations (animations), comprehension is improved by signaling techniques that not only direct the learner's attention but also emphasize the structure of the learning material (de Koning et al., 2009) or the relation between elements, such as causal chains for example (Boucheix and Lowe, 2010). Furthermore, dynamic signaling improves the comprehension of transient information more than static signaling (Boucheix et al., 2013).

1.3.2 Levels of signaling in complex visual IVR

As mentioned above and as far as we are aware, little previous research has investigated the signaling effect in IVR. The study conducted by Albus et al. (2021), used signals in the form of textual annotations (written labels) during learning from a 3D animation on the subject of seawater desalination presented with a low end VR-HMD set-up. The effect of the presence or absence (control group) of signals on learning outcomes and extraneous and germane cognitive load was investigated. Results showed that written annotation signals improved learners' recall performance and germane load compared to the control group but did not improve either deeper processing (comprehension and transfer) or extraneous cognitive load. Adding textual annotations might therefore be an appropriate approach in IVR learning situations. However, it seems that the written annotation signals used in the learning material of this study were written localized "repetitions" of the aural audio information delivered by the animation, and it is therefore possible that there was a redundancy effect (Fiorella and Mayer, 2022; Kalyuga and Sweller, 2022) that weakened the signaling effect. Whatever the case may be, Albus et al. (2021) confirmed the signaling effect and also suggested that other forms of signaling should be tested, in particular dynamic signals (Boucheix and Lowe, 2010; Boucheix et al., 2013). In their recent investigation, Zhang et al. (2023) used a VR training simulation of the process of assembling computer hardware and confirmed that textual cues boosted immediate knowledge gain (retention) but did not improve transfer.

In the present study, we focused on testing the potential benefits of visual signals rather than relying exclusively on textual signals. We used a typical training task given to agricultural forestry students. In this task, the students have to identify the specific ecosystems and biodiversity of forest parcels before deciding on whether and how to intervene (by cutting trees, for example). Both comprehension and diagnostic activity are required in order to identify the quality of the ecosystems of the parcels. Due to the information density and the potential *"sense of proprioceptive visuospatial comprehensiveness"* in IVR, we propose that not only one but several levels of signaling could be needed in order to help users better organize the relevant information in the environment. Different signaling levels could then highlight different levels of the information structure of the visual environment: in the forest scenario, for example, these could include the level of trees and plant-related information and the level of soil information (including soil moisture levels and wildlife information). This type of differentiated signaling would not only highlight the structure of the relevant information but also could direct attention toward conceptual relations that might link the signaling levels: for example, between the soil composition level and the tree and plant level. However, using too many signals could impose a greater perceptual and cognitive load.

1.4 Feedback with generative activities in IVR and signaling

The provision of informative feedback is widely recognized to be an effective instructional method that enhances learning performance and increases the learner's engagement (see, for example, Hattie and Timperley, 2007; Hattie, 2008). According to the feedback principle, students in multimedia learning situations learn better with informational and explanatory feedback than with only corrective feedback (Johnson and Marraffino, 2022). Recently, and interestingly, Stenberdt and Makransky (2023) used two types of feedback in a study which investigated the effect of mastery experiences in IVR on promoting pro-environmental waste sorting behavior. "Conventional" corrective feedback was compared to an exaggerated feedback which consisted in showing learners the effect of incorrect waste management activities on the environment. The depicted environmental changes were exaggerated so that sorting one waste item (incorrectly) reflected the effect of many people persistently sorting this type of waste in the same way.

In the present study, informative feedback was given to learners during the training task, in particular after they had made a first action decision based on their diagnostic of the forest ecosystem and before making a second action decision. We expected the feedback principle to impact task performance, in particular given that during the learning-by-exploration time in the IVR environment, the learners were actively able to use the joysticks associated with the IVR headset to navigate toward specific forest elements (trees, plants, soils etc.) and, on reaching them, obtain information about their nature and characteristics (see the details in the Method section).

We are not aware of any previous research that has studied the combined effect of signaling and feedback in multimedia-based or IVR learning. We hypothesized that there would be an interaction effect of signaling and feedback on task performance. We speculated that the cognitive processing mechanism underlying such an interaction could act as follows. The effectiveness of the cognitive processing and interpretation of information feedback may depend on the relevance and quality of the knowledge and information acquired and memorized immediately beforehand during the task (also including prior knowledge). If so, the cued items of information preselected for learners in a signaling condition, which are relevant by definition, limited in number and reveal the underlying structure of the information, might be better retrieved from working memory and processed for treating the feedback information than in a non-signaling condition. In this latter condition, the internal activation of more information, which is potentially irrelevant and understructured, would not facilitate the cognitive processing of the feedback information. In other word, the signaling of task-relevant information could make it easier to establish the necessary internal relations between the content of the feedback information and the content of the previous information memorized during the task before this feedback and indeed improve these relations. As a consequence, the positive effect of feedback on task performance might be greater when signaling is used than when it is not.

1.5 The present study

As mentioned above, the present study investigated the influence of two levels of visual signaling and information feedback in a vocational training task involving (i) the exploration, and interrogation (forest elements searching), of forest areas for the purpose of diagnosing the ecosystem and (ii) two subsequent decisions, including a justification given by the learner: a first decision before information feedback on the forest elements present in the areas visited during the exploration and a second decision after this feedback. The action decisions made by forestry professionals and students in agricultural colleges in order to ensure forest sustainability, for example whether to cut trees, how to manage plots, etc., must result from the application of knowledge about biological ecosystems and lead to a diagnosis of the biological potential of the forest or the parcel. By learning and applying such knowledge, learners are able to predict the effect, whether positive or negative, of human action decisions on forest development (trees, plants, animals etc.) in the short (1 to 5 years), medium (5 to 10 years) and long term (more than 20–50 years to 100 years). An IVR environment based on authentic agronomic forestry models could be an effective learning and training tool. The IVR environment used in the present study is a part of a wider project called Silva-Numerica (involving several collaborating partners), which has involved the design, construction and implementation of a realistic live forest simulator which is able to simulate forest development (trees, plants, soil, etc.) and, in particular, the effect of human action on future changes. It makes use of computer algorithms derived from agronomic models.

The project started by testing and implementing a screen-based (desktop) simulator for classroom use (college and undergraduate university levels). In the present study, we used a later IVR version (Figure 1) which induces a high level of perceived presence, including realistic 3D features, and provides verbal and pictorial information on visible and invisible elements during the exploration of forest parcels (types of trees and plants, fungi and mushrooms, soil types, animals, moisture content, micro-habitats, etc., see details in the Method section). We also used a typical training task taken from the agro-ecology curriculum. Students were told to explore (and interrogate) several (small) forest areas in order to decide which one would be the most suitable for building a public reception area with (a forest observatory and) a picnic area and keep the impact on the nearby forest ecosystem to a minimum. This task involves (i) a first phase of exploration-based learning of the areas in order to build a mental model of the characteristics and richness of the ecosystem of each area and (ii) making a decision about the most suitable area for the location of the public reception area. Naturally, the participants were required to give a clear justification for their decisions (see the details in the Method section). The cognitive processing required before making the decision involved comprehension-diagnostic activities: the selection and identification of relevant ecosystem elements (types of trees, trees planned for the future, plant species, fungi, soil features, potential wildlife) and the establishment of relations between the identified elements.

Complementary influencing factors were also controlled for the study. First of all, prior knowledge of participants (agricultural education students) was assessed. Secondly, since the participants had to navigate in forest areas and read verbal information about selected forest elements, their spatial abilities [see the recent paper by Hartmann et al. (2023), on spatial abilities and IVR] and verbal working memory spans were measured and controlled. In addition, and based on the CAMIL model (*cf.* Makransky and Petersen, 2021), several technological features, affordances and cognitive-affective factors were assessed using subjective scales based on the assessment tool proposed by Makransky et al. (2017): perceived realism and authenticity, presence and immersion, perceived task facility-difficulty, usability of the environment's functionalities, specific knowledge requirements, cybersickness, overall enjoyment during the IVR experience (see Method section for details).

1.6 Hypotheses

Four main hypotheses were formulated in the light of the foregoing.

> *H1*: We expected an effect of visual signaling on the number of elements (trees, plants etc.) explored, e.g., targeted (and then selected) with the joystick prior to decision-making. In the signaled conditions, we expected learners to target and select fewer elements than in the non-signaled conditions. Targeting fewer items would help participants select the relevant information and organize and integrate it before making a decision.

> *H2*: We expected a positive effect of visual signaling on correct (and justified) decisions. This would apply to both the first and second decisions. We did not formulate any hypothesis about the question of whether there might be differences between the levels of signaling, i.e., the signaling of trees and plants (which tended to be at or above standing height) and the signaling about the soils and less visible information (which tended to be at ground level). Both signaling levels are important in order to infer the wealth of biodiversity in the explored area.

H3: We predicted that the information feedback provided after the first decision would have a positive effect on performance on the second decision. Information feedback about the forest elements relevant for building a mental model of the ecosystem of the visited forest areas would help participants to make the correct decision. Naturally, the provided information did not indicate which area had the richest ecosystem and biodiversity. However, it did provide an informative description of specific, task-relevant, information about the forest elements present in the area (types of trees, plant species, soil types, animals, fungi and mushrooms etc.).

H4: We expected to observe an interaction between signaling and feedback on decision performance, with learners in the signaled conditions outperforming those in the non-signaled condition for the second decision after the feedback. The internal matching between the stored task-relevant information before the feedback and the relevant information provided by the feedback would be facilitated in the signaled conditions, thus facilitating the elaboration of a high-quality mental model of the various forest ecosystems. In the non-signaled condition, learners might store both irrelevant and relevant ecosystem-related information before the feedback, making internal processing of the feedback more difficult and potentially producing subsequent interference.

H5: Regarding justifications, we expected a higher number of correct justifications of decisions made in the signaled conditions than in the non-signaled condition. Furthermore, signaling was expected to increase the number of justifications based on considerations of ecosystem biology rather than justifications based on human wellbeing and comfort. Finally, regression and covariance analyses were run to explore the relations between subjective measures, and in particular realism, presence and immersion, perceived task facility-difficulty, usability of the environment's functionalities and decision performances in the four experimental conditions. This led to H6, namely an expected significant covariant relation between presence and performance, which would be consistent with the immersion principle (Makransky, 2022).

2 Method

2.1 Participants and design

Eighty-nine students from a French agricultural college took part in this study (average age: 16.19 years, 39 girls and 50 boys, respectively 43.82 and 56.18%). Their curriculum was composed of a common core including general subjects (French, Math, English, Life and Earth Sciences) and two important special options: agricultural production technology and development and outdoor space enhancement with a focus on forestry. Four of the college's classes were invited to take part in this experiment, i.e., two classes per grade: two 10th-grade classes and two 9th-grade classes. The experimental design involved four groups with two between-subjects factors corresponding to the two signaling levels factors (2×2). One group saw no signaling (no-signal group, $n = 23$), i.e., there was no highlighting of the task-relevant trees and plants by means of flashing colors (F-) and no signaling marker stones on the ground (S-, see Materials section for details); two groups saw either the flashing (highlighted) task-relevant trees and plants ($n = 21$) or the signaling marker stones on the ground ($n = 22$) (F+S- or F-S+, respectively); one group saw both signaling levels, i.e., both the flashing trees and plants and the marker stones on the ground ($n = 23$, F+S+). Feedback was the within-subjects factor for each of the four groups. The 89 students were randomly assigned to the four groups and the groups were matched on prior knowledge, spatial orientation ability and grade (see below).

Previous research into the benefits of signaling on learning or training performances has indicated small to medium effect sizes (see above, Section 1.1). We conducted two power analyses based on a medium effect size for a two-way ANOVA analysis, e.g., with two between-subjects factors corresponding to the two levels of signaling and feedback as a within-subjects factor. A compromise power analysis (compute implied α and power, given the β/α ratio, sample size and effect size) performed with G*power 3.1 (Faul et al., 2007) indicated a β/α ratio of 1 and a power (1- β err.prob.) reaching 0.83 with a sample of 89 participants for an effect size *f* of 0.25. A sensitivity power analysis was also performed with G*Power (3.1, Faul et al., 2007) to estimate the minimum effect size that could be detected by a factorial ANOVA with the four groups ($N = 21$ to 23). This analysis indicated that a medium effect size *f* of 0.28 would be detectable with the current sample size. We used Cohen's conventions defining small ($d = 0.20$, $\eta p^2 = 0.02$, $f = 0.10$), medium ($d = 0.50$, $\eta p^2 = 0.13$, $f = 0.25$) and large ($d = 0.80$, $\eta p^2 = 0.26$, $f = 0.40$) effects (Cohen, 1988).

The experiment included two sessions: (i) a paper-and-pencil-based pre-test session, (ii) a learning (training) IVR session, which was immediately followed by decision 1 (with justification, performance on post-test 1) before feedback was provided and decision 2 made (with justification, performance on post-test 2). Finally, the subjective post-test questionnaires were administered.

The paper-based pre-test session took place in the classroom and the IVR session in a special large room used for virtual reality teaching (see Figure 2). During the pre-test session, students completed a series of tests to assess their working memory and spatial skills and answered a prior knowledge questionnaire on the subject of the IVR exploration: the forest ecosystem. Students' performance on these tests and their average grade scores in agricultural disciplines, including ecosystems theme, were used to create four homogeneous groups (with $N = 21$ to 23 participants per group) corresponding to the four IVR forest conditions. In the second session, which took place between one and three weeks later, students individually explored and interrogate the forest space in virtual reality using an IVR headset (HTC Vive).

This exercise, involving the learning by exploration of forest areas, was followed by a first decision task. Feedback was then provided, followed by the second decision task. Finally, each participant completed a series of questionnaires: (i) the subjective scales about the IVR experience, (ii) a demographic questionnaire. Each session lasted approximately 60 min and the total duration of the experiment was 120 min. The first session was conducted as a whole class, whereas the participants performed the second session individually. At the end of the first session, students were informed that they would participate in a second immersive virtual reality session, but they were not informed of the nature and content of the task they would have to complete.

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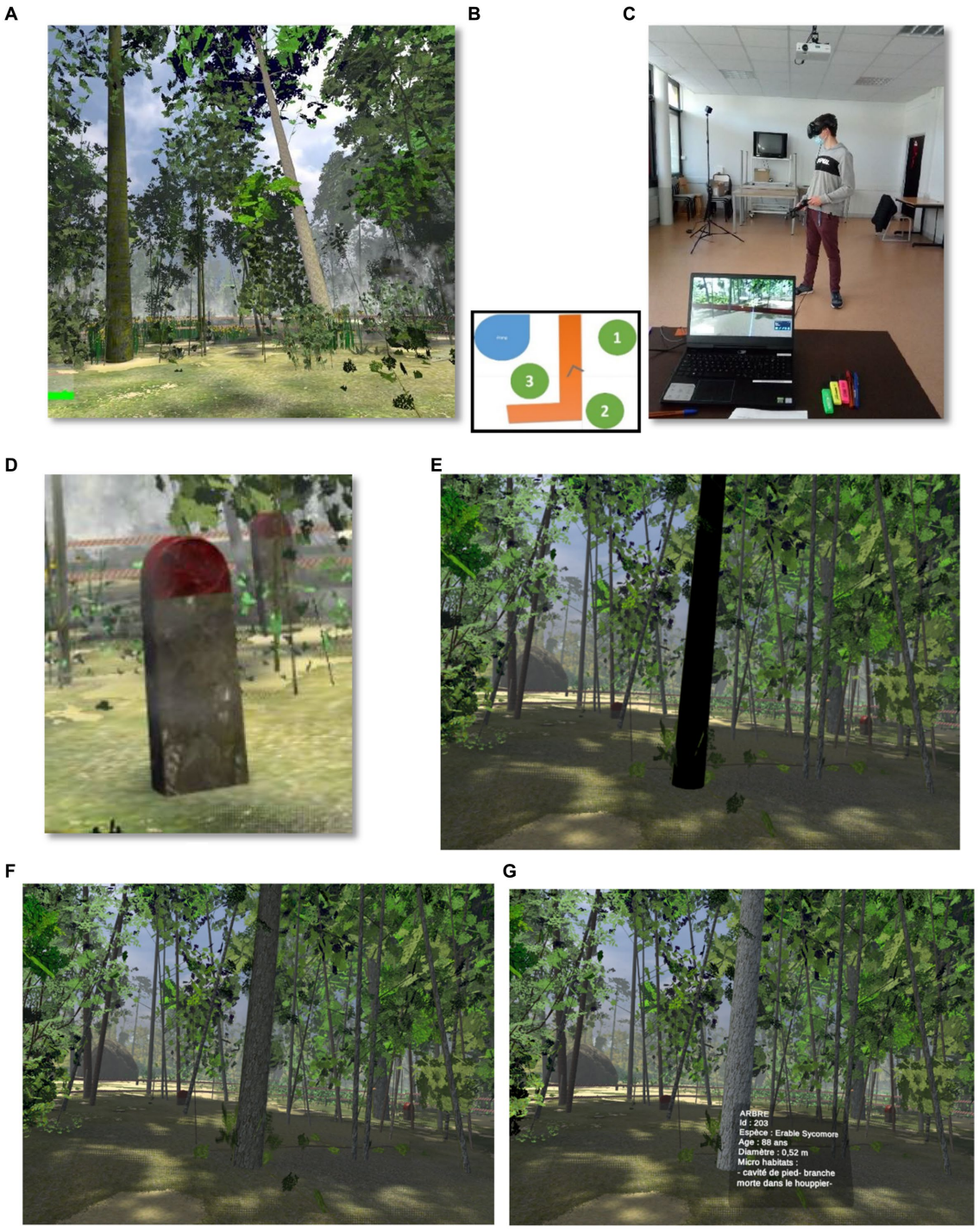

FIGURE 2
Snapshots of the IVR environment with **(A)** a forest area; **(B)** a reproduction of the map accessible in the virtual environment, including a body of water (blue), the three zones (green) and a path (orange); **(C)** a participant during the task; **(D)** an example of a marker stone, with the textual information which popped when targeted and selected; **(E, F)** an example of a flashing tree, and **(G)** in white, the textual information which popped on a targeted and selected tree: Tree; Id: 203; Species: Sycamore Maple; Diameter: 0.52 meter; Microhabitats: root cavity, dead branch in crown.

2.2 Learning material and experimental equipment

2.2.1 Pre-tests

During the pre-test session, participants completed three paper-based tests in order to allow us to form homogeneous controlled experimental groups: (i) a spatial orientation test; (ii) a verbal working memory test and (iii) a prior knowledge test. As it can sometimes be difficult to orient oneself in space when immersed in a VR environment, (see Drai-Zerbib et al., 2022; Mayer et al., 2022), we also asked the participants to perform a spatial orientation test. The spatial orientation test was a French translation of the "Perspective Taking/

Spatial Orientation Test" developed by Hegarty et al. (2008). This test was composed of 12 items organized as follows: various objects, such as a car, a house, a cat or a flower, were depicted on a half-page. An instruction displayed below the images asked the participants to imagine themselves in the place of one of the pictures, look at another picture, and from there determine the location of a third item. To answer, they had to draw a line in a circular dial located under the instruction and were given 5 min to complete the twelve items. The Danneman and Carpenter (1980), adapted into French by Desmette et al. (1995), was used to assess the verbal working memory span. In this test, participants are asked to listen to a series of orally presented sentences. At the end of each set of sentences, they must recall the last word of each sentence in the set. Each set consists of 2, 3, 4, 5, or 6 sentences. The participant must therefore listen to the sentences and keep the last word of each sentence active in working memory. The participants in our study had to listen to the series of sentences and then write down the last word of each sentence in the answer booklet, but only after receiving the "go" signal. Two scores were calculated from the students' responses: the more demanding criterion for scoring the responses was the number of completely successful sets of sentences (without errors or missing words, out of 15), and the less demanding criterion was the number of words correctly and completely recalled in the correct order in all sets of sentences (max. 40). Both scores were transformed into percentages and we used the average of the two scores for data analyses.

The factual knowledge pre-test consisted of two open-ended questions: (i) Define as precisely as possible what a forest ecosystem is, what its characteristics are; (ii) With reference to the ecosystems present, what is the best way to manage a forest area?

We chose this question format, firstly because it uses the types of questions usually asked by teachers to students, and also in order to avoid influencing the answers given during the following experimental phase. Indeed, proposing MCQ encompassing biodiversity, soil characteristics and management of the forest environment could have led the students to reason differently and give different answers during the IVR exploration. In addition, this type of production and generative task is thought to have more discriminant power than an MCQ-type questionnaire (Mayer and Fiorella, 2022).

To rate these written accounts, we developed a coding criteria matrix based on the answers given by a specialist, the life science student's teacher, to these questions. We used the 10 main criteria (together with their definitions) provided by the teacher: diversity, human intervention, adaptation of flora and fauna (appropriateness), dynamic system, biotope, interaction between species, renewal cycle, stable environment, sustainability of the environment. Each criterion was scored out of 1 as follows: 1 point was awarded to the student when the criterion was present and defined completely correctly; 0.5 points were awarded when the criterion was mentioned by the student in an undeveloped or imprecise way and 0 points were awarded when the criterion was absent or wrongly defined and explained. The experimenter coding of these written data was double checked by the specialist teacher. The scores out of 10 were transformed into percentages for statistical analysis. The prior knowledge pre-test was followed by a demographic information questionnaire that included questions about the participants' age, gender, use of computers and digital tools such as social networking and video games. We also asked them if they wore glasses and if they knew of any learning disabilities.

2.2.2 Learning material

To permit the use of the HTC Vive HMD IVR headset, we delimited a nine square meter exploration area using sensors installed on tripods at a height of 2 meters. These two sensors were arranged diagonally across the room, each marking the corner of a 3-meter square. This surface was set up and calibrated using the controllers on a Windows 10 "gaming" computer running SteamVR software. This action area allowed users to move safely through an obstacle-free zone. To indicate the boundary of the exploration area, a blue grid appeared in the headset as the user approached it. In this way, users could reorient themselves to stay safely within the boundary while they were exploring and analyzing the forest areas. The environment proposed a simulation-reproduction of typical forest plots of varying ages that can be found in real forest environments in France (see Figures 1, 2). The numerical model and algorithms of the forest environment were based on an agronomic and biological model of forest development built in cooperation with scientific experts and a research laboratory specializing in image computing and AI. The VR implementation was made with Unity.

The aim was to immerse learners in this forest environment so that they could explore and analyze various forest areas featuring the different elements present (different types of trees, herbaceous plants, microhabitats, types of soils with various humidity levels, see below) in order to make a diagnosis of the forest ecosystem spaces and authorize or prohibit the installation of structures intended to welcome walkers and visitors, while having only minimal impact on the ecosystems of the visited forest areas. The students arrived at their diagnosis of the ecosystem by exploring and analyzing three forest areas while also extracting – i.e., targeting and selecting – and linking relevant elements. This enabled them to decide in favor of or against the installation of a public reception area, such as a forest observatory with a picnic area. This task met our needs in terms of research on the cognitive processes related to learning in immersive virtual reality environments and also dovetailed with the pedagogical needs of the learners in their field practice related to their future professional activity.

The students were welcomed individually by one of two experimenters, each accommodated in a room dedicated to virtual reality experimentation in the college. The two rooms were each equipped with a computer running the experimental software and an HTC Vive HMD.

In order to familiarize each participant with the forest environment and the ways in which they could interact with this environment using the controllers, a tutorial including a simple task in some very simple natural areas was administered prior to the main task.

The tutorial was composed of three areas delimited by barriers (boundaries). Each of the areas had a marker stones and an herbaceous plant. The goal was to allow the students to become familiar with the IVR environment and with the control options made possible by the joysticks, such as targeting and selecting an element or moving from one area to another, without immediately immersing them in the forest environment.

The main virtual environment: This consisted of three areas or zones within the virtual forest. The student's task was to learn by exploring and analyzing these three zones. While doing so, they consulted (targeting-selecting) the different elements present in each zone (trees, shrubs, herbaceous plants, fungi, soils) and learned their

specific characteristics. The students could walk in the area and move around by teleporting into the environment using the joysticks. They could also consult and select items and also cancel these selections.

Each element consulted, targeted and selected was automatically recorded by the computer. A variety of tree species with a wide range of ages and heights was present in each of the three areas: oak, ash, spruce, beech, maple, elm, hornbeam, alder. Regarding the layout of the different zones, the number and types of trees, their ages and heights, as well as the types of shrubs, herbaceous plants, microhabitats, soils, were strictly controlled, naturally in the light of the level of biodiversity of the ecosystem of each of the three areas. The visual density of the trees and plants was also balanced across the three areas. In Zone 1, a wetland was located near a water body and was partly composed of highly biodiverse elements specific to marshy soils, such as iris, ferns, beech and elm trees. A second area, Zone 2, was located away from the water body and had stable soil with moderate biodiversity: mostly oak but also hawthorn, spurge, beech, maple. The third zone was located between the other two zones and had stable soil and rich biodiversity: hawthorn, spurge, maple, ash, hornbeam, beech, oak and spruce. Microhabitats could be found in all three zones and were composed of polypore fungi and mushrooms, woodpecker cavities, dead trunks on the ground etc. Thus, the level of biodiversity was high in each of the zones, preventing the task from being too simple and instead requiring a fine-grained analysis of the area of vegetation (trees, plants etc.) of wood.

This controlled diversity and fine-grained difference in terms of biodiversity (scarcity of plant species, competition between trees, and number of "interesting" trees, e.g.: straight, balanced, vigorous and of high productive value of wood) and soil stability between the three areas required an in-depth analysis of the elements present in each area in order to come to a reasoned decision after the environment had been fully explored. At the end of the period of IVR exploration, each participant had to decide which of the three zones could be used to build a public reception area that made the least possible impact on the ecosystem and biodiversity of the forest (see below).

Each zone was delimited by barriers, and only the elements located inside these three zones were available for consultation. Each zone was composed of approximately 30 trees, 15 shrubs and 20 herbaceous plants present in similar densities (including a visual impression of similar density) in order not to influence the students' responses. Each zone was generated by a software program reproducing the real forest balance specific to the type of zone created. At any point during the exploration of the forest areas, the students were able to access a map via the trigger on the controller in order to find their way around the virtual environment (Figure 2B). An arrow indicated the student's position and orientation in real time. Each area had a number on it, allowing the students to find their way around and then subsequently communicate their choices. Three types of numbering were programmed and counterbalanced, as was the order of exploration of the three zones.

Each of the forest elements could be targeted, viewed and selected with the joysticks. Once the element was targeted, a tooltip gave the following written information: the type of element (for example, tree/shrub/herbaceous plant etc.) and its name. For the trees, the information provided consisted of the tree species (type of tree, e.g., oak, beech, alder etc.), its age, diameter, and the presence of dead branches in the crown, microhabitats, woodpecker cavities, polypore fungi and mushrooms or foot cavities (Figure 2G).

In the signaling conditions, whether F+S+, or F+S- F-S+, elements relevant for ecosystem diagnosis were signaled. As mentioned above, two signaling levels were created using a 2×2 design with four groups. The first level was that of trees, shrubs and plants. The signals on the relevant elements consisted of contrasting flashing colors, F. In flashing mode (Figures 2E,F), the elements flashed one after the other, getting darker and then lighter until the student targeted and looked at them. The flashing signals did not prevent participants from identifying the element, a tree for example, from its visual appearance (such as its texture and color). Once the student had looked at an element, it stopped flashing and the student had to look for the next flashing element.

The second signaling level was that of soil information as well as of less visible or invisible information (such as soil moisture, for example). The signals took the form of marker stones S, which were placed at specific locations in each zone (Figure 2D). Once targeted, the marker stones provided written information about the environment that was not directly visible, such as: stable soil, wet soil, presence of frogs, dragonflies, and garter snakes. However, in the non-signaled control condition, F-S-, the same information was accessible and could be obtained by targeting the relevant forest element with the joystick. The verbal justifications given by the students both during and after their periods of exploration were recorded with a voice recorder during the entire experimental phase: (i) during the learning-by-exploration phase and (ii) when explaining the two decisions, before and after the feedback. These verbal justifications were transcribed and the arguments given for each targeted and selected element were listed for each participant. We recorded the total number of elements selected by each student during their exploration and for the two decisions, i.e., before and after the feedback.

2.2.3 Feedback materials

The feedback (Figure 3) consisted of three A4 multimedia documents, with one page per forest area. Each page consisted of a screenshot of a characteristic frame of the relevant area and a written summary description (approximately 50 words, see Figure 3) of the area's most important characteristics (types of trees and plants, soil properties – for example soil moisture and soil stability – presence of micro-habitats and animals). This feedback was presented after the learners had made their initial decision in order to allow them to confirm or change it. The information text presented together with the picture was intended to allow them to compare the information stored in memory during the learning-by-exploration phase with the information presented in the feedback and establish internal relations between them. We thought that these relational and comparative activities might make learners aware of the presence of relevant forest elements that they might not have noticed during the exploration phase. They could thus compare the different areas with each other and interpret the role of potential new elements in the light of those found during the IVR exploration.

2.2.4 Subjective scales

Finally, we administered post-test subjective scales presented in a questionnaire about the IVR experience. This consisted of 10 scales (see Appendix A) intended to assess ten items inspired by the CAMIL model and based on the multimodal virtual scale for virtual reality published by Makransky et al. (2017), and in particular on two of the

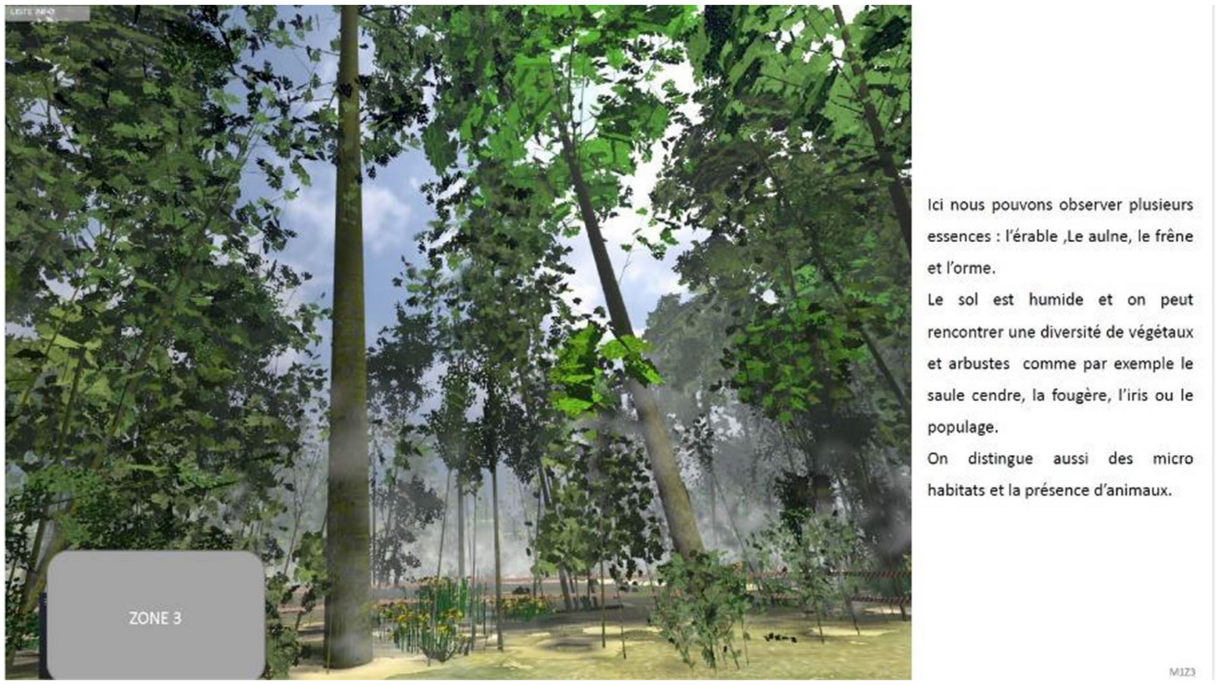

FIGURE 3
Example of multimedia feedback given to the students. Here is the English version of the textual information on the right of the picture: "Here, we can observe several species: maple, alder, ash and elm. The soil is moist, and a variety of plants can be encountered, including ash willow, fern, iris and marigold. There are also micro-habitats and the presence of animals".

three subscales of the overall questionnaire: physical presence and self-presence. However, although we kept the specific themes from the Makransky et al. (2017) scale, we did not always use the exact wording of the scale, as we were obliged to adapt the items to the particular characteristics of the forest environment and to the nature of the training task we had designed. The 10 items belonged to one of three categories: C1, Presence, including 4 items (immersion, realism, ease of recognition of forest VR elements, ease of graphical recognition); C2: Cognitive Complexity, Extrinsic, including 2 items: ease of movement in the environment, ease of use of interaction features (joystick, map, elements targeting and selection); C3: Cognitive Complexity, Intrinsic, including 2 items: cognitive complexity of exploration of the environment (navigation), cognitive difficulties in the use of specific knowledge about forest elements. In addition, there were two categories with one item each: C4: feeling of cyber sickness; C5: overall enjoyment. For each item, participants had to select a number on a scale from 1 to 5. The questionnaire ended with an open question: "Do you have any comments on the use of the program and virtual reality: strengths/weaknesses, other." For each of the categories C1, C2 and C3, we used the mean of the items of the category (out of 5).

2.3 Procedure

In total, the experiment took 120 min. The first session lasted 60 min. Participants completed the three pre-tests: the verbal working memory test, the spatial orientation test, and the prior knowledge test. They were also asked to complete a demographic questionnaire that included questions about their age, gender, use of computers and digital tools such as social networking and video games, and finally signed a consent form. They were also asked if they wore glasses and if they knew whether they had any learning disabilities. The tests were conducted as a whole class (with N: between 20 and 25 per class) using specific individual booklets and were supervised by three experimenters and a teacher. At the end of the session, the students were informed that they would be invited to a second session in which they would have to perform various activities. The second session took place one to three weeks after the first and also lasted 60 min. The students were received individually by one of the two experimenters. The sessions conducted by the two experimenters took place in parallel in two large rooms of the agricultural college. The experimenter explained the general course of the experiment to the student and then equipped her/him with the virtual reality headset (HTC Vive). The session started with a tutorial in which three uncluttered areas were delimited by barriers. Each of the areas had a shrub and a marker stones. Students were shown the joystick controls and then asked to look at the map, teleport in, look at an item, target and select it. When the learner was confident about using the equipment, he or she was asked to teleport to a specific area of the tutorial. This step took about 10 min depending on how comfortable the participant was with the equipment. The students were then given the task instructions: namely to explore and analyze the three zones and then, at the end of this exploration, to decide in which of them they would choose to set up a public reception facility including an equipped picnic area while respecting the forest ecosystem as much as possible. The students' task was to explore and visually analyze each area and to target and select the elements that seemed important to the task requirements. Each time they selected an element, they had to justify it. The students had 6 min to explore each zone, i.e., a total

of 18 min. When the 6 min were over, the experimenter told them which zone to go to next (counterbalanced order).

After exploring each area, the students removed the virtual reality headset and were asked to say where, in which of the three areas, they would locate the public reception and picnic area and to verbally justify the decision. They then sat at a table where feedback was presented. The experimenter provided the series of multimedia documents, i.e., images accompanied by a short explanatory text. They could then study the feedback images/text document (Figure 3) before making their second decision about the best area, allowing them to confirm their initial decision or change their minds. In both cases, they had to verbally justify the second decision. Finally, participants were asked to complete the subjective scales about their experience with the IVR. The experimenter remained available to answer students' questions at the end of the experiment and told them not to tell their classmates anything about the content or course of the experiment.

2.4 Criteria for coding decision answers

The data for the two decisions was coded by the specialist teacher (of the students' classes) and the two experimenters.

2.4.1 Criteria for decision coding

We assigned a score between 0 and 1 to each of the two decisions based on the following criteria: 1 point was awarded when the choice of the zone and the corresponding justifications were correct; 0.5 point were awarded when the choice was correct and the associated justifications were partially correct; 0 point when the area chosen was not the correct one or when the area chosen was the correct one but the justifications produced by the student were wrong or absent.

2.4.2 Criteria for coding verbal justification data

To analyze the justification data, we recorded (i) the total number of arguments given by students during the exploration of the virtual forest, and (ii) the number of arguments given during their first and second decisions. For each argument, we coded (i) the correctness of the argument and (ii) the nature of the argument. For correctness, we determined whether the argument was true, false, partial or absent. We assigned a point to the corresponding category (or categories), i.e., true, false, partial, no argument. An argument was considered true when the explanation corresponding to the item was correct, and false in the opposite case. An argument was considered partial when the student provided an incomplete argument. An absence of argument was noted when the student could not justify his or her choice when selecting the element or when making the decision, e.g., "*I know it's important, but I cannot explain why*." For the nature of the arguments, we noted the number of arguments given in favor of preserving the ecosystem, – "eco-system protection" argument- and the number of arguments given in favor of human well-being in the environment, – "human welfare" argument. Human welfare arguments may conflict with biological arguments in the field of ecosystem preservation. We distinguished between the three different justification times: area exploration time, first decision time (decision given immediately after exploration), and second decision time (decision given after feedback). The coding of these written data was checked by the specialist teacher.

2.4.3 Coding example for correctness and nature of arguments

"There are bacteria and fungi and mushrooms so it's not especially good for the human body, it's not very hygienic." Here, the argument was rated as false and also in favor of human welfare rather than biodiversity in the forest ecosystem.

"I do not know if it's beneficial or not, but there are microhabitats, so if after the presence of humans and all that, it takes everything away, it's important to preserve it." This argument was rated as partial, in favor of protecting the forest ecosystem.

"Holly is not useful so we are taking it out." This argument was rated as false (holly is a protected species).

Stable soil marker: *"Well, the soil structure is good. There is no risk of soil collapse or settling."* Here the argument was rated as true.

2.4.4 Statistical analysis of data

Factorial, mixed ANOVAs and analyses of covariance ANCOVAs were performed to analyze the data. Regression analyses were also conducted in order to analyze the effect of the controlled factors and subjective scales on decision performance. Because the dependent variable "decision accuracy of choices 1 and 2" (including decision answer + justification) varied from 0 to 1 for each decision time, we additionally verified the main results of the ANOVAs by conducting nonparametric, rank-order, Kruskal-Wallis ANOVAs. For all analyses presented in this study, we used $p < 0.05$ as the criterion for significance. Partial eta squared (ηp^2) and Cohen's d values are provided as effect size measures for all main effects, interactions, and *post hoc* comparisons. The ηp^2 values of 0.01, 0.06, and 0.14 represent small, moderate, and large effect sizes, respectively (Clark-Carter, 2004), and the Cohen's d values of 0.20, 0.50, 0.80, and 1.3 represent small, moderate, large, and very large effect sizes, respectively.

TABLE 1 Means (and SD) for each contolled factor (prior konwledge, school grade, working memory, spatial oroientation abilities) in the four experimental signaling conditions, F+S+, F+S-, F-S+, F-S-.

Signaling conditions Participants number: *N*	F+S+	F-S+	F+S-	F-S-
	N = 23	*N* = 22	*N* = 21	*N* = 23
Prior knowledge score /10	1.85 (1.02)	1.84 (0.86)	1.50 (0.50)	1.52 (0.68)
School grade /20	11.86 (1.84)	12.03 (1.50)	12.26 (1.45)	12.68 (1.71)
Daneman & Carpenter WM test Correctly recalled words / 40	34.43 (3.35)	33.30 (3.62)	34.37 (4.20)	33.64 (3.38)
Hegarty's spatial orientation test /12	6.42 (3.32)	6.99 (2.24)	6.46 (3.55)	6.63 (2.45)

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TABLE 2 Means and SD for, respectively, the number of selected elements and the decision performances before and after the feedback in the four experimental signaling conditions, F+S+, F+S-, F-S+, F-S-.

Signaling conditions Participants number: *N*	F+S+ *N* = 23	F-S+ *N* = 22	F+S- *N* = 21	F-S- *N* = 23
Mean number of *selected (targeted) forest elements* during the exploration phase (sum for the three areas)	50.89 (29.25)	85.51 (60.73)	35.98 (13.87)	83.37 (70.42)
Decision ratio (correct justification): *decision 1, Before feedback*	0.70 (0.33)	0.82 (0.29)	0.43 (0.45)	0.24 (0.33)
Decision ratio (correct justification): *decision 2, After feedback*	0.87 (0.22)	0.77 (0.30)	0.83 (0.33)	0.56 (0.38)

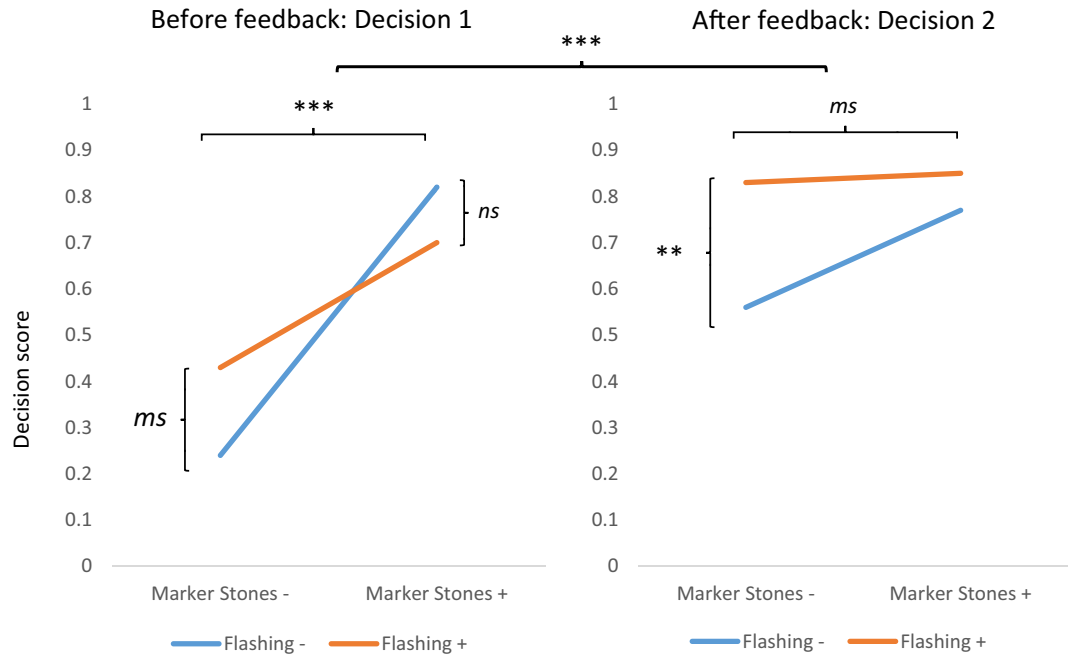

FIGURE 4
Mean decision scores in each signaling condition: for decision 1 before the feedback and decision 2 after the feedback, respectively. Statistical *p* values: ***$p < 0.0001$; **$p < 0.01$, *ms* = marginally significant, $p < 0.10$, *ns*, no significant.

3 Results

3.1 Controlled factors

Controlled factors help prevent potential biases when constituting reliable experimental samples. The results for the four controlled factors, prior knowledge, average school grade, verbal working memory span and spatial orientation abilities, are presented in Table 1 for each experimental condition.

No significant effect, main effect or between-groups comparisons were found for any of the four measures in the four ANOVAs conducted, respectively; (i) for the prior knowledge score, $F(3,85) = 1.29$, $p = 0.28$, $\eta p^2 = 0.04$, and when the two most different groups were compared (e.g., F+S+ vs. F+S-, Table 1), $F(1,85) = 2.08$, $p = 0.15$, $d = 0.43$; (ii) for the average school grade, $F(3,85) = 1.10$, $p = 0.35$, $\eta p^2 = 0.04$, and when the two most different groups were compared (e.g., F+S+ vs. F-S-, Table 1), $F(1,85) = 2.92$, $p = 0.10$, $d = 0.46$; (iii) for the verbal working memory test score, $F(3,85) = 0.51$, $p = 0.67$, $\eta p^2 = 0.017$, and when the two most different groups were compared (e.g., F+S+ vs. F-S+, Table 1) $F(1,85) = 1.06$, $p = 0.30$, $d = 0.32$; (iv) for the spatial orientation test $F(3,85) = 0.17$, $p = 0.91$, $\eta p^2 = 0.006$, and when the two most different groups were compared (e.g., F-S+ vs. F+S+, Table 1) $F(1,85) = 0.43$, $p = 0.51$, $d = 0.20$. The four groups were homogeneous on the four controlled factors.

3.2 Information selection during exploration of the environment and effect of signaling on decision performances

Results are presented in Table 2 and Figure 4.

Regarding the number of selected elements, the factorial ANOVA with flashing and marker stones as two between-factors showed that the number of selected elements was significantly lower when first-level signals, i.e., flashing, were present $F(1,85) = 13.09$, $p < 0.001$, $\eta p^2 = 0.15$. As expected, this result reveals that this signaling level directly affects the attention learners pay to relevant information. However, with regard to the second level of signaling, the effect of the presence of marker stones was not significant, $F(1,85) = 0.57$, $p = 0.45$, $\eta p^2 = 0.007$.

With regard to decision performances, a mixed ANOVA with flashing and marker stones as two between-factors, and feedback,

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TABLE 3 Mean number of arguments (and SD) provided in each phase of the task (exploration time, decision 1 before feedback, decision 2 after feedback) and for each type of argument (true, partial, false, absent and biodiversity or human), in the four experimental signaling conditions, F+S+, F+S-, F-S+, F-S-.

Task stage	Condition Argument type	F+S+ *N* = 23	F-S+ *N* = 22	F+S- *N* = 21	F-S- *N* = 23
Exploration time	True	**4.56 (3.90)**	**3.05 (2.33)**	**3.38 (3.23)**	**3.04 (3.75)**
	Partial	9.83 (4.61)	8.71 (5.26)	8.90 (4.50)	9.35 (4.44)
	False	2.13 (2.07)	1.62 (1.46)	0.71 (1.05)	1.43 (1.62)
	Absent	5.52 (4.50)	4.19 (4.39)	6.47 (6.64)	5.60 (4.81)
	Biodiversity	**7.39 (4.45)**	**4.27 (3.25)**	**6.52 (6.62)**	**3.96 (3.28)**
	Human	2.26 (3.27)	2.27 (2.43)	0.81 (1.56)	0.82 (1.46)
Decision 1 before feedback	True	**1.52 (1.08)**	**1.31 (1.13)**	**0.52 (0.75)**	**0.56 (0.78)**
	Partial	1.65 (1.19)	1.04 (0.78)	1.86 (0.85)	1.48 (1.12)
	False	0.17 (0.49)	0.18 (0.66)	0.28 (0.47)	0.52 (0.67)
	Absent	0.35 (0.65)	0.27 (0.70)	0.48 (0.81)	0.30 (0.47)
	Biodiversity	**1.09 (0.99)**	**0.77 (0.92)**	**0.76 (0.83)**	**0.48 (0.73)**
	Human	0.04 (0.20)	0.14 (0.35)	0.38 (0.59)	0.26 (0.62)
Decision 2 after feedback	True	**1.09 (1.24)**	**0.54 (0.86)**	**1.67 (1.24)**	**0.91 (1.08)**
	Partial	0.69 (0.93)	0.23 (0.53)	1.09 (0.99)	1.08 (1.04)
	False	0.01 (0.01)	0.09 (0.29)	0.14 (0.48)	0.35 (0.77)
	Absent	0.001 (0.001)	0.09 (0.30)	0.28 (0.64)	0.08 (0.42)
	Biodiversity	**0.74 (0.75)**	**0.41 (0.85)**	**1.14 (1.15)**	**0.69 (0.76)**
	Human	0.08 (0.29)	0.04 (0.21)	0.28 (0.29)	0.13 (0.34)

measured on the basis of decision 1 before feedback and decision 2 after feedback, as dependent repeated measures indicated a significant positive main effect of the marker stones signaling level $F(1,85) = 18.91$, $p < 0.0001$, $\eta p^2 = 0.18$; a marginal main effect of the flashing signaling level, which failed to reach significance, $F(1,85) = 2.97$, $p = 0.088$ $\eta p^2 = 0.03$; and a strong main effect of feedback, $F(1,85) = 41.64$, $p < 0.00001$, $\eta p^2 = 0.33$. The interaction between flashing and marker stones revealed a marginal effect, $F(1,85) = 3.72$, $p = 0.057$, $\eta p^2 = 0.042$ (see Figure 4 for a better visual representation of the interactions). This interaction showed that in the absence of marker stones, tree/plant flashing improved decision performance, whereas it induced no change in performance when marker stones are present.

Furthermore, the interaction between feedback and flashing was significant, $F(1,85) = 5.01$, $p = 0.027$, $\eta p^2 = 0.055$, as was the interaction between feedback and marker stones, $F(1,85) = 20.46$, $p < 0.0001$, $\eta p^2 = 0.19$. While a positive effect of the presence of the tree/plant flashing signaling level was observed on decision 1, this positive effect increased significantly after the feedback for decision 2. In addition, the detrimental effect of the absence of marker stones level-2 signaling was largely compensated for by the feedback.

Two factorial ANOVAs were conducted to explore the performances on each decision. One ANOVA was performed for each decision, with the two levels of signaling, i.e., tree/plant flashing and marker stones, as the two between-factors and decision 1 or 2 as the dependent measure.

For decision 1, a main effect of the presence of marker stones was found, $F(1,85) = 31.53$, $p < 0.00001$, $\eta p^2 = 0.27$, whereas there was no effect of the presence of flashing, $F(1,85) = 0.20$, $p = 0.65$, $\eta p^2 = 0.002$ but a significant interaction between flashing and marker stones, $F(1,85) = 4.29$, $p = 0.04$, $\eta p^2 = 0.05$. The analysis of this interaction revealed a marginal significant difference in favor of the presence of flashing when there were no marker stones, $F(1,85) = 3.12$, $p = 0.08$, $d = 0.47$; but when marker stones were present, no difference was observed whether flashing was present or not, $F(1,85) = 1.34$, $p = 0.25$, $d = 0.39$.

For decision 2, the ANOVA revealed a main effect of flashing $F(1,85) = 7.58$, $p = 0.007$, $\eta p^2 = 0.08$, a marginal effect of the presence of marker stones $F(1,85) = 3.38$, $p = 0.07$, $\eta p^2 = 0.04$, and no interaction between the two factors $F(1,85) = 1.67$, $p = 0.20$, $\eta p^2 = 0.02$.

Finally, in order to extend and improve the reliability of these analyses, which were conducted with dependent measures including a three-point scale (e.g., 0, 0.5, 1) for each decision (e.g., 5 point scales for the two decisions), we subjected each decision to a between-groups Kruskal-Wallis ANOVA, non-parametric by rank. These analyses confirmed the previous results. For decision 1, significant differences between the four groups were found, $H(3, N = 89) = 26.03$, $p < 0.00001$, with the following mean Rank order: F-S-, R = 27.26; F+S-, R = 38.47; F+S+, R = 53.48; F-S+, R = 60.90. For decision 2, significant differences between the four groups were also found, $H(3, N = 89) = 11.27$ $p = 0.01$, with the following mean Rank order: F-S-, R = 32.28; F-S+, R = 45.13; F+S-, R = 51.19; F+S+, R = 51.93.

Taken together, these results for decision performances after the learning-by-exploring phase suggest a significant trend toward a cumulative positive, bounded effect (see Table 1) of the two signaling levels. This point will be further discussed in the final section.

TABLE 4 Means (and SD) for each of the subjective scale categories and items (out of 5 points) for presence, cognitive complexity-extrinsic, cognitive complexity-intrinsic, sickness and enjoyment in the four experimental signaling conditions, F+S+, F+S-, F-S+, F-S-.

Task stage	Condition Scale items	F+S+ $N = 23$	F-S+ $N = 22$	F+S- $N = 21$	F-S- $N = 23$
Presence 1: low; 5: high	Immersion	4.23 (0.79)	4.12 (075)	4.33 (0.86)	4.22 (0.52)
	Realism	3.58 (0.83)	3.28 (0.92)	3.38 (0.97)	3.36 (0.57)
	Recognition Elements	3.86 (1.01)	3.56 (0.95)	3.90 (0.83)	3.90 (0.73)
	Recognition Graph	4.18 (0.72)	3.96 (0.49)	4.09 (0.62)	4.05 (0.64)
	Total Mean/5	3.96 (0.59)	3.73 (0.49)	3.93 (0.66)	3.88 (0.37)
Cognitive Complexity Extrinsic 1: difficult; 5: easy	Ease of movements	4.54 (0.72)	4.57 (0.56)	4.33 (0.79)	4.59 (0.78)
	Ease of interaction features	4.46 (0.72)	4.53 (0.57)	4.71 (0.46)	4.62 (0.48)
	Total Mean/5	4.50 (0.45)	4.55 (0.34)	4.52 (0.46)	4.59 (0.50)
Cognitive Complexity Intrinsic 1: easy; 5: complex	Navigation complexity	1.41 (0.72)	1.67 (0.69)	1.38 (0.74)	1.72 (0.81)
	Specific knowledge	3.23 (0.73)	3.36 (0.63)	3.28 (1.00)	3.32 (0.87)
	Total Mean/5	2.32 (0.51)	2.51 (0.48)	2.33 (0.58)	2.52 (0.67)
Sickness 1: none; 5: high level	Mean/5	1.14 (0.34)	1.39 (0.47)	1.24 (0.44)	1.23 (0.42)
Enjoyment 1: low; 5: high	Mean/5	4.45 (0.72)	4.27 (0.60)	4.28 (0.56)	4.32 (0.46)

3.3 Analysis of justifications

The results for justifications are presented in Table 3. The two types of justification criteria (respectively, quality: true, partial, false and absent, and theme of the argument: biodiversity and human well-being) were analyzed for exploration time, decision 1 and decision 2. Factorial ANOVAs were performed on the number of true arguments and on the theme of the argument -biodiversity- in each learning phase.

For the exploration phase, no effects were found on the number of true arguments, i.e., no main effect of flashing, $F(1,85) = 1.52$, $p = 0.22$, $\eta p^2 = 0.017$ or marker stones $F(1,85) = 0.79$, $p = 0.37$, $\eta p^2 = 0.009$, and no interaction between the two factors, $F(1,85) = 0.58$, $p = 0.44$, $\eta p^2 = 0.006$. However, for the theme of the argument, we found a main effect of flashing on the number of biodiversity arguments, $F(1,85) = 8.61$, $p = 0.0004$, $\eta p^2 = 0.09$, but no effect of the marker stones signals, $F(1,85) = 0.37$, $p = 0.54$, $\eta p^2 = 0.004$ and no interaction, $F(1,85) = 0.08$, $p = 0.78$, $\eta p^2 = 0.0009$. In addition, there was a difference between the most signaled condition (F+S+) and the non-signaled condition (F-S-): $F(1,85) = 6.50$, $p = 0.012$, Cohen's $d = 2.01$.

For decision 1, the factorial ANOVA revealed a main effect of marker stones on the number of true arguments, $F(1,85) = 17.82$, $p < 0.0001$, $\eta p^2 = 0.17$, but no effect of flashing, $F(1,85) = 0.11$, $p = 0.77$, $\eta p^2 = 0.001$, and no interaction [$F(1,85) = 0.44$, $p = 0.51$, $\eta p^2 = 0.005$]. For the theme of the argument, the number of biodiversity-based justifications was higher in the signaled conditions, i.e., for both flashing and marker stones (F+S+ and F-S+), but the differences failed to reach significance, respectively for flashing, $F(1,85) = 2.57$, $p = 0.11$, $\eta p^2 = 0.03$, and for marker stones $F(1,85) = 2.78$, $p = 0.09$, $\eta p^2 = 0.03$, and the interaction was also not significant, $F(1,85) = 0.0006$, $p = 0.93$. However, there was a difference between the most signaled condition (F+S+) and the non-signaled condition (F-S-): $F(1,85) = 5.55$, $p = 0.021$, Cohen's $d = 0.84$.

For decision 2, the factorial ANOVA showed, on the one hand, that flashing led to a significant increase in the number of true arguments after the feedback, $F(1,85) = 7.48$, $p = 0.007$, $\eta p^2 = 0.08$, and, on the other, that learners who did not see a marker stones during the exploration phase produced significantly more true arguments after feedback $F(1,85) = 4.005$, $p = 0.48$, $\eta p^2 = 0.045$. This is consistent with the strong significant effect of feedback on the elaboration of true arguments for decision 2. There was no interaction between flashing and marker stones [$F(1,85) = 0.20$, $p = 0.65$, $\eta p^2 = 0.002$]. Similar results were found for the theme of the argument. On one hand, flashing led to a significant increase in the number of true arguments after the feedback, $F(1,85) = 4.24$, $p = 0.042$, $\eta p^2 = 0.05$, while, on the other, learners who had not seen a marker stones during the exploration phase produced marginally more true arguments $F(1,85) = 3.35$, $p = 0.07$, $\eta p^2 = 0.037$. There was no interaction between flashing and marker stones [$F(1,85) = 0.10$, $p = 0.76$, $\eta p^2 = 0.001$].

3.4 Complementary subjective scales and performances

Results for the 5 categories of items (Presence, Cognitive Complexity -Extrinsic-, Cognitive Complexity – Intrinsic-, Cyber-sickness and Enjoyment) are presented in Table 4 (see Appendix A for the exact wording of the items).

Firstly, participants all understood well the scales, and at the descriptive level, the scores observed for the four groups were fairly similar. The subjective scores for presence are high (3.73 to 3.96/5), in particular for the item relating to the specific sense of immersion (4.12 to 4.33/5). As far as extrinsic complexity is concerned, learners found their experience easy (4.50 to 4.59/5). Intrinsic complexity was scored lower, not because of the complexity of navigation, which was judged to be easy (1.41 to 1.72/5), but because of the perceived requirement for specific knowledge (3.23 to 3.36/5).

10.3389/fpsyg.2024.1359071

TABLE 5 Linear regression analyses for each of the five subjective scale items categories (presence, cognitive complexity-extrinsic, cognitive complexity-intrinsic, sickness and enjoyment) for decision 1 and decision 2. Main regression effects on decisions and interactions between subjective scale categories and signaling factors, respectively, flashing and marker stones. In bold, significant effects.

Scales items categories	Decision time	Main regression effect of subjective scale categories on decisions	Interactions between subjective scale categories and signaling factors: flashing and marker stones
Presence	Decision 1	**Presence: $F(1,81) = 4.91$, $p < 0.03$ $\beta = 0.21$**	Pres*flash: $F(1,81) = 0.32$, $p = 0.85$ Pres*marker stones: $F(1,81) = 0.51$, $p = 0.47$
	Decision 2	**Presence: $F(1,81) = 5.83$, $p < 0.02$ $\beta = 0.26$**	Pres*flashing: $F(1,81) = 0.19$, $p = 0.66$ Pres*marker stones: $F(1,81) = 0.25$, $p = 0.56$
Cognitive Complexity Extrinsic	Decision 1	Extrinsic Complexity: $F(1,81) = 0.1$, $p = 0.98$	ECompl*flash: $F(1,81) = 0.11$, $p = 0.73$ ECompl*marker stones: $F(1,81) = 0.33$, $p = 0.56$ **ECompl*Flash*marker stones: $F(1,81) = 5.00$, $p < 0.03$**
	Decision 2	Extrinsic complexity: $F(1,81) = 0.01$, $p = 0.99$	ECompl*flash: $F(1,81) = 0.20$, $p = 0.66$ ECompl*marker stones: $F(1,81) = 0.95$, $p = 0.33$
Cognitive Complexity Intrinsic	Decision 1	Intr-Complexity: $F(1,81) = 0.19$, $p = 0.66$	ICompl*flash: $F(1,81) = 1.31$, $p = 0.25$ ICompl*marker stones: $F(1,81) = 0.23$, $p = 0.63$
	Decision 2	Intr-Complexity: $F(1,81) = 0.10$, $p = 0.92$	ICompl*flash: $F(1,81) = 0.71$, $p = 0.40$ ICompl*marker stones: $F(1,81) = 0.040$, $p = 0.84$
Sickness	Decision 1	Sickness: $F(1,81) = 1.07$, $p = 0.30$	Sick*flash: $F(1,81) = 0.05$, $p = 0.82$ Sick*marker stones: $F(1,81) = 3.52$, $p = 0.07$
	Decision 2	Sickness: $F(1,81) = 0.037$, $p = 0.85$	Sick*flash: $F(1,81) = 0.30$, $p = 0.58$ Sick*marker stones: $F(1,81) = 3.12$, $p = 0.08$
Enjoyment	Decision 1	Enjoyment: $F(1,81) = 1.98$, $p = 0.16$	Enjoy*flash: $F(1,81) = 2.27$, $p = 0.13$ Enjoy*marker stones: $F(1,81) = 1.21$, $p = 0.27$
	Decision 2	**Enjoyment: $F(1,81) = 3.55$, $p = 0.063$, $\beta = 0.19$**	**Enjoy*flash: $F(1,81) = 5.92$, $p = 0.017$** Enjoy*marker stones: $F(1,81) = 0.52$, $p = 0.47$

Main regression effects on decisions and interactions between subjective scale categories and signaling factors, respectively, flashing and marker stones.

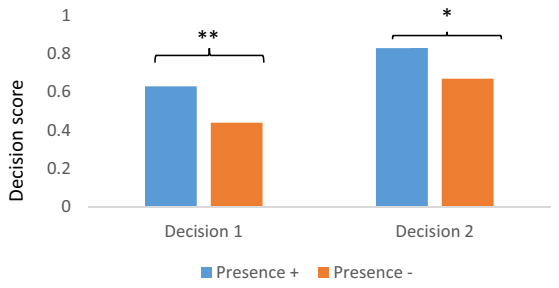

FIGURE 5
Mean performances (ratio) for decision 1 and decision 2, for participants with a high presence score (>the median = 3.87/5) and participants with a lower presence score (< the median of the group 3.87/5). Statistical p values: $^{**}p < 0.01$, $^{*}p < 0.05$.

While participants did not feel sickness (with low scores from 1.14 to 1.39/5), overall enjoyment was scored quite high (from 4.27 to 4.45).

Secondly, in order to explore the hypotheses, about the relation between decision performances and subjective experience of presence, perceived cognitive complexity, sickness and overall enjoyment, and especially H6, linear regressions with the homogeneity-of-slopes model were conducted for each of the five categories of measures, with the subjective score included as the continuous covariant predictor, the two signaling levels as between-subjects factors and the performance on decision 1 and decision 2 as the dependent variables. Models such as this can be used to test whether continuous predictors, as covariate moderators, have different effects at different level of categorical independent variables. For each regression, we included the interactions between the subjective factor and the signaling factors (i) tree/plant flashing and (ii) marker stones in the model. Such analyses could reveal a potential moderating effect of the perceived level of presence on decision performances.

The results of the regression analyses are presented in Table 5.

As shown in Table 5, positive significant effects of presence on performances for decision 1 and 2 were found, as was a marginal positive effect of enjoyment in decision 2. The effect of presence on performance was not significantly moderated by signaling. Enjoyment was positively influenced by flashing for decision 2. The main result for presence is summarized in Figure 5.

In order to analyze these results, we performed a factorial ANOVA with flashing, marker stones and presence group relative to the median, e.g., presence + vs. presence –, as between-subjects factors, and decision 1 and decision 2, respectively, as dependent variable. The analysis showed a main positive (medium size) effect of presence for decision 1, $F(1,81) = 6.18$, $p = 0.015$, $\eta p^2 = 0.07$, as well as for decision 2, $F(1,81) = 5.33$, $p = 0.023$, $\eta p^2 = 0.062$.

In sum, the results for the relation between performances and subjective presence scales are consistent with the immersion principle developed by Makransky (2022).

4 Discussion-conclusion

The goal of this research was to investigate the effect of the signaling and feedback principles in an IVR learning environment. To date, very little previous research has investigated signaling (Albus and Seufert, 2022; Zhang et al., 2023) and feedback (Stenberdt and Makransky, 2023) in learning in IVR environments and, to our knowledge, no study has tested the combined use of signaling and feedback. The results of the few previous studies are consistent with the large body of research conducted in multimedia learning that have shown a small to medium positive effect of signaling on learning, comprehension and transfer (de Koning et al., 2007, 2009, 2010a,b; Boucheix and Lowe, 2010; de Koning et al., 2011; Boucheix et al., 2013; Richter et al., 2016; Schneider et al., 2018; Alpizar et al., 2020). We designed two levels of signaling in the light of the CAMIL (Makransky and Petersen, 2021), CTML (Mayer, 2009) and APM (Lowe and Boucheix, 2008, 2016) models, and because of what we have speculatively called the *"sense of proprioceptive visuospatial comprehensiveness"* in IVR relative to the potential *"all-encompassing information sensation"* of IVR (see also, Naccache, 2020).

The goal of the signals was to enhance the structuring of forest elements at the ecosystem level during information processing, mainly in terms of their spatial location in the environment.

Regarding feedback, an information text was presented together with pictures of the forest areas in an on-screen multimedia document. The goal was to prompt learners to compare the information stored in memory during the learning-by-exploration phase with the information presented in the feedback and to establish relations between these elements. Making internal comparisons might make learners aware of the presence of relevant forest elements that they may not have noticed during the exploration phase. They could then compare the different areas with each other and interpret the role of potential new elements in the light of those found during the IVR exploration.

With regard to H1 and H2, the results of this vocational education and training task, in which the participants had to make decisions regarding a human intervention having a potential impact on an ecosystem in an IVR environment, showed a positive (medium size) effect of signaling on decision performances. Signaling not only reduced the number of relevant forest elements selected (indicating that signals efficiently direct students' attention toward the task-relevant information) but also significantly increased correct decision (decision + justification) performances.

As predicted by H3, a strong effect of informative feedback on decision 2 performances was found. This is consistent with the feedback principle in multimedia learning (Johnson and Marraffino, 2022). Additionally, and more interestingly, the interaction between signaling levels and feedback indicated that the levels of signaling had different weights at the two decision-making times, i.e., decision 1 after exploration, and decision 2 after feedback (H4).

For decision 1, the presence of marker stones (signaling soil properties, microhabitats) improved decision performance, whereas flashing (signaling tree and plant species) did not greatly affect decision performance; however, in the absence of marker stones, flashing did improve decision 1 performance. Decision performances were poorest in the no-signals condition. However, as shown in Table 2, the cumulative presence of both signaling levels did not change decision performance for this first decision compared to the marker stones-only signaling level.

For decision 2, which was given after the informative feedback, the positive effect of flashing significantly increased decision performances, and the detrimental effect of the absence of the marker stones signaling level seemed to be compensated for by the feedback. In sum, the two levels of signaling both contributed to the elaboration of high-quality mental models of the ecosystems of the forest areas at different times during training.

While our results appear to favor the use of different levels of signaling in complex immersive environments because they allow students to better organize the relevant elements in these environments, there is such thing as too much, because the accumulation of too many signals could be counterproductive and increase cognitive load. Further research is still needed on this issue.

One interesting potential explanation of the interaction between signaling levels and feedback in decision performances might involve a two-step cognitive mechanism. (i) During the learning-by-exploring phase, signaling effectively directs learners' attention toward relevant information in such a way that the amount of task-relevant information to be stored and remembered (e.g., forest elements potentially relevant for ecosystem preservation) is reduced and more structured (compared to the no-signals condition); (ii) During the processing of the information in the feedback (multimedia document), the activation, retrieval from memory, and comparison of this selected, condensed information about the task-relevant concepts present in the feedback information could be enhanced. As a consequence, decisions are taken on the basis of higher-quality mental models of the ecosystems in the forest areas and are therefore more relevant. Of course, this explanatory hypothesis of interaction between signaling and feedback will require further empirical investigation.

As predicted by H5, the pattern of results regarding justifications was consistent with the decision performances. The two signaling levels, flashing and marker stones, had positive effects on the verbalization of true arguments focusing mainly on biodiversity, but again exerted these effects at different stages of the task, i.e., at decision 1 and decision 2. The presence of marker stones signals was more influential in decision 1, when the flashing level had only a marginal positive effect. However, the flashing level was more influential for decision 2. Furthermore, while the signaling conditions enhanced the production of more true arguments than the no-signal condition both before and, to a less extent, after feedback, the number of true arguments also increased in the no or less signaled conditions after the feedback. This trend was consistent with the effect of feedback on correct decisions. Finally, the effect of signaling on the correct justification of the selected elements was less significant in the exploration phase. This result appears logical and consistent with the idea that students were, at this stage, exploring the forest areas and then progressively building a mental model of the ecosystem of each area over time.

The relation between the complementary subjective measures of (i) presence, (ii) cognitive – extrinsic – ease of interactions, (iii) cognitive – intrinsic – task complexity, (iv) sickness, (v) enjoyment and decision performance was assessed. The main goal of the regression analyses, in which the signaling factors were included as moderators, was to identify the potential covariant relation between presence and decision performances (H6) within the framework of the immersion principle (Makransky, 2022). The main result showed a significant positive effect (medium size) of presence on decision performances for both, decision 1 and decision 2, a finding which is consistent with the immersion principle.

However, the non-significant interactions between signaling factors and presence indicated that the positive effect of presence on decision performances seemed to be unaffected by signaling (either marker stones or flashing). This is a potentially interesting result in itself, suggesting that adding guiding signals in an IVR environment does not seem to greatly disrupt the sense of presence. This should clearly be further investigated in follow-up experiments.

In sum, our main result seems consistent with the few previous studies that have investigated the signaling principle in IVR, showing its effectiveness in the same way as in multimedia screen-based presentations. Albus and Seufert (2022) and Zhang et al. (2023) tested the effect of verbal signaling, while we tested the effect of more visual cueing.

The present study also has some limitations. First of all, we did not use a typical "conventional multimedia learning lesson" but instead a more vocational learning -or training- task. This type of task is naturally of greater ecological interest, particularly in the context of recent changes in forestry training and student learning geared toward sustainable forestry management in response to global warming. However, the generalizability of the signaling principle should be also tested in more conventional IVR learning contexts.

Furthermore, the feedback provided to the students after the first decision, following the exploration phase, was limited to giving a "standard" multimedia information about the composition of the forest areas (trees, plants, moisture etc.) in static text-picture digital documents presented outside of the IVR environment. As a consequence, the feedback was not part of the IVR experience. However, more realistic feedback presented as part of the IVR experience and dynamically showing realistically the effect of the decision on the ecosystem of the forest area would be much more relevant. In the task used in the present study, this type of dynamic feedback could simulate what happens to the ecosystem once the public reception area has been set up. In particular, this should enhance the establishment of relations between the selected elements that are processed during the exploration phase, the decision and the dynamic feedback of information. These considerations will be addressed in a subsequent follow-up study.

Different levels of signaling were used. Our results suggest that different levels of signaling may have distinct effects at different levels of learning performance. However, signaling levels should be better defined and, in particular, their potential effects should be tested in more varied learning situations. It is necessary to investigate in greater detail the ways in which signals are perceptually and cognitively processed in IVR environments and how learners build relations between the signaled information and the feedback information. Direct and online measures, such as eye tracking integrated into the VR headset, could be used. This will also form part of a future experiment.

Further, the present work was conducted within the specific framework of testing multimedia learning principles (Mayer and Fiorella, 2022) in IVR environments, and in the background context of educational cognitive psychology. However, our results about the benefits of visual (and verbal) guidance techniques, and more generally about IVR environments for learning, could be used in other engineering sciences. For example, in Brain Computer Interface, IVR, as well as multimedia principles, could be investigated in order to test cost-effect balance (Mridha et al., 2021). Similarly, comparisons between IVR, Augmented Reality (AR) and Mixed Reality in learning STEM may be of great interest (Parong, 2022). Time locked attentional processes and cognitive load during IVR learning could be better assessed using precise physiological measures such as eye-tracking (Holmqvist and Andersson, 2017) and EEG (Makransky et al., 2019b) that open windows on internal cognitive processes. Such measures could be compared to the signal processing devices. Then, eye tracking and brain activity measurement data (EEG, fNIRS- functional Near Infrared Spectroscopy) could be used in the analysis of programming technologies such as LINQ (Language Integrated Query: name for a set of technologies based on the integration of query capabilities directly into the C# language) and algorithms. Finally, there are many other research avenues that could be investigated using IVR. For example, and among many other possibilities, in the domain of metacognition, it could be relevant to address how learning experience in IVR can change a person's self-confidence or self-efficacy (de Bruin et al., 2020), or in a very different field, specific IVR software or programs could, perhaps, be developed to support vision screening.

In conclusion, this study was carried out as part of a recent line of research which consisted in systemically testing the application of multimedia principles (Mayer, 2009; Mayer and Fiorella, 2022; Makransky, 2022) to IVR environments. The present work is consistent with the small number of studies that have already been conducted in this area (Albus and Seufert, 2022; Zhang et al., 2023) and suggests that the signaling principle has significant beneficial effects in immersive environments.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by the Ethics Committees of the Academic Inspection of the French National Education, Bourgogne Franche-Comté region, and the Regional Direction for Digital Education (DRNE). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

LP: Conceptualization, Formal analysis, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. J-MB: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. LR: Resources, Software, Visualization, Writing – original draft, Writing – review & editing. VD-Z: Formal analysis, Investigation, Supervision, Writing – original draft, Writing – review & editing. J-LM: Software, Supervision, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Ahn, S. J., Nowak, K. L., and Bailenson, J. N. (2022). Unintended consequences of spatial presence on learning in virtual reality. *Comput. Educ.* 186:104532:104532. doi: 10.1016/j.compedu.2022.104532

Albus, P., and Seufert, T. (2022). The modality effect reverses in a virtual reality learning environment and influences cognitive load. *Instr. Sci.* 51, 545–570. doi: 10.1007/s11251-022-09611-7

Albus, P., Vogt, A., and Seufert, T. (2021). Signaling in virtual reality influences learning outcome and cognitive load. *Comput. Educ.* 166:104154. doi: 10.1016/j.compedu.2021.104154

Alpizar, D., Adesope, O. O., and Wong, R. M. (2020). A meta-analysis of signaling principle in multimedia learning environments. *Educ. Technol. Res. Dev.* 68, 2095–2119. doi: 10.1007/s11423-020-09748-7

Andersen, S. A., Klingenberg, S., Petersen, G. B., Creed, P. A., and Makransky, G. (2022). Fostering science interests through head-mounted displays. *J. Comput. Assist. Learn.* 39, 369–379. doi: 10.1111/jcal.12749

Araiza-Alba, P., Keane, T., Chen, W. S., and Kaufman, J. (2020a). Children's memory of a story experienced with virtual reality versus traditional media technology. *Int. J. Virtual Real.* 20, 55–69. doi: 10.20870/IJVR.2020.20.2.3151

Araiza-Alba, P., Keane, T., Chen, W. S., and Kaufman, J. (2021b). Immersive virtual reality as a tool to learn problem-solving skills. *Comput. Educ.* 164:104121. doi: 10.1016/j.compedu.2020.104121

Araiza-Alba, P., Keane, T., and Kaufman, J. (2020b). Are we ready for virtual reality in K-12 classrooms? Available at: https://edarxiv.org/ux8hs/

Araiza-Alba, P., Keane, T., Matthews, B., Simpson, K., Strugnell, G., Chen, W. S., et al. (2021a). The potential of 360-degree virtual reality videos to teach water-safety skills to children. *Comput. Educ.* 163:104096. doi: 10.1016/j.compedu.2020.104096

Baceviciute, S., Mottelson, A., Terkildsen, T. S., and Guido Makransky, G. (2020). Investigating representation of text and audio in educational VR using learning outcomes and EEG. Proceedings of the CHI 2020, April 25–30, 2020, Honolulu, HI, USA

Baceviciute, S., Terkildsen, T. S., and Guido Makransky, G. (2021). Remediating learning from non-immersive to immersive media: using EEG to investigate the effects of environmental embeddedness on reading in virtual reality. *Comput. Educ.* 164:104122. doi: 10.1016/j.compedu.2020.104122

Bagher, M. M., Sajjadi, P., Wallgrün, O. J., LaFemina, P., and Klippel, A. (2023). Virtual reality for geospatial education: immersive technologies enhance sense of embodiment. *Cartogr. Geogr. Inf. Sci.* 50, 233–248. doi: 10.1080/15230406.2022.2122569

Boucheix, J.-M., and Lowe, R. K. (2010). An eye tracking comparison of external pointing cues and internal continuous cues in learning with complex animations. *Learn. Instr.* 20, 123–135. doi: 10.1016/j.learninstruc.2009.02.015

Boucheix, J.-M., Lowe, R. K., Putri, D. K., and Groff, J. (2013). Cueing animations: dynamic signaling aids information extraction and comprehension. *Learn. Instr.* 25, 71–84. doi: 10.1016/j.learninstruc.2012.11.005

Breves, P., and Stein, J.-P. (2022). Cognitive load in immersive media settings: the role of spatial presence and cybersickness. *Virtual Reality* 27, 1077–1089. doi: 10.1007/s10055-022-00697-5

Clark-Carter, D. (2004). *Quantitative psychological research*, (*2nd Edn*). London: Taylor & Francis Group.

Coban, M., Bolat, Y. I., and Goksu, I. (2022). The potential of immersive virtual reality to enhance learning: a meta-analysis. *Educ. Res. Rev.* 36:100452. doi: 10.1016/j.edurev.2022.100452

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (*2nd Edn*). Mahwah, NJ: Lawrence Erlbaum Associates Publishers.

Danneman, M., and Carpenter, P. A. (1980). Individual differences in working memory and reading. *J Verbal Learn. Verbal Behav.* 19, 450–466.

de Bruin, A. B. H., Roelle, J., Carpenter, S. K., and Baars, M. (2020). Synthetizing cognitive load and self-regulation theory: a theoretical framework and research agenda. *Educ. Psychol. Rev.* 32, 903–915. doi: 10.1007/s10648-020-09576-4

de Koning, B. B., Tabbers, H. K., Rikers, R. M. J. P., and Paas, F. (2007). Attention cueing as a mean to enhance learning from an animation. *Appl. Cogn. Psychol.* 21, 731–746. doi: 10.1002/acp.1346

de Koning, B. B., Tabbers, H. K., Rikers, R. M. J. P., and Paas, F. (2009). Towards a framework for attention cueing in instructional animations: guidelines for research and design. *Educ. Psychol. Rev.* 21, 113–140. doi: 10.1007/s10648-009-9098-7

de Koning, B. B., Tabbers, H. K., Rikers, R. M. J. P., and Paas, F. (2010a). Attention guidance in learning from a complex animation: seeing is understanding? *Learn. Instr.* 20, 111–122. doi: 10.1016/j.learninstruc.2009.02.010

de Koning, B., Tabbers, H. K., Rikers, R. M. J. P., and Paas, F. (2010b). Improved effectiveness of cueing by self-explanations when learning from a complex animation. *Appl. Cogn. Psychol.* 25, 183–194. doi: 10.1002/acp.1661

Decker, D., and Merkt, M. (2023). Desktop virtual reality learning environments: can cues reduce search time and support learning? Paper presented at the 20th Biennale

EARLI Conference, "Education as a Hope in Uncertain Times", Thessaloniki, Greece, August 22–26.

Desmette, D., Hupet, M., Schelstraete, M.-A., and Van Der Linden, M. (1995). Adaptation en langue française du « Reading Span Test » de Daneman et Carpenter (1980). *Annee Psychol.* 95, 459–482. doi: 10.3406/psy.1995.28842

Drai-Zerbib, V., Bernigaud, L., Gaston-Bellegarde, A., Boucheix, J. M., and Baccino, T. (2022). Eye movements during comprehension in virtual reality: the influence of a change in point of view between auditory and visual information in the activation of a mental model. *Front. Virtual Real.* 3:874054. doi: 10.3389/frvir.2022.874054

Faul, F., Erdfelder, E., Lang, A. G., and Buchner, A. (2007). G*power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav. Res. Methods* 39, 175–191. doi: 10.3758/bf03193146. PMID: 17695343

Fiorella, L., and Mayer, R. E. (2022). "Principles for reducing extraneous processing in multimedia learning: coherence, signaling, redundancy, spatial contiguity and temporal contiguity principles" in *The Cambridge handbook of multimedia learning*. eds. R. Mayer and L. Fiorella. *3rd* ed (Cambridge: Cambridge University Press), 185–198.

Hartmann, C., Orli-Idrissi, Y., Pflieger, L. C. J., and Bannert, M. (2023). Imagine & immerse yourself: does visuospatial imagery moderate learning in virtual reality? *Comput. Educ.* 207:104909. doi: 10.1016/j.compedu.2023.104909

Hattie, J. (2008). *Visible learning: A synthesis of over 800 meta-analyses relating to achievement*. Routledge: Abingdon, 392.

Hattie, J., and Timperley, H. (2007). The power of feedback. *Rev. Educ. Res.* 77, 81–112. doi: 10.3102/003465430298487

Hegarty, M., Kozhevnikov, M., and Waller, D. (2008). Perspective Taking/Spatial Orientation Test. For electronic copies of those publications and this test package. Available at: http://www.psych.ucsb.edu/~hegarty/

Holmqvist, K., and Andersson, R. (2017). *Eye tracking: A comprehensive guide, methods, paradigms and measures*. Lund, Sweeden: Lund Eye-Tracking Research Institute.

Johnson, C. I., and Marraffino, M. D. (2022). "The feedback principle in multimedia learning" in *The Cambridge handbook of multimedia learning*. eds. R. Mayer and L. Fiorella. *3rd* ed (Cambridge: Cambridge University Press), 403–417.

Kalyuga, S., and Sweller, J. (2022). "The redundancy principle in multimedia learning" in *The Cambridge handbook of multimedia learning*. eds. R. Mayer and L. Fiorella. *3rd* ed (Cambridge: Cambridge University Press), 212–220.

Klingenberg, S., Fisher, R., Zettler, I., and Makransky, G. (2022). Facilitating learning in immersive virtual reality: segmentation, summarizing, both or none? *J. Comput. Assist. Learn.* 39, 218–230. doi: 10.1111/jcal.12741

Lowe, R. K., and Boucheix, J.-M. (2008). "Learning from animated diagrams: how are, mental models built?" in *Diagrammatic representation and inference*. eds. G. Stapleton, J. Howse and J. Lee (Berlin: Springer), 266–281.

Lowe, R. K., and Boucheix, J.-M. (2011). Cueing complex animation: does direction of attention foster learning processes? *Learn. Instr.* 21, 650–663. doi: 10.1016/j.learninstruc.2011.02.002

Lowe, R. K., and Boucheix, J. M. (2016). Principled animation design improves comprehension of, complex dynamics. *Learn. Instr.* 45, 72–84. doi: 10.1016/j.learninstruc.2016.06.005

Lowe, R. K., Schnotz, W., and Boucheix, J. M. (2022). "The animation composition principle in multimedia learning" in *The Cambridge handbook of multimedia learning*. eds. R. Mayer and L. Fiorella. *3rd* ed (Cambridge: Cambridge University Press), 313–323.

Makransky, G. (2021). "The immersion principle in multimedia learning" in *The Cambridge handbook of multimedia learning (Cambridge handbooks in psychology)*. eds. R. Mayer and L. Fiorella (Cambridge: Cambridge University Press), 296–303.

Makransky, G. (2022). "The immersion principle in multimedia learning" in *The Cambridge handbook of multimedia learning*. eds. R. Mayer and L. Fiorella. *3rd* ed (Cambridge: Cambridge University Press), 313–323.

Makransky, G., Andreasen, N. K., Baceviciute, S., and Mayer, R. E. (2020a). Immersive virtual reality increases liking but not learning with a science simulation and generative learning strategies promote learning in immersive virtual reality. *J. Educ. Psychol.* 113, 719–735. doi: 10.1037/edu0000473

Makransky, G., Borre-Gude, S., and Mayer, R. E. (2019a). Motivational and cognitive benefits of training in immersive virtual reality based on multiple assessments. *J. Comput. Assist. Learn.* 35, 691–707. doi: 10.1111/jcal.12375

Makransky, G., and Klingenberg, S. (2022). Virtual reality enhances safety training in the maritime industry: an organizational training experiment with a non-WEIRD sample. *J. Comput. Assist. Learn.* 38, 1127–1140. doi: 10.1111/jcal.12670

Makransky, G., and Lilleholt, L. (2018). A structural equation modeling investigation of the emotional value of immersive virtual reality in education. *Educ. Technol. Res. Dev.* 66, 1141–1164. doi: 10.1007/s11423-018-9581-2

Makransky, G., Lilleholt, L., and Aaby, A. (2017). Development and validation of the multimodal presence scale for virtual reality environments: a confirmatory factor analysis and item response theory approach. *Comput. Hum. Behav.* 72, 276–285. doi: 10.1016/j.chb.2017.02.066

Makransky, G., and Mayer, R. E. (2022). Benefits of taking a virtual field trip in immersive virtual reality: evidence for the immersion principle in multimedia learning. *Educ. Psychol. Rev.* 34, 1771–1798. doi: 10.1007/s10648-022-09675-4

Makransky, G., Mayer, R., Nøremølle, A., Cordoba, A. L., Wandall, J., and Bonde, M. (2020b). Investigating the feasibility of using assessment and explanatory feedback in desktop virtual reality simulations. *Educ. Technol. Res. Dev.* 68, 293–317. doi: 10.1007/s11423-019-09690-3

Makransky, G., and Petersen, G. B. (2019). Investigating the process of learning with desktop virtual reality: a structural equation modeling approach. *Comput. Educ.* 134, 15–30. doi: 10.1016/j.compedu.2019.02.002

Makransky, G., and Petersen, G. B. (2021). The cognitive affective model of immersive learning (CAMIL): a theoretical research-based model of learning in immersive virtual reality. *Educ. Psychol. Rev.* 33, 937–958. doi: 10.1007/s10648-020-09586-2

Makransky, G., Petersen, G. B., and Klingenberg, S. (2020c). Can an immersive virtual reality simulation increase students 'interest and career aspirations in science? *Br. J. Educ. Technol.* 51, 2079–2097. doi: 10.1111/bjet.12954

Makransky, G., Terkildsen, T. S., and Mayer, R. E. (2019b). Adding immersive virtual reality to a science lab simulation causes more presence but less learning. *Learn. Instr.* 60, 225–236. doi: 10.1016/j.learninstruc.2017.12.007

Mayer, R. E., and Fiorella, L. (2022). (*3rd Edn*) *Cambridge handbooks in psychology: The Cambridge handbook of multimedia learning*. Cambridge: Cambridge University Press.

Mayer, R. E. (2009). *Multimedia Learning*. Cambridge University Press. Second Edition.

Mayer, R. E., Makransky, G., and Parong, J. (2022). The promise and pitfalls of learning in immersive virtual reality. *Int. J. Human Comput. Interact.* 39, 2229–2238. doi: 10.1080/10447318.2022.2108563

Mridha, M. F., Chandra Das, S., Kabir, M. M., Lima, A. A., Islam, R., and Watanobe, Y. (2021). Brain-computer Interface: advancement and challenges. *Sensors* 21:5746. doi: 10.3390/s21175746

Naccache, L. (2020). *Le cinéma intérieur. Projection privée au cœur de la conscience*. Paris: Odile Jacob.

Parong, J. (2022). "Multimedia learning in mixed, and virtual reality" in *Cambridge handbooks in psychology: The Cambridge handbook of multimedia learning*. eds. R. Mayer and L. Fiorella. *3rd* ed (Cambridge: Cambridge University Press)

Parong, J., and Mayer, R. E. (2018). Learning science in immersive virtual reality. *J. Educ. Psychol.* 110, 785–797. doi: 10.1037/edu0000241

Petersen, G. B., Pektakis, G., and Makransky, G. (2022). A study of how immersion and interactivity drive VR learning. *Comput. Educ.* 179:104429. doi: 10.1016/j.compedu.2021.104429

Plechatà, A., Hielkema, M., Merkl, L.-M., Makransky, G., and Frost, M. B. (2022a). Fast forward: influencing the future in virtual reality increases real-life pro-environmental behavior. *Res. Square*, 1–25. doi: 10.21203/rs.3.rs-2338078/v1

Plechatà, A., Morton, T., Perez-Cueto, F. J. A., and Makransky, G. (2022b). Why just experience the future when you can change it: virtual reality can increase pro-environmental food choices through self-efficacy. *Technol. Mind Behav.* 3:80. doi: 10.1037/tmb0000080

Richter, J., Scheiter, K., and Eitel, A. (2016). Signaling text-picture relations in multimedia learning: a comprehensive meta-analysis. *Educ. Res. Rev.* 17, 19–36. doi: 10.1016/j.edurev.2015.12.003

Schmidt-Weigand, F., Kohnert, A., and Glowalla, U. (2009). A closer look at split visual attention in system- and self-paced instruction in multimedia learning. *Learn. Instr.* 20, 100–110. doi: 10.1016/j.learninstruc.2009.02.011

Schneider, S., Beege, M., Nebel, S., and Rey, G. D. (2018). A meta-analysis of how signaling affects learning with media. *Educ. Res. Rev.* 23, 1–24. doi: 10.1016/j.edurev.2017.11.001

Skulmowski, A. (2023). Guidelines for choosing cognitive load in perceptually rich environments. *Mind Brain Educ.* 17, 20–28. doi: 10.1111/mbe.12342

Stenberdt, A. S., and Makransky, G. (2023). Mastery experiences in immersive virtual reality promote pro-environmental waste-sorting behavior. *Comput. Educ.* 198:104760. doi: 10.1016/j.compedu.2023.104760

Sweller, J., Ayres, P., and Kalyuga, S. (2011). *Cognitive load theory*. Berlin: Springer.

Van Gog, T. (2022). "The signaling (or cueing) principle in multimedia learning" in *The Cambridge handbook of multimedia learning*. eds. R. Mayer and L. Fiorella. *3rd* ed (Cambridge: Cambridge University Press), 221–230.

Vandeweerdt, C., Luong, T., Atchapero, M., Mottelson, A., Holz, C., Makransky, G., et al. (2022). Virtual reality reduces COVID-19 vaccine hesitancy in the wild: a randomized trial. *Sci. Rep.* doi: 10.17605/OSF.IO/WUFXK

Wu, B., Yu, X., and Gu, X. (2020). Effectiveness of immersive virtual reality using head-mounted displays on learning performance: a meta-analysis. *Br. J. Educ. Technol.* 51, 1991–2005. doi: 10.1111/bjet.13023

Zhang, H., Zhang, Y., Xu, T., and Zhou, Y. (2023). Effects of VR instructional approaches and textual cues on performance, cognitive load, and learning experience. *Educ. Tech Res. Dev.* doi: 10.1007/s11423-023-10313-1

Appendix A

For each question, circle the answer that best describes you on this scale. There are no right or wrong answers ☺.
Presence

1- The graphic design is realistic and easy to interpret. (From not at all to yes, absolutely)
2- The virtual environment allowed me to feel (bodily) immersed – as if I were present there- in the experience. (From not at all to yes, absolutely)
3- The virtual environment appeared real. (From not at all to yes, absolutely)
4- It was easy for me to recognize and identify the elements of the virtual reality environment. (From not at all to yes, absolutely)

Cognitive complexity – Extrinsic

5- I was quickly able to move around and get to grips with the interface. (From not at all to yes, absolutely)
6- The features (mark a tree, access the map, etc.) were useful to me. (From not at all to yes, absolutely)

Cognitive complexity – Intrinsic

7- I lost time during exploration because of the complexity of the environment. (From not at all to yes, absolutely)
8- I had to call on my own knowledge in order to answer the problems posed by the experiment. (From not at all to yes, absolutely)

Sickness

9- I felt uncomfortable during this experiment: uncomfortable helmet, nausea, loss of orientation (From not at all to yes, absolutely)

Enjoyment

10- My appraisal of this virtual reality experience was rather: (From Highly negative to Highly positive)

Open question

11- Comments on the use of the program and virtual reality: qualities/possible defects; other:

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Prevalence of phubbing behaviour in school and university students in Spain

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Objective: This study examined the prevalence of phubbing behavior among school and university students in Spain and analyzed the correlation of phubbing with other indicators of psychological well-being and mental health.

Methods: The study sample comprised a total of 1,351 school and university students, with ages ranging from 12 to 21years. The study used the Phubbing Scale (PS), the Compulsive Internet Use Scale (CIUS), the Rosenberg Self-Esteem Scale (RSE), and the Interpersonal Emotion Regulation Questionnaire (IERQ) for data collection.

Results: The results showed evidence of phubbing among approximately half of the students. Statistically significant differences were found based on gender and educational level in the Phone Obsession subscale and the PS total score, with male students and university students scoring higher in their respective parameters. In addition, phubbing was positively correlated with problematic internet use and negatively correlated with self-esteem.

Conclusion: Phubbing behavior is highly prevalent among adolescents aged 12–21 years and is positively correlated with low self-esteem and problematic internet use. Developing strategies for addressing this widespread issue at early ages, particularly within the educational context, such as schools, is crucial for implementing preventive measures. The inappropriate use of technological devices, including smartphones, in schools has the potential to negatively affect students' well-being and ability to adapt to school.

KEYWORDS

phubbing, adolescence, well-being, mental health, education

Introduction

Adolescence is a critical developmental period with crucial consequences on individuals' identity, self-concept, self-esteem, and values, among other aspects (Liu et al., 2022). Given these large-scale changes, adolescence is also a period of vulnerability to many psychological problems, including behavioral addictions (Rial Boubeta et al., 2015; Chotpitayasunondh and Douglas, 2016). Psychological problems prevailed among 10–20% of individuals aged between 12 and 16 years (de Vries et al., 2018), and three out of four mental health disorders among the adult population were first diagnosed during adolescence (Fusar-Poli, 2019). Adolescence is, thus, a critical period to prevent and address mental health issues (Irarrázaval et al., 2016; Moreno et al., 2019).

Adolescent smartphone owners are almost ubiquitous in Western Europe, with the use of smartphones including, but not limited to, work, study, and social interactions. In fact,

Information and Communication Technologies (ICT), including the smartphone, have been integrated into classroom activities and educational programs (Cabero Almenara, 2015; Amores Valencia and De Casas Moreno, 2019; Navaridas-Nalda et al., 2020; Palacios-Rodríguez et al., 2023). Nonetheless, studies have questioned its adequacy in educational settings (Shahibi and Rusli, 2017; Twenge and Campbell, 2018; Burns, 2021). In this context, although some authors have recognized the benefits of incorporating technologies in the classroom, other authors' contributions indicate contrasting views. These perspectives indicate the association between the use of smartphones and the specific behaviors that can adversely affect the teaching–learning process (Bisquerra Alzina and Chao Rebolledo, 2021). One such behavior is described using a relatively new term, phubbing; it is defined as the practice of ignoring the presence of others in a social environment while focusing on one's smartphone (Karadağ et al., 2015; Chotpitayasunondh and Douglas, 2016). A phubber, a person who neglects others in favor of his smartphone, may lack the necessary self-control to appropriately use both phone and the internet (Arenz and Schnauber-Stockmann, 2023). This behavior can be characterized by a compulsive fear of missing out on other gratifying events and an inability to regulate the use of one's phone (Chotpitayasunondh and Douglas, 2016); therefore, it may be described as an addiction-like behavior.

The use, or more precisely, the inappropriate use of smartphones, has been linked to symptoms of over-dependence, tolerance, and withdrawal (Fischer-Grote et al., 2019). Specifically, previous literature has shown adverse outcomes of phubbing, revealing that phubbing has a negative correlation with life satisfaction and a positive correlation with depression (Parmaksiz, 2021) as well as the feeling of loneliness and low self-esteem (Błachnio and Przepiorka, 2019). In addition, mental health issues, such as depression and anxiety, have been associated with the abuse of smartphones (Guazzini et al., 2019; Ergün et al., 2020). Furthermore, smartphone addiction has been shown to negatively moderate the relationship between self-regulation and well-being (Mascia et al., 2020). Other studies have revealed negative consequences of phubbing, including a decline in the quality of face-to-face relationships, a lower connection with individuals using smartphones in others' presence (Przybylski and Weinstein, 2013; Zhang et al., 2023), and lowered empathy and limited social skills associated with phubbing behavior (Chotpitayasunondh and Douglas, 2016, 2018). Davey et al. (2018) indicated an alteration in eye contact and a reduction of social interactions due to phone misuse.

Studies have shown two notable negative consequences of phubbing behavior for romantic relationships (McDaniel and Coyne, 2016; Roberts and David, 2016; Al-Saggaf and MacCulloch, 2019; Ekimchik and Kryukova, 2022; Gorla et al., 2024) and family settings (Zhang et al., 2023). For instance, partner phubbing has been associated with an increase in the feeling of jealousy and depressive symptoms and a decrease in relationship satisfaction, although the reasons for these effects remain uncertain (McDaniel and Coyne, 2016; Roberts and David, 2016). In the context of adolescents, Zhang et al. (2023) found a positive correlation between teenage phubbing and conflicts with parents. Moreover, parental phubbing was related to depression in students of different educational levels in China (Kong et al., 2021; Hu et al., 2023; Mi et al., 2023).

The prevalence rates of phubbing generally appear to differ according to gender although this trend may depend on the culture and context. In general, most studies found higher rates of phubbing behavior among women (Anshari et al., 2016; Villafuerte-Garzón and Vera-Perea, 2018; Błachnio and Przepiorka, 2019; Balta et al., 2020; Escalera-Chávez et al., 2020; Błachnio et al., 2021). For example, the study of Anshari et al. (2016) on Brunei's university students revealed that female students had higher prevalence rates than their counterparts. Another study conducted on college students in Mexico (Escalera-Chávez et al., 2020) indicated that women were more likely to exhibit phubbing behavior. Similarly, a study conducted on adolescents and adults in Turkey revealed higher prevalence rates for women than for men (Balta et al., 2020). Two studies conducted in South America showed results that deviated from these findings; the study conducted in Ecuador found a greater prevalence of phubbing among men (Villafuerte-Garzón and Vera-Perea, 2018), whereas research conducted in Peruvian universities indicated no gender-based differences (Ríos Ariza et al., 2021).

Many studies have investigated phubbing behavior in educational contexts, with results suggesting a high prevalence of phubbing among students. For instance, a prevalence rate of 45.2% was found in adolescents in Spain (Cebollero Salinas et al., 2022), and 88.8% of university students in Turkey reported engaging in phubbing behavior (Ahmed et al., 2023). Based on a phubbing scale, college students in India had a 49.3% prevalence of phubbing (Davey et al., 2018). Similar prevalence rates were found among medical college students in India (42.7%) (Purwar et al., 2023) and pharmacy college students in the United States (41.3%) (Lo et al., 2022). However, research on the effect of gender on phubbing manifestation did not yield consistent results. For example, a study conducted on Saint Petersburg university students in Russia concluded no phubbing behavior among the students (Dushkin and Barinova, 2023).

Considering the widespread prevalence of phubbing, the differences in this phenomenon according to demographics, and the various detrimental consequences of phubbing, this study examined the prevalence of phubbing among Spanish adolescent students. The specific objectives of the study were (a) to determine the prevalence of phubbing in adolescents, (b) to analyze the effect of gender and educational levels on phubbing manifestations, (c) to investigate the correlation between phubbing and other indicators of well-being and mental health issues, and (d) to analyze the incidence of phubbing in different educational levels.

Methodology

Participants and procedures

A total of 1,351 students aged 12–21 years participated in the study. Students were enrolled in different educational levels, including secondary education, high school, vocational training, and university degree programs. The participants were selected through convenience sampling, and surveys were conducted in their educational institutions. Individual participants completed the questionnaires within approximately 20 min. Among the participants, 81% responded using their smart devices (mobile phones or laptops), whereas the remaining completed on-paper questionnaires. The gender distribution of the participants was as follows: 54.25% were men, 42.78% were women, less than 1% answered "other," and approximately 2% chose not to specify their gender. Among the participants, 20% were employed or engaged in internships, with studies not being their exclusive or primary activity. The present study was approved by the Ethical Committee of Research of University of La Rioja, Spain.

Instruments

Phubbing scale (PS)

The PS developed by Karadağ is a questionnaire comprising 10 items, with each question rated on a five-point Likert scale ranging from 1 (indicating never) to 5 (indicating always). The PS quantifies the frequency and severity of the behavior of neglecting the people around while being preoccupied with an internet-connected device, specifically a smartphone (Karadağ et al., 2015). Blanca and Bendayan (2018) developed an adapted version of the PS for the Spanish population, analyzing its consistency with the original study, particularly regarding disruptions in communication and obsession with the smartphone, which are the two dimensions of the scale. They also found evidence that phubbing is associated with internet addiction (Blanca and Bendayan, 2018). The internal consistency of the scale was confirmed using McDonald's omega coefficient, which was 0.787 for the total score and 0.705 and 0.709 for the subscales of Communication Disturbance and Phone Obsession, respectively.

Rosenberg self-esteem scale (RSE)

The RSE, developed by Rosenberg in 1965, is a widely used tool for measuring an individual's self-esteem. The RSE consists of 10 statements about an individual's self-concept and self-evaluation. Each statement is rated on a four-point scale ranging from "strongly agree" to "strongly disagree." Generally, the higher the RSE score, the higher the individual's perceived self-esteem (Ronseberg, 1965). This study used the Spanish version of the RSE (Martín-Albo et al., 2007), which had a McDonald's omega coefficient of 0.798 for the total score.

Interpersonal emotion regulation questionnaire (IERQ)

The IERQ, developed by Hoffman, consists of 20 items divided into four factors: Enhancing Positive Affect, Perspective Taking, Soothing, and Social Modeling. These factors are related to an individual's inclination to seek out others to amplify their feelings of happiness and joy, turn to others as a reminder to not worry and feel better comfort, and learn from others how to handle a specific situation (Hofmann et al., 2016), respectively. This study used the Spanish adaptation of the IERQ (D'Orey Roquete et al., 2023), which was confirmed to have internal consistency with a McDonald's omega coefficient of 0.918 for the total score.

Compulsive internet use scale (CIUS)

The CIUS is a 14-item self-assessment scale designed to measure the severity of internet addiction and compulsive, pathological, or problematic internet use (PIU). The 14 items are rated on a four-point scale ranging from 0 (indicating never) to 4 (indicating very often). The present study used the CIUS adapted to the Spanish context (Lopez-Fernandez et al., 2019; Ortuño-Sierra et al., 2022), which had a McDonald's omega coefficient of 0.912.

Data analysis

The present study used descriptive statistics including the percentage distribution of the PS items. Distributions were reported according to gender and educational level. A multivariate analysis of variance (MANOVA) was conducted using educational level and gender as fixed variables and the PS items and total score as dependent variables. For the cases where MANOVA indicated statistical significant differences, an analysis of variance (ANOVA) was conducted to analyze specific differences within groups. Finally, the correlation between phubbing and other mental health indicators was analyzed.

Results

Descriptive statistics and percentage distribution of PS items

Table 1 shows the mean and standard deviation of the PS items according to gender (i.e., man, woman, and others), educational level (i.e., non-university and university), and the total sample of $N = 1{,}351$. In addition, the percentage of participants scoring 4 or 5, corresponding to the options "almost always" and "always," were calculated, and the results are shown in Table 2. The results reveal that 74.5% of the participants indicated that always or almost always had their phones within their reach (item 6); among them, 79.7% were university students and 70.8% were non-university students. Regarding gender, 77% of men and 71.9% of women reported that they always or almost always had their phones within their reach (item 6). In addition, 42.6% of the participants revealed that they always or almost always checked their phones when they woke up in the morning (Item 7). By contrast, only 16.8% of participants always or almost always found their eyes wandering on their phones when they were with others (item 1), and 11.3% revealed that they had the perception of annoying others when they were busy with their phones (item 5). Furthermore, only 3.7% stated that they were always or almost always busy with their mobile phones when they were with their friends (item 2); 5.7% had a similar perception regarding their family (item 4).

Phubbing based on gender and educational level

To analyze the possible effect of gender and educational level on the manifestation of phubbing behavior, MANOVA was performed with gender and educational level as fixed factors and the PS total score and subscales of phubbing as dependent variables. The Wilks' Lambda (λ) was used to detect statistically significant differences among the variables. The Partial Eta Square (η^2) was used to analyze the effect size. The mean and standard deviations of the subscales and the total score based on gender, educational level, and the total sample are shown in Table 3. The *Wilks'* λ values indicated statistically significant differences in gender (*Wilks'* $\lambda = 0.987$, p-value <0.001, $\eta^2 = 0{,}013$) and educational level (*Wilks'* $\lambda = 0.931$, p-value <0.001, $\eta^2 = 0{,}013$).

Subsequent ANOVA indicated statistically significant differences in the Phone Obsession subscale ($F = 12.630$, p-value <0.001, partial $\eta^2 = 0.010$) and the PS total score ($F = 4.416$, p-value $= 0.036$, partial $\eta^2 = 0.003$). In addition, ANOVA for educational level revealed statistically significant differences in the Phone Obsession subscale ($F = 85.995$, p-value <0.001, partial $\eta^2 = 0.062$) and the PS total score ($F = 44.341$, p-value <0.001, partial $\eta^2 = 0.033$). No statistical differences were found in the Communication Disturbance subscale for both gender and educational level.

TABLE 1 Descriptive statistics (means and standard deviations) of the Phubbing Scale items.

	Total Sample (N = 1,351)	Male students (n = 733)	Female students (n = 578)	Non-university students (n = 789)	University students (n = 562)
	M (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Communication disturbance					
1. My eyes start wandering on my phone when I'm together with others	2.65 (0.91)	2.71 (0.92)	2.59 (0.89)	2.56 (0.92)	2.79 (0.89)
2. I am busy with my mobile phone when I'm with my friends	2.05 (0.78)	2.03 (0.78)	2.06 (0.79)	1.99 (0.78)	2.13 (0.77)
3. People complain about me dealing with my mobile phone	1.77 (0.95)	1.76 (0.94)	1.76 (0.96)	1.82 (0.98)	1.71 (0.89)
4. I'm busy with my mobile phone when I'm with my family	2.10 (0.85)	2.08 (0.86)	2.10 (0.82)	2.00 (0.87)	2.23 (0.81)
5. I think that I annoy my partner when I'm busy with my mobile phone (or family. if you do not have a partner)	2.00 (1.10)	1.95 (1.06)	2.05 (1.14)	2.07 (1.14)	1.89 (1.04)
Phone obsession					
6. My phone is within my reach	4.03 (1.02)	4.08 (0.98)	3.95 (1.05)	3.94 (1.11)	4.15 (0.86)
7. When I wake up in the morning. I first check the messages on my phone	3.07 (1.40)	3.32 (1.38)	2.79 (1.38)	2.66 (1.42)	3.66 (1.14)
8. I feel incomplete without my mobile phone	2.21 (1.12)	2.35 (1.17)	2.01 (1.02)	2.07 (1.10)	2.39 (1.11)
9. My mobile phone use increases day by day	2.04 (0.90)	2.10 (0.90)	1.97 (0.88)	1.92 (0.86)	2.22 (0.93)
10. The time allocated to social. Personal or professional activities decreases because of my mobile phone	1.95 (1.04)	1.92 (1.03)	1.97 (1.05)	1.91 (1.01)	2.01 (1.07)

TABLE 2 Number and percentage of participants who scored 4 or 5 for the Phubbing Scale items.

	Total sample (N = 1,351)	Male students (n = 733)	Female students (n = 578)	Non-university students (n = 789)	University students (n = 562)
	n (%)	*n* (%)	*n* (%)	*n* (%)	*n* (%)
Communication disturbance					
1. My eyes start wandering on my phone when I'm together with others	226 (16.8)	135 (18.4)	84 (14.7)	114 (14.6)	112 (19.9)
2. I am busy with my mobile phone when I'm with my friends	50 (3.7)	26 (3.5)	22 (3.8)	27 (4.4)	23 (4.1)
3. People complain about me dealing with my mobile phone	85 (6.3)	46 (6.3)	37 (6.4)	56 (7.1)	29 (5.2)
4. I'm busy with my mobile phone when I'm with my family	76 (5.7)	39 (5.3)	30 (5.2)	42 (5.4)	34 (6)
5. I think that I annoy my partner when I'm busy with my mobile phone (or family, if you do not have a partner)	153 (11.3)	71 (9.7)	74 (12.8)	103 (13.1)	50 (8.9)
Phone obsession					
6. My phone is within my reach	1,004 (74.5)	564 (77)	414 (71.9)	556 (70.8)	448 (79.7)
7. When I wake up in the morning, I first check the messages on my phone	575 (42.6)	366 (50.2)	194 (33.6)	240 (30.4)	336 (59.6)
8. I feel incomplete without my mobile phone	190 (14.1)	134 (18.3)	50 (8.7)	94 (11.9)	96 (17.1)
9. My mobile phone use increases day by day	80 (5.9)	49 (6.7)	27 (4.7)	34 (4.3)	46 (8.2)
10. The time allocated to social, personal or professional activities decreases because of my mobile phone	128 (9.5)	68 (9.3)	55 (9.5)	63 (8)	65 (11.6)

Correlation between phubbing and indicators of well-being, emotion regulation, and PIU

The correlation of the PS subscales and total score with different variables of well-being and emotion regulation was analyzed using Pearson's correlation, and the results are presented in Table 4. The results indicate that all correlations were statistically significant, with the exception of the correlation between IERQ Enhancing Positive Affect and the PS Communication Disturbance subscale and that between IERQ Social Modeling and the RSE total score. The correlation coefficients of the PS and the other indicators ranged between 0.51 (PS total and CIUS total scores) and 0.045 (IERQ Enhancing Positive Affect and PS Communication Disturbance).

Discussion

Although phubbing behavior is a prevalent problem that affects adolescents' well-being (Guzmán-Brand and Gelvez-García, 2022),

TABLE 3 Descriptive statistics of the Phubbing Scale subscales and total score.

Phubbing scale subscales	Total sample (N = 1,351)	Male students (n = 733)	Female students (n = 578)			Non-university students (n = 789)	University students (n = 562)		
	M (DT)	M (DT)	M (DT)	p-value	η^2	M (DT)	M (DT)	p-value	η^2
Communication disturbance	10.56 (3.16)	10.54 (3.17)	10.55 (3.14)	0.871	0.000	10.44 (3.15)	10.75 (3.18)	0.081	0.002
Phone obsession	13.30 (3.79)	13.76 (3.73)	12.68 (3.68)	< 0.001	0.010	12.49 (3.76)	14.42 (3.40)	< 0.001	0.062
Total score	23.87 (5.95)	24.31 (5.98)	23.24 (5.86)	0.036	0.003	22.93 (5.94)	25.17 (5.72)	< 0.001	0.033

TABLE 4 Correlation between phubbing and other mental health indicators.

	1	2	3	4	5	6	7	8	9
PS total (1)	–								
PS communication disturbance (2)	0.836**	–							
PS phone obsession (3)	0.885**	0.485**	–						
IERQ enhancing positive affect (4)	0.090**	0.045	0.103**	–					
IERQ perspective taking (5)	0.076**	0.063*	0.066*	0.358**	–				
IERQ social modeling (6)	0.138**	0.080**	0.152**	0.559**	0.623**	–			
IERQ soothing (7)	0.123**	0.124**	0.091**	0.447**	0.650**	0.639**	–		
IERQ total (8)	0.132**	0.101**	0.125**	0.698**	0.820**	0.865**	0.861**	–	
CIUS total (9)	0.501**	0.408**	0.454**	0.063*	0.154**	0.180**	0.142**	0.170**	–
RSE total	−0.170**	−0.134**	−0.155**	0.097**	0.167**	0.037	0.060*	0.111**	−0.259**

**p-value < 0.01; *p-value < 0.05.

evidence confirming its impact on adolescent populations remains limited. Therefore, the present study mainly aimed to analyze the prevalence of phubbing among Spanish adolescents and the possible effect of gender and educational level on the manifestation of phubbing behavior. In addition, the study analyzed the correlation between phubbing and other indicators of psychological well-being.

The results of the present study indicated that phubbing was prevalent among adolescents. For instance, three out of four participants reported that their phone was almost always within their reach; one in six reported, "My eyes start wandering on my phone when I'm together with others." Indicators of both obsession and communication were prevalent. The overall results are consistent with those of recent studies (Davey et al., 2018; Cebollero Salinas et al., 2022; Ahmed et al., 2023; Purwar et al., 2023). Similar to the present study's results, Davey et al. (2018) found a 49.3% prevalence of phubbing. Purwar et al. (2023) revealed that 42.7% in India exhibited phubbing behavior, while Lo et al. (2022) showed 41.3% prevalence of phubbing. However, some other studies have shown results that are incongruent with the abovementioned results. For example, Dushkin and Barinova (2023) did not find phubbing indicators among Russian students. The present study's finding that phubbing is gaining prevalence among Spanish school and university students is of significant concern considering that previous literature has related phubbing with negative consequences such as a decline in face-to-face communications (Przybylski and Weinstein, 2013; Zhang et al., 2023).

Subsequently, the study analyzed the possible effects of gender and educational level on the manifestation of phubbing behavior. With regard to gender, previous studies indicated that women exhibit a higher prevalence of phubbing than men (Anshari et al., 2016; Villafuerte-Garzón and Vera-Perea, 2018; Błachnio and Przepiorka, 2019; Balta et al., 2020; Escalera-Chávez et al., 2020; Błachnio et al., 2021). The results of the present study did not agree with this finding considering the higher prevalence rate obtained for men.

In the present study, university students exhibited higher prevalence rates for Phone Obsession and the total score of Phubbing than those from lower educational levels. This result indicates that university students have a particularly high prevalence of phubbing, which agrees with another study that showed a prevalence rate of 88.8% among university students from Turkey (Ahmed et al., 2023). Alonso and Romero (2021) suggested that PIU increases with age among adolescents. Research has shown the negative consequences of phone addiction, specifically phubbing (Nikhita et al., 2015; Błachnio and Przepiorka, 2019), and the fact that addiction-related behaviors are likely to transcend to larger problems in adulthood (Anderson et al., 2017). Therefore, analyzing the development of phubbing and related phenomena during adolescence is crucial (Dahl and Bergmark, 2020) for implementing prevention strategies that can help individuals at an early stage. The use of technological devices in classrooms, including smartphones, which may lead to problematic behaviors such as phubbing, can hinder students' ability to adapt to educational institutes. Therefore, detailed research on the possible adverse effects of smartphone usage in the teaching and learning processes is critical, as

emphasized by other studies (Bisquerra Alzina and Chao Rebolledo, 2021). Such research will enable the implementation of preventive strategies in educational settings.

Finally, the present study analyzed the correlation between phubbing and different indicators of psychological well-being and mental health. Previous literature indicated that phubbing is negatively correlated with relevant aspects of well-being such as life satisfaction and self-esteem and positively correlated with mental health issues such as the feeling of loneliness, depression, and anxiety (Guazzini et al., 2019; Ergün et al., 2020). The results of the present study are consistent with these previous studies. The results indicated that phubbing was negatively correlated with adolescents' self-esteem and positively correlated with PIU. Interestingly, all indicators of emotion regulation were either poorly correlated or positively correlated with phubbing. These findings imply that adolescents with higher levels of emotion regulation were at a higher risk of exhibiting phubbing behavior. This observation contradicts the idea that phubbing behavior causes a decrease in connection with others (Przybylski and Weinstein, 2013; Zhang et al., 2023) or lowers the levels of empathy and social skills (Chotpitayasunondh and Douglas, 2016, 2018) related to phubbing behavior. As indicated in previous studies, the use of ICT may allow and favor establishing social relationships and social networks (Arrivillaga et al., 2021; Pérez et al., 2021).

From these findings, it is evident that the results are contradictory and inconclusive. Therefore, further investigation is required to establish the causal relationships between phubbing and mental health issues and psychological well-being. Educational authorities are increasingly concerned about the widespread use of smartphones among students. Recent studies have highlighted the importance of comprehending how specific technologies could impact adolescent students (Pérez et al., 2021) and investigating the potential impact of technology use on adolescent mental health (Capilla Garrido et al., 2021; Lapierre and Zhao, 2024). Such insights can enable the development of strategies to protect individuals from the potential adverse effects of technology use (Cebollero-Salinas et al., 2022).

The present study has the following limitations. It relied on self-report instruments, which are based on certain assumptions and may include response bias. Thus, future research should introduce experimental data (e.g., behavioral or neuroimaging) and include other sources of information such as parents, teachers, or relatives. The study examined the effect of gender, rather than biological sex, on the manifestation of phubbing. Future studies could further explore this issue considering sex at birth or both as variables. In addition, due to the cross-sectional nature of the study, the cause–effect relationships could not be established. Finally, the study was conducted for a particular region in Spain; therefore, the results cannot be generalized to other regions.

Notwithstanding these limitations, this study provided insights into phubbing, a detrimental phenomenon related to the use of mobile phones, which are an integral part of the lives of adults and adolescents nowadays. Phubbing has been associated with potential mental health problems, which may have physical and psychological consequences, specifically during adolescence. In addition, phubbing may affect adolescents' ability to adapt to school settings. Considering that studies analyzing phubbing behavior in the school context are still limited, the present study contributes valuable information about the prevalence of phubbing among Spanish adolescent students. Further research is crucial for a comprehensive understanding of the phenomenon of phubbing, particularly focusing on its potential impact on students' socioemotional well-being and the ability to adjust to school.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Research Ethics Committee. University of La Rioja. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin. Written informed consent was obtained from the individual(s), and minor(s)' legal guardian/next of kin, for the publication of any potentially identifiable images or data included in this article.

Author contributions

NB-C: Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. FN-N: Conceptualization, Methodology, Writing – review & editing. OM: Writing – original draft, Conceptualization. JO-S: Conceptualization, Methodology, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Ahmed, A. H., Elemo, A. S., and Hamed, O. A. O. (2023). Smartphone addiction and phubbing in international students in Turkey: the moderating role of mindfulness. *J. Coll. Stud. Dev.* 64, 64–78. doi: 10.1353/csd.2023.0002

Alonso, C., and Romero, E. (2021). Uso problemático de internet en adolescentes: factores personales de riesgo y consecuencias emocionales y conductuales. [Problematic Internet use in adolescents: personal risk factors and emotional and behavioral consequences]. *Rev. Iberoame. de Psicol. y Salud.* 12, 76–89. doi: 10.23923/j.rips.2021.02.046

Al-Saggaf, Y., and MacCulloch, R. (2019). Phubbing and social relationships: Results from an Australian sample. *J. Relation. Res.* 10:e10. doi: 10.1017/jrr.2019.9

Amores Valencia, A. J., and De Casas Moreno, P. (2019). El uso de las TIC como herramienta de motivación para alumnos de enseñanza secundaria obligatoria. Estudio de caso español [The use of ICT as a motivation tool for compulsory secondary education students. Spanish case study]. *HAMUT'AY* 6:37. doi: 10.21503/hamu.v6i3.1845

Anderson, E. L., Steen, E., and Stavropoulos, V. (2017). Internet use and problematic internet use: a systematic review of longitudinal research trends in adolescence and emergent adulthood. *Int. J. Adolesc. Youth*. 22, 430–454. doi: 10.1080/02673843.2016.1227716

Anshari, M., Alas, Y., Hardaker, G., Jaidin, J. H., Smith, M., and Ahad, A. D. (2016). Smartphone habit and behavior in Brunei: personalization, gender, and generation gap. *Comput. Hum. Behav.* 64, 719–727. doi: 10.1016/j.chb.2016.07.063

Arenz, A., and Schnauber-Stockmann, A. (2023). Who "phubs"? A systematic meta-analytic review of phubbing predictors. *Mobile Media. Commun.* doi: 10.1177/20501579231215678

Arrivillaga, C., Rey, L., and Extremera, N. (2021). Perfil emocional de adolescentes en riesgo de un uso problemático de internet [emotional profile of adolescents at risk of problematic internet use]. *Rev Psicol Clínica Con Niños Adolesc* 8, 47–53. doi: 10.21134/rpcna.2021.08.1.6

Balta, S., Emirtekin, E., Kircaburun, K., and Griffiths, M. D. (2020). Neuroticism, trait fear of missing out, and phubbing: the mediating role of state fear of missing out and problematic Instagram use. *Int. J. Ment. Heal. Addict.* 18, 628–639. doi: 10.1007/s11469-018-9959-8

Bisquerra Alzina, R., and Chao Rebolledo, C. (2021). Educación emocional y bienestar: por una práctica científicamente fundamentada [Emotional education and well-being: for a scientifically based practice]. *Rev. Int. Educ. Emocional Bienestar* 1, 9–29. doi: 10.48102/rieeb.2021.1.1.4

Błachnio, A., and Przepiorka, A. (2019). Be aware! If you start using Facebook problematically you will feel lonely: phubbing, loneliness, self-esteem, and Facebook intrusion. A cross-sectional study. *Soc. Sci. Comput. Rev.* 37, 270–278. doi: 10.1177/0894439318754490

Błachnio, A., Przepiórka, A., Gorbaniuk, O., Bendayan, R., McNeill, M., Angeluci, A., et al. (2021). Measurement invariance of the phubbing scale across 20 countries. *Int. J. Psychol.* 56, 885–894. doi: 10.1002/ijop.12790

Blanca, M. J., and Bendayan, R. (2018). Spanish version of the phubbing scale: internet addiction, facebook intrusion, and fear of missing out as correlates. *Psicothema* 30, 449–454. doi: 10.7334/psicothema2018.153

Burns, M. (2021). *Technology in Education: background paper for 2023 global education monitoring report Technology in education background paper prepared for the 2023 global education monitoring report*. United Nations Educational, Scientific and Cultural Organization.

Cabero Almenara, J. (2015). Reflexiones educativas sobre las tecnologías de la información y la comunicación (TIC). [Educational reflections on information and communication technologies (ICT)]. *Rev. Tecnol. Ciencia Educ.*, 19–27. doi: 10.51302/tce.2015.27

Capilla Garrido, E., Issa, T., Gutiérrez Esteban, P., and Cubo Delgado, S. (2021). A descriptive literature review of phubbing behaviors. *Heliyon* 7:e07037. doi: 10.1016/j.heliyon.2021.e07037

Cebollero Salinas, A., Bautista Alcaine, P., Íñiguez Berrozpe, T., and Elboj Saso, C. (2022). ¿Te importaría prestarme atención? El Phubbing en la adolescencia como reto educativo en la convivencia digital y presencial [Would you mind paying attention to me? Phubbing in adolescence as an educational challenge in digital and in-person coexistence]. *Rev. Complut. Educ.* 33, 601–610. doi: 10.5209/rced.76360

Cebollero-Salinas, A., Cano-Escoriaza, J., and Orejudo, S. (2022). Are emotional e-competencies a protective factor against habitual digital behaviors (media multitasking, cybergossip, phubbing) in Spanish students of secondary education? *Comput. Educ.* 181:104464. doi: 10.1016/j.compedu.2022.104464

Chotpitayasunondh, V., and Douglas, K. M. (2016). How "phubbing" becomes the norm: the antecedents and consequences of snubbing via smartphone. *Comput. Hum. Behav.* 63, 9–18. doi: 10.1016/j.chb.2016.05.018

Chotpitayasunondh, V., and Douglas, K. M. (2018). The effects of "phubbing" on social interaction. *J. Appl. Soc. Psychol.* 48, 304–316. doi: 10.1111/jasp.12506

D'Orey Roquete, M., Sáez-Suanes, G. P., Álvarez-Couto, M., and Hofmann, S. G. (2023). A Spanish adaptation and validation of the interpersonal emotion regulation questionnaire. *Environ. Soc. Psychol.* 8:1697. doi: 10.54517/esp.v8i2.1697

Dahl, D., and Bergmark, K. H. (2020). Persistence in problematic internet use—a systematic review and Meta-analysis. *Front. Sociol.* 5, 1–13. doi: 10.3389/fsoc.2020.00030

Davey, S., Davey, A., Raghav, S., Singh, J., Singh, N., Blachnio, A., et al. (2018). Predictors and consequences of "phubbing" among adolescents and youth in India: an impact evaluation study. *J. Fam. Community Med.* 25, 35–42. doi: 10.4103/jfcm.JFCM_71_17

de Vries, P. J., Davids, E. L., Mathews, C., and Aarø, L. E. (2018). Measuring adolescent mental health around the globe: psychometric properties of the self-report strengths and difficulties questionnaire in South Africa, and comparison with UK, Australian and Chinese data. *Epidemiol. Psychiatr. Sci.* 27, 369–380. doi: 10.1017/S2045796016001207

Dushkin, A., and Barinova, M. (2023). Gender-specific manifestations of phubbing in cadets of higher education institutions of the Ministry of Internal Affairs of Russia. *Russian J. Deviant Behav.* 3, 59–74. doi: 10.35750/2713-0622-2023-1-59-74

Ekimchik, O. A., and Kryukova, T. L. (2022). Measuring Phubbing in Close Relationships: E. Karadağ`s Phubbing Scale and J. Roberts' Scale of Partner Phubbing. *Couns. Psychol. Psychothe.* 30, 112–128. doi: 10.17759/cpp.2022300307

Ergün, N., Göksu, İ., and Sakız, H. (2020). Effects of phubbing: relationships with Psychodemographic variables. *Psychol. Rep.* 123, 1578–1613. doi: 10.1177/0033294119889581

Escalera-Chávez, M. E., García-Santillán, A., and Molchanova, V. S. (2020). Phubbing behavior: is there a gender difference in college students? *Eur. J. Contemp. Educ.* 9. doi: 10.13187/ejced.2020.3.546

Fischer-Grote, L., Kothgassner, O. D., and Felnhofer, A. (2019). Risk factors for problematic smartphone use in children and adolescents: a review of existing literature. *Neuropsychiatrie* 33, 179–190. doi: 10.1007/s40211-019-00319-8

Fusar-Poli, P. (2019). Integrated mental health Services for the Developmental Period (0 to 25 years): a critical review of the evidence. *Front. Psych.* 10:355. doi: 10.3389/fpsyt.2019.00355

Gorla, L., Rothenberg, W. A., Lansford, J. E., Bacchini, D., Bornstein, M. H., Chang, L., et al. (2024). Adolescents' relationships with parents and romantic partners in eight countries. *J. Adolesc.* doi: 10.1002/jad.12306

Guazzini, A., Duradoni, M., Capelli, A., and Meringolo, P. (2019). An explorative model to assess individuals' phubbing risk. *Fut. Internet* 11:21. doi: 10.3390/fi11010021

Guzmán-Brand, V., and Gélvez-García, L. (2022). Phubbing en los adolescentes un comportamiento que afecta la interacción social. Una revisión sistemática. [Phubbing in adolescents a behavior that affects social interaction. A systematic review] (2022). *Rev. Estud. Psicol.* 2, 7–19. doi: 10.35622/j.rep.2022.04.001

Hofmann, S. G., Carpenter, J. K., and Curtiss, J. (2016). Interpersonal emotion regulation questionnaire (IERQ): scale development and psychometric characteristics. *Cogn. Ther. Res.* 40, 341–356. doi: 10.1007/s10608-016-9756-2

Hu, Y., Wang, J., Lin, Y., and Zhang, B. (2023). The relation of parental phubbing to academic engagement and the related mechanisms in elementary students. *Learn. Individ. Differ.* 101:102251. doi: 10.1016/j.lindif.2022.102251

Irarrázaval, M., Prieto, F., and Armijo, J. (2016). Prevención e intervenciones tempranas en salud mental: una perspectiva internacional [prevention and early interventions in mental health: an international perspective]. *Acta Bioethica* 22, 37–50. doi: 10.4067/S1726-569X2016000100005

Karadağ, E., Tosuntaş, Ş. B., Erzen, E., Duru, P., Bostan, N., Şahin, B. M., et al. (2015). Determinants of phubbing, which is the sum of many virtual addictions: a structural equation model. *J. Behav. Addict.* 4, 60–74. doi: 10.1556/2006.4.2015.005

Kong, F., Liu, G., Gao, Q., and Deng, J. (2021). From early to late adolescence: effect of problematic mobile phone use on depression of adolescents. *Sch. Psychol. Int.* 42, 638–656. doi: 10.1177/01430343211039266

Lapierre, M. A., and Zhao, P. (2024). Problematic smartphone use versus "Technoference": examining their unique predictive power on relational and life satisfaction. *Psychol. Popular Media* 13, 23–33. doi: 10.1037/ppm0000438

Liu, M., Kamper-DeMarco, K. E., Zhang, J., Xiao, J., Dong, D., and Xue, P. (2022). Time spent on social media and risk of depression in adolescents: a dose-response meta-analysis. *Int. J. Environ. Res. Public Health* 19:5164. doi: 10.3390/ijerph19095164

Lo, M., Malcom, D. R., and Cain, J. (2022). Prevalence of phubbing by student pharmacists at two colleges of pharmacy. *Curr. Phar. Teach. Learn.* 14, 425–431. doi: 10.1016/j.cptl.2022.03.008

Lopez-Fernandez, O., Griffiths, M. D., Kuss, D. J., Dawes, C., Pontes, H. M., Justice, L., et al. (2019). Cross-cultural validation of the compulsive internet use scale in four forms and eight languages. *Cyberpsychol. Behav. Soc. Netw.* 22, 451–464. doi: 10.1089/cyber.2018.0731

Martín-Albo, J., Núñez, J. L., Navarro, J. G., and Grijalvo, F. (2007). The Rosenberg self-esteem scale: translation and validation in university students. *Span. J. Psychol.* 10, 458–467. doi: 10.1017/S1138741600006727

Mascia, M. L., Agus, M., and Penna, M. P. (2020). Emotional intelligence, self-regulation, smartphone addiction: which relationship with student well-being and quality of life? *Front. Psychol.* 11:00375. doi: 10.3389/fpsyg.2020.00375

McDaniel, B. T., and Coyne, S. M. (2016). "Technoference": the interference of technology in couple relationships and implications for women's personal and relational well-being. *Psychol. Pop. Media Cult.* 5, 85–98. doi: 10.1037/ppm0000065

Mi, Z., Cao, W., Diao, W., Wu, M., and Fang, X. (2023). The relationship between parental phubbing and mobile phone addiction in junior high school students: a moderated mediation model. *Front. Psychol.* 14:1117221. doi: 10.3389/fpsyg.2023.1117221

Moreno, C. R. C., Marqueze, E. C., Sargent, C., Wright, K. P. Jr., Ferguson, S. A., and Tucker, P. (2019). Working time society consensus statements: evidence-based effects of shift work on physical and mental health. *Ind. Health* 57, 139–157. doi: 10.2486/indhealth.SW-1

Navaridas-Nalda, F., Clavel-San Emeterio, M., Fernández-Ortiz, R., and Arias-Oliva, M. (2020). The strategic influence of school principal leadership in the digital transformation of schools. *Comput. Hum. Behav.* 112:106481. doi: 10.1016/j.chb.2020.106481

Nikhita, C. S., Jadhav, P. R., and Ajinkya, S. (2015). Prevalence of mobile phone dependence in secondary school adolescents. *J. Clin. Diagn. Res.* 9, VC06–VC09. doi: 10.7860/JCDR/2015/14396.6803

Ortuño-Sierra, J., Pérez-Sáenz, J., Mason, O., Pérez de Albeniz, A., and Fonseca Pedrero, E. (2022). Uso Problemático de Internet en adolescentes: Validación en español de la Escala de Uso Compulsivo de Internet (CIUS) [Problematic Internet Use among adolescents: Spanish validation of the Compulsive Internet Use Scale (CIUS)]. Adicciones.

Palacios-Rodríguez, A., Llorente-Cejudo, C., and Cabero-Almenara, J. (2023). Editorial: educational digital transformation: new technological challenges for competence development. *Front. Educ.* 8:1267939. doi: 10.3389/feduc.2023.1267939

Parmaksiz, İ. (2021). Predictive effect of phubbing and life satisfaction on depression symptoms in adults. *Bağımlılık Dergisi* 22, 236–247. doi: 10.51982/bagimli.888038

Pérez, A., Belén, , García, G., Ignacio, , Boubeta, R., and Antonio, et al. (2021). Impacto de la tecnología en la adolescencia relaciones, riesgos y oportunidades: Un estudio comprensivo e inclusivo hacia el uso saludable de las TRIC [impact of technology on adolescence, relationships, risks and opportunities: A comprehensive and inclusive study towards the healthy use of TRIC]. UNICEF España. Available at: https://www.observatoriodelainfancia.es/oia/esp/documentos_ficha.aspx?id=7670.

Przybylski, A. K., and Weinstein, N. (2013). Can you connect with me now? How the presence of mobile communication technology influences face-to-face conversation quality. *J. Soc. Pers. Relat.* 30, 237–246. doi: 10.1177/0265407512453827

Purwar, N., Chauhan, A., Pawaiya, A. S., Tyagi, N., Mahajan, H., and Srivastava, S. (2023). Phenomenon and its determinants among medical college students in greater noida: a cross-sectional study. *J Clin of Diagn Res.* 17, LC01–LC06. doi: 10.7860/JCDR/2023/60424/17919

Rial Boubeta, A., Golpe Ferreiro, S., Gómez Salgado, P., and Barreiro Couto, C. (2015). Variables related with problematic internet use among adolescents. *Health Addict.* 15, 25–38. doi: 10.21134/haaj.v15i1.223

Ríos Ariza, J. M., Matas-Terron, A., Rumiche Chávarry, R. P., and Chunga Chinguel, G. R. (2021). Scale for measuring phubbing in Peruvian university students: adaptation, validation and results of its application. *J. New Appr. Educ. Res.* 10, 175–189. doi: 10.7821/naer.2021.7.606

Roberts, J. A., and David, M. E. (2016). My life has become a major distraction from my cell phone: partner phubbing and relationship satisfaction among romantic partners. *Comput. Hum. Behav.* 54, 134–141. doi: 10.1016/j.chb.2015.07.058

Ronseberg, M. (1965). *Society and the adolescent self-image*. Princeton University Press. Available at: http://www.jstor.org/stable/j.ctt183pjjh

Shahibi, M. S., and Rusli, K. N. K. K. (2017). The influence of internet usage on Student's academic performance. *Int. J. Academic Res. Bus. Soc. Sci.* 7, 873–887. doi: 10.6007/IJARBSS/v7-i8/3301

Twenge, J. M., and Campbell, W. K. (2018). Associations between screen time and lower psychological well-being among children and adolescents: evidence from a population-based study. *Prev. Med. Rep.* 12, 271–283. doi: 10.1016/j.pmedr.2018.10.003

Villafuerte-Garzón, C. M., and Vera-Perea, M. (2018). Phubbing y género en un sector académico en Quito: Uso, abuso e interferencia de la tecnología [phubbing and gender in an academic sector in Quito: use, abuse and interference of technology]. *Converg. Rev. Ciencias Soc.* 79:01. doi: 10.29101/crcs.v0i79.9156

Zhang, H., Gao, T., Hu, Q., Zhao, L., Wang, X., Sun, X., et al. (2023). Parental marital conflict, negative emotions, phubbing, and academic burnout among college students in the postpandemic era: a multiple mediating models. *Psychol. Sch.* 60, 1488–1498. doi: 10.1002/pits.22707

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Ethnocultural empathy development of future language teachers through digital multiliteracy resources for low-literacy adult migrants

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The increasingly digital and multicultural 21st-century society requires future teachers to be prepared for the changes and challenges they may encounter. Not only language and digital competences, but critical-thinking and problem-solving skills are needed. Moreover, well developed socio-affective abilities, empathy among them, are also key when dealing with others. This is even more relevant when teachers are to work with a non-mainstream population, such as adult migrants with low literacy levels, and to design student-centered curricula or activities. Empathy is a multifaceted process involving, among others, perception, intellection, affect and other sensory aspects of the lived experience. It has been argued that the first-person perspective-taking involved in empathic engagement must necessarily involve rational computation and cognitively mediated processing. Training future teachers in the Pedagogy of Multiliteracies is a means to integrate multimodal digital instruction and aggregate cognitive as well as socio-emotional features to the education of future language teachers.

Method: A mixed-method pre-post study was conducted with 48 trainee teachers who participated in stand-alone digital multiliteracy interventions, in which they were encouraged to envisage themselves as future teachers of low-literate migrants. Policy documents such as the reference guide on Literacy and Second Language Learning for the Linguistic Integration of Adult Migrants, journal articles, audiovisual resources as well as examples of existing educational materials aimed at the target audience, were made available to them on an online platform. In two separate studies, trainees were encouraged to collaboratively produce two different multimodal outputs. The Revised Scale of Ethnocultural Empathy was administered before and after the intervention, subjecting the data obtained to quantitative analysis. Qualitative data was also collected to gain a better understanding of the affective and cognitive processes experienced by the participants.

Results: Simple statistical analysis coupled with the comparison of means was used to respond to the research questions. Statistical hypothesis testing, including correlations and non-parametric statistics were used to analyze the relationship between each of the factors within the RSEE and the participants, considering the different interventions applied. Non-parametric tests (U-Mann Whitney) were used to compare the differences between the levels of ethnocultural empathy of the participants in the two studies. Significant differences were found in

Factor 3 (Empathy) and Factor 5 (Anxiety) between the groups and their post-intervention results, with a *p* value of 0.053 and 0.038, respectively. The effect size r was calculated, obtaining a size effect of 0.625 for Factor 3 (Empathy) and 0.674 for Factor 5 (Anxiety). These results indicate that the significant differences and the size effect between both groups are large. U-Mann Whitney non-parametric analysis also revealed gender differences in Factor 3 (Empathy), showing females higher levels than males. Effect size r analysis showed a large size effect of 0.708 for Factor 3 (Empathy). The findings pertaining to gender-related differences in empathy levels confirm the conclusions drawn by previous studies. When contrasting study 1 and 2, statistical differences were also shown after the intervention for the 'Anxiety and Lack of Multicultural Self-efficacy' factor. The qualitative data analysis was carried out with Atlas.ti v.8, in order to isolate and categorize the broader themes and the most significant explanatory quotes extracted from the participants' records and interviews. The results reveal the learning strategies that each group of learners applied to successfully complete the task at hand, as well as the participants' deployment of their critical thinking skills and the awakening of a sense of awareness of their own professional competence development process.

Conclusion: This study set out to compare how effective two digital multiliteracy interventions were in developing future language teachers' ethnocultural empathy and cognitive abilities when appraising the educational needs of low-literacy migrants. Despite the small sample size, the study certainly adds to our understanding of the impact of multimodal tasks involving critical thinking skills on trainees' cognitive and affective abilities. Besides, it expands the growing body of research that points to the desirability of embedding digitally-based content creation tasks in training curricula for future language teachers.

KEYWORDS

ethnocultural empathy, language teacher education, critical thinking skills, multiliteracy, digital resources, multimodality

1 Introduction

In an increasingly diverse society, with constant migration bringing people from different linguistic and cultural backgrounds into the educational systems of receiving countries, teachers need to be well prepared for the changes they will encounter. In particular, language teachers play a critical role in facilitating the integration of migrants into their host communities (Carlsen et al., 2023), as becoming literate in an additional language is often part of the survival kit that migrants need. In fact, individuals whose language is different from the dominant one in the country tend to have lower literacy levels, a tendency increasing with age (OECD, 2017). This also reduces migrants' employability rates, wages (Himmler and Jäckle, 2018), in general, hinders their successful participation in society (Joyce, 2019), and potentially leads to social exclusion (Leone et al., 2005). This situation is replicated from one generation to the next, as children of parents with low educational attainment and a lower socio-economic status are prone to have poor literacy skills themselves (Hemmerechts et al., 2017; Fernández-Corbacho, 2018). The circumstances are even more complex for those migrants who, upon arrival, are faced with the need to acquire both oral and literacy skills in the target language, which poses additional problems for communication and involvement in the societies they wish to live in (Minuz et al., 2022). They typically find themselves in a situation where they have little exposure to the new language, lack the time to attend classes due to family and work obligations; and, if able to attend class, the large variance in what are often mixed-ability classrooms prevents individuals from receiving the attention they need to progress (Haznedar et al., 2018). Consequently, language teachers should not make assumptions about their learners' abilities and should be aware of the diverse and complex cognitive skills they need to develop (Gonzalves, 2021), as they are different from the mainstream learners they are usually trained to attend to. Namely, adult migrants are already speakers or readers of other languages and these home languages are valuable resources that can help them become interculturally competent citizens, as Haznedar et al. (2018) point out. Moreover, being orally competent or literate in the home language reduces marginalization and increases empowerment within the community. In all cases, these adults require qualified teachers who provide the specialized instruction necessary to reflect the diverse language profiles of individuals in a classroom (Haznedar et al., 2018).

Regarding educational contexts, migrant students are reported to have decreased levels of *affective happiness* (Rodríguez et al., 2020). Furthermore, research has shown that the negative stereotypes that educators hold about migrant pupils are detrimental to how they perform academically (Froehlich et al., 2022). Thus, language teachers need to gain an understanding of the affective factors that might have a positive or negative bearing on learners' performance, such as

beliefs, identity, anxiety or motivation, which are particularly useful when considering the adult language learning process (Fonseca-Mora, 2023). However, Canales and Rovira (2016) report the scarce development of socioemotional or socio-personal competencies in teacher training, attributing it to the current lack of emotional literacy in society, and insisting on the need to address psychosocial well-being and empathy in teacher training courses. It is also of utmost importance that teachers be aware of their own bias towards diversity in their classroom; in this sense, fostering teacher empathy is key. It is therefore imperative to address this concern in teacher education programs, which must be able to respond to the needs of adult learners with a migration background, arising from the unique experiences and challenges they face in their daily lives. Adult migrant learners may be exposed to situations of violence, racism and hostility that affect their ability to participate fully in language learning (Baynham, 2006). With these potential struggles in mind, Mercer (2016) outlines how promoting empathy improves group dynamics and cultivates cooperative and collaborative relationships among students, which, in turn, fosters an environment conducive to effective language learning and the strengthening of interpersonal and communicative skills.

Despite these earlier contributions, a recent review of trainee teachers' practical experiences in their classroom interactions reveals that student teachers often harbor negative beliefs and concerns about working with learners of non-native backgrounds, while acknowledging the importance of empathy in their training to educate them (Hanna, 2023). Cognitive perspective-taking, implying the integration of one's own and others' mental representations, has been found to mitigate intergroup assumptions, biases and preconceptions towards stereotypical target groups, and has therefore been proposed as a possible means of stimulating the willingness to engage in cross-group contact and initiate rapprochement-oriented actions (Wang et al., 2014). Mutual comprehension towards others and readiness for intergroup collaboration might also be attained through fostering empathy, that is, the affective state elicited by experiencing the emotions of the other, in the awareness that those third-party emotions are the source of one's affective state (de Vignemont and Singer, 2006). This cognitive-affective dichotomy may be problematic, as earlier works have identified how perspective-taking towards oneself may attenuate positive emotions (Wallace-Hadrill and Kamboj, 2016) or even exacerbate out-group rejection (Klimecki et al., 2020).

Given that cultivating positive other-regarding emotions is thought to be one of the mechanisms for inducing empathy towards individual subjects, which can generalize to favorable attitudes towards other members of the target group (Klimecki, 2019) and which is essential for effective intercultural communication (Mercer, 2016), further research exploring these links has been encouraged. In this light, Martínez-Otero Pérez (2011) raises the need to promote empathy in university curricula for the training of education professionals, placing special emphasis on the incorporation of the empathic intersubjective educational style in the instructional process. Such style, which entails a "balanced cognitive and affective approach to the emotional reality of others" (equilibrada aproximación cognitiva y afectiva a la realidad emocional ajena) (Martínez-Otero Pérez, 2011, p. 187), is instrumental in the training for future teachers and educators. Similarly, Warren (2018) argues for the provision of a curriculum that supports empathic dispositions in teacher education programs as a forerunner of culturally responsive teaching approaches which cater to culturally and linguistically diverse students. Thus, language classes for migrants should be adapted to enable effective learning of a new language in a context that recognizes and respects their cultural identities and prior experiences, so that "the identity of 'student' itself can constitute a stable point in the highly unstable lifeworld" (Baynham, 2006, p. 25).

Whilst general empathy may be defined as the ability to relate to another person's emotions with a certain degree of understanding of their emotional state (Decety and Jackson, 2004), ethnocultural empathy, also referred to as cross-group empathy (DeTurk, 2001), could be defined as the empathy felt towards people from other cultures which, in order to thrive, challenges obstacles not encountered in having empathy towards those belonging to the same cultural community. In that vein, the first instrument available for assessing ethnocultural empathy, the Scale of Ethnocultural Empathy (Wang et al., 2003), adopted a culture-oriented framework with and ethnic perspective, and operationalized ethnocultural empathy as composed of three dimensions: intellectual empathy, that is, "ability to understand a racially or ethnically different person's thinking and/or feeling"; empathic emotions, which implies "to the feeling of a person or persons from another ethnocultural group"; and communicative empathy, which is the "expression of ethnocultural empathic thoughts (intellectual empathy) and feelings (empathic emotions)" (p. 222). Nonetheless, Rasoal et al. (2011b) found "strong correlation between *basic* and ethnocultural empathy" (p. 927), implying that the two overlap considerably. In this regard, both are regarded as flexible human capacities, whereby basic empathy is "susceptible to social-cognitive intervention, such as through training or enhancement programs for targeting various goals" (Decety and Jackson, 2004, p. 94) and ethnocultural empathy is deemed "something dynamic that can be learned and developed over time" (Rasoal et al., 2011a, p. 8), and therefore, amenable to expansion. In the same vein, Meskill (2005) found that in-service and pre-service foreign language teachers gained greater sensitivity to intercultural differences when teacher education programs featured training opportunities to foster their empathy towards students from other countries.

More recently, a range of studies have underscored the importance of intercultural empathy for pre-service second language teachers. Whitford and Emerson (2019) found that cultural empathy positively correlates with multicultural sensitivity and understanding and can thus reduce implicit out-group bias. Kapıkıran (2023, p. 11510) affirms that ethnocultural empathy may reduce "conflicts and discriminatory attitudes in preservice teachers." Trainee teachers' reported levels of ethnocultural empathy score high (Tutkun, 2019), being attributed to the fact that teaching is strongly correlated with altruistic behavior and empathetic attitudes. In other words, second language teachers are ideally placed to mediate the successful socialization of migrant learners in the local school setting, as they tend to show higher levels of openness to new situations, empathy and understanding of the difficulties faced by multilingual learners (Rokita-Jaśkow, 2023). Indeed, when working with a diverse student population, the appropriate use of "intercultural empathy and positive affect ensures effective communication" (Yang et al., 2019, p. 309) and supports the building of rapport between diverse students and teachers. Along the same lines, Hanna (2023) posits that disregarding the role of empathy as a core value for prospective teachers is linked to the difficulties in nurturing critical self-reflection among aspiring educators and raises

questions about the adequacy of initial teacher education in preparing them for engaging effectively with migrant students.

As Mercer (2016) points out, trainee teachers' awareness of the importance of interpersonal skills in language learning can help them to assess the potential effects that such skills have on classroom life and cross-cultural communication. Prospective empathetic teachers therefore require cognitive skills to interpret emotional cues, adopt diverse perspectives, and foster an inclusive and supportive learning environment (Underhill, 2013). In addition, critical thinking (CT) skills remain essential in equipping qualified citizens to face the challenges of ever-shifting digital environments that are transforming society (Lincoln and Kearney, 2019). Along the same lines, Mallinckrodt et al. (2014) point to the expanding body of research linking multicultural university programs to increases in students' empathy, intergroup understanding, communication skills and CT skills. CT is thus even more central to teacher education, since learners need to be provided with the skills to become effective and creative educators of new generations. Research shows that higher levels of teachers' cognitive skills raise pupil performance significantly (Hanushek et al., 2014). However, teachers first need to develop CT themselves to promote it in their students (Lorencová et al., 2019).

Over the past few decades, the concept of CT has been iteratively addressed and defined. However, the conceptual framework developed by the Delphi Committee in 1990 is probably the most widely used in research on the subject. The so-called *Delphi Report* defines CT as "purposeful, self-regulatory judgment which results in interpretation, analysis, evaluation, and inference, as well as explanation of the evidential, conceptual, methodological, criteriological, or contextual considerations upon which that judgment is based" (Facione, 1990, p. 3). Apart from this definition, six key cognitive skills, which the ideal critical thinker is expected to develop, have been identified: interpretation, analysis, evaluation, inference, explanation and self-regulation, each of them comprising several sub-skills (Table 1).

TABLE 1 Framework of critical thinking skills (Facione, 1990, 2020).

Skills	Sub-skills
1 Interpretation	Categorization
	Decoding significance
	Clarifying meaning
2 Analysis	Examining Ideas
	Identifying arguments
	Analyzing arguments
3 Evaluation	Assessing claims
	Assessing arguments
4 Inference	Querying evidence
	Conjecturing alternatives
	Drawing conclusions
5 Explanation	Stating results
	Justifying procedures
	Presenting arguments
6 Self-regulation	Self-examination
	Self-correction

Although research points out that effective CT development requires explicit instruction for learners (Abrami et al., 2008; Marin and Halpern, 2011), some positive results can also be achieved, albeit to a lesser extent, without working specifically on CT (Lorencová et al., 2019). However, other variables can affect the effectiveness of such interventions, like teachers' specific training on CT (Lorencová et al., 2019). In any case, as Dwyer et al. (2014) point out, the use of CT skills should be encouraged in all problem-solving and other real-life tasks undertaken in the classroom, as learners need to be prepared to critically appraise new information "so that they can constructively solve problems, draw reasonable conclusions and make informed decisions" (p. 50). Not only is teaching CT crucial, as it develops decision-making and problem-solving skills, but it also supports the development of dispositional factors (Dwyer et al., 2014) that lead to acting critically. That is, it is a two-way relationship, in which both CT and higher-order thinking skills come into play when learners have to make decisions to complete a complex task that requires effective problem-solving (Snyder and Snyder, 2008). Thus, CT skills could be developed through the introduction of action-oriented tasks whereby learners are expected to collaborate and mediate in producing a multimodal final product which also involves problem-solving skills.

In our ever-changing digital and multicultural societies, developing literacy skills among migrant populations can be a challenging task for educators. In fact, the concept of literacy has evolved over the last decades, not only referring to reading and writing, but extending to the OECD concept of "understanding, using, evaluating, reflecting on and engaging with texts in order to achieve one's goals, to develop one's knowledge and potential and to participate in society" (2019, p. 28). This definition also includes screen-based text, which is in line with current common digital practices. Indeed, the texts that we use to communicate contain multimodal elements, such as visual, oral, or gestural input, reflecting the ways in which people make meaning depending on their sociolinguistic and cultural backgrounds. Those enriching socially-situated literacy practices are acknowledged by the Pedagogy of Multiliteracies (New London Group, 1996) and have an impact on literacy development (Cope and Kalantzis, 2000). In this pedagogical approach learners are considered active participants, producers of texts that convey the diversity of our multilingual digital society. In the classroom, this requires inclusive and equitable pedagogical practices (Warren and Ward, 2019) that spur a process of transformation in learners. Consequently, the multiliteracy-based Learning by Design framework (Yelland et al., 2008) puts an emphasis on teaching practices that require learners' deep reflection and decision making. In this line, previous studies advocate for the use of multiliteracies to develop learners' CT skills. Zhang-Leimbigler (2014) affirms that when a multiliteracies approach is introduced, students become more involved in observing and analyzing their performance, and in transferring their learning to new situations. In fact, critical literacy is central to multiliteracies, as Warner and Dupuy (2018) assert, "literacy involves critical thinking and in particular the awareness that texts are not neutral" (p. 124). On the other hand, critical literacy requires educators to be active designers of social change. That is, multiliteracies call for literacy practices that lead to social justice through a critical approach to learning in language teacher education programs, which should promote the recognition of diverse meaning-making practices. Thus, when working with diverse learners, multiliteracies create spaces for analyzing the complex situations and experiences of adult learners. In

the case of migrant learners, well-trained educators can help them to transfer their skills from familiar contexts to the new situations they encounter in the host countries.

As indicated above, the concept of multimodality is central to multiliteracies: a multimodal way of meaning making includes linguistic (oral and written), visual, audio, gestural, tactile, and spatial patterns (New London Group, 1996). Thus, individuals have to learn how to acquire and construct knowledge from many different sources and representation modes. In fact, previous research (Gouthro and Holloway, 2013) has found benefits for culturally and linguistically diverse learners when they use more inclusive broader literacy practices, associated with multiliteracies. A multimodal approach to literacy can promote lifelong learning; multiliteracies also promote a positive approach to language diversity, and a more flexible and multilingual approach to language learning, for example through the recognition and validation of the use of vocabulary from learners' mother tongue (Holloway and Gouthro, 2020). As stated in Ávila-López and Rubio-Alcalá (2023) systematic review, effective multiliteracies teaching practices embrace the potential of multimodalities to improve multilingual competences. Moreover, "multiliteracies and multimodality foster creativity and criticality, engage marginalized learners, and provide greater versatility in meaning-making practices" (Holloway and Qaisi, 2022, p. 85). Consequently, taking a multiliteracies approach to language teaching requires educators to acknowledge the different modalities in which students engage in the learning process (Holloway and Gouthro, 2020).

As García-Barroso and Fonseca-Mora (2023) conclude in their narrative review, the use of digital technologies facilitates literacy development of adult learners of additional languages by promoting the digital practices and skills required for navigating the multimodal texts encountered in everyday life. In fact, digital technologies are not new to migrants, who, in many cases, are defined as "connected migrants," based on the digital communication practices during their migratory experience (Diminescu, 2008). Furthermore, they engage in multilingual practices that promote their literacy skills (D'Agostino and Mocciaro, 2021). Regarding educators, it has been argued that the use of digital tools and adapted computer and authoring technologies raises trainee teachers' interest in their future career and in the development of a culture of empathetic behavior to a greater extent than the application of traditional training methods (Salamatina, 2019). Similarly, previous studies have shown that the use of audiovisual material in the training of future language teachers can cultivate empathetic attitudes, enabling trainees to relate to their future learners and appreciate the challenges that those learners might experience during the L2 acquisition process (Lee, 2019). New avenues of research have recently been pursued within this domain, extending the existing traditional notion of empathy to the digital realm and conceptualizing constructs such as *digital empathy*, understood as "the cognitive and emotional capacity to be reflective and socially responsible in the strategic use of digital media" (Jiang and Gao, 2020, p. 72). Fundamentally, Jiang and Gao's study (Jiang and Gao, 2020) sought to identify empathic changes, as well as their affective or cognitive nature, arising from an innovative pedagogical intervention which engages foreign language learners in the creation of multimodal content. One conclusion that emerges is the need for teachers and practitioners to embrace a multimodal approach to language teaching, regarding language as a semiotic device for meaning-making and broadening the focus of language learning to achieve "more empathetic and responsible literacy practices through digital tools" (Jiang and Gao, 2020, p. 83). Such practices enhance teacher education by helping student teachers to become critically reflective educators.

In the light of the studies reviewed above, the undertaking of action-oriented tasks that require learners to collaborate and mediate concepts and communication in order to make decisions, solve problems and produce a multimodal product aimed at low-literacy migrants could promote future teachers' ethnocultural empathy and CT skills. Thus, in our study, the main objective of the interventions carried out was to raise learners' awareness of the linguistic and social needs of adult migrants for their inclusion into the host society. In addition, learners' empathy toward the migrant population was expected to be developed. Besides, by introducing multiliteracy activities focused on the development of empathy, we expected learners to activate self-regulating CT skills. To that end, this study set out to compare how effective two digital multiliteracy interventions were in developing future language teachers' ethnocultural empathy and cognitive abilities when appraising the educational needs of low-literacy migrants.

Specifically, the research questions guiding our study are:

> RQ1: Can student teachers' ethnocultural empathy be developed by designing multimodal products related to low literacy adult migrants?
>
> RQ2: Does ethnocultural empathy unfold differently depending on the type of multimodal product designed by student teachers?
>
> RQ3: What differences can we observe across the other variables studied in the sample, such as sex, CT skills or academic attainment and the development of ethnocultural empathy?
>
> RQ4: What cognitive processes/abilities and CT skills are promoted while designing multimodal products intended for adult migrants?
>
> RQ5: What perceptions about their experience during the production of multimodal outputs do participants report?

2 Methods

2.1 Participants

A total of 48 participants initially started the research. Their informed consent was obtained at the beginning of the study. A total of 6 participants were excluded from the study due to discontinued involvement or age disparity. They were a group of third-year undergraduate students of both English Studies and the double degree program in English and Hispanic Philology in an Andalusian university, who were enrolled in a language acquisition course featuring a language teacher education module. They were randomly split into two different groups (study 1 and study 2) depending on the task they were assigned. Therefore, the participants in study 1 were instructed to create teaching materials; whilst the participants in study 2 had to create a video. When considering the total group, the sample was not representative in terms of gender. Of the final sample of 42 participants 13 were male (31% of the total sample) and 29 were

TABLE 2 Sociodemographic descriptive statistics for the sample.

		Frequency	Percentage
Volunteering	No	38	90.5
	Yes	4	9.5
Mother tongue	Spanish	36	85.7
	French	1	2.4
	German	1	2.4
	Turkish	3	7.1
	Spanish_Darija	1	2.4
Nationality	Spanish	35	83.3
	French	1	2.4
	Turkish	2	4.8
	Moroccan	1	2.4
	Chinese	1	2.4
	Mexican	1	2.4
	Italian	1	2.4
English level	B1	4	9.5
	B2	13	31
	C1	22	52.4
	C2	3	7.1

female (69% of the total sample), with mean age of 21 years old and standard deviation of 1,274; the age range was between 20 and 25 years old. In turn, the group that participated in study 1 comprised a total of 11 male participants (46%) and 13 female participants (54%); the group that participated in study 2 consisted of a total of 2 male participants (11%) and 16 female participants (89%). Table 2 summarizes the descriptive statistics for the sample.

The group is characterized by a predominance of Spanish participants (83.3%) and a small but varied representation of other nationalities (16.6%) and mother tongues. The participants were also asked about their experience in volunteering programs with migrants. Again, there is a large majority who have no experience in this context, in fact, only 9.5% had been volunteers working with the migrant population. Besides, 25% had attended a workshop where they had been interacting with migrants. However, the high variability and low representation of each group makes it difficult to carry out statistical analyses for comparative purposes.

2.2 Instruments

2.2.1 Revised scale of ethnocultural empathy, Spanish version

Finck et al. (2021) adapted the Everyday Multicultural Competencies Scale/Revised Scale of Ethnocultural Empathy (EMC/RSEE; Mallinckrodt et al., 2014) to be administered to Spanish speaking university students in Colombia. This validated Spanish version has introduced some changes to the original tool: the number of items is slightly reduced, and cognitive and affective empathy are merged into one single factor. Thus, the 5 resulting factors are: (1) "Cultural Openness and Desire to Learn" (Cultural Openness hereafter), (2) "Awareness of Contemporary Racism" (Awareness of Racism, henceforth), (3) "Empathy," (4) "Resentment and Cultural Dominance" (from now on, Resentment) and (5) "Anxiety and Lack of Multicultural Self-Efficacy" (hereafter Anxiety). The scale is based on the notion of intercultural competence, which comprises communication as well as "effective and appropriate behavior across intercultural situations" (Finck et al., 2021, p 164), and aims at measuring learners' empathy toward population from diverse linguistic and sociocultural backgrounds, as well as considering issues of racism or the lack of self-efficacy in members of the dominant cultural community. All the items can be found in Finck et al. (2021, p. 175).

2.2.2 Reflection logs and interview

At the end of the interventions different tools for collecting qualitative data were used. In study 1 each participant completed a reflection log. They were asked to reflect on the difficulties and positive aspects of the project, their perception of what they had learnt, what had helped them, and their opinion about the products they had designed. In study 2, a group of three students participated in an in-depth semi-structured interview. They were all asked questions about the intervention, they were encouraged to talk about the final task they had completed and give their opinion about the knowledge they had gained and how it could impact their future teaching practices.

2.2.3 Final products designed by participants

Data on their academic attainment has been collected through the grades they received in the final products they designed. Students participating in study 1 were divided in groups of 4–5 and required to design teaching materials for migrants, more specifically, a bilingual (English–Spanish) teaching unit to teach the target language to low-literacy adult migrants. The materials created had to fulfil several criteria: select a relevant topic for the target learners; include the descriptors presented in the reference guide on Literacy and Second Language Learning for the Linguistic Integration of Adult Migrants (LASLLIAM; Minuz et al., 2022); identify an adequate difficulty level; and adhere to a multimodal design.

In study 2, participants divided in groups of 3 were asked to read an article about the situation of low-literacy migrants. Then, participants had to create a video presenting the key contents and the conclusions they drew from the reading. They also had to add images, subtitles, and their own voices. This ensured the delivery of a multimodal, audiovisual digital product. At the end of the video, 3 comprehension questions for viewers had to be included. Both conceptual and technical aspects were considered in the evaluation of students' video submissions.

2.3 Procedures

2.3.1 Intervention

The intervention took place during the second semester of the academic year 22/23, in a module specifically related to teaching languages to migrants within a language acquisition course. Two studies were carried out. In both cases, a digital technology-supported six-week intervention was delivered in a language teacher education course. The main objectives were to raise prospective teachers' awareness of the linguistic and social needs of adult migrants, as well as to promote participants' empathy toward the migrant population

and to activate self-regulating CT skills. A wide range of resources were made available in an online platform: policy documents, such as the reference guide on Literacy and Second Language Learning for the Linguistic Integration of Adult Migrants (Minuz et al., 2022), journal articles, audiovisual resources and examples of existing educational materials intended for the target audience. Learners were encouraged to make use of interactive online tools for in-class and out-of-class activities when needed. Both interventions were similar in terms of contents and materials used, but learners were required to design two different final products. The interventions followed the same pattern: the first step focused on getting familiar with the main concepts dealt with in the project: literacy, multiliteracies or multimodality; the second step zoomed in on the target population, who they are, or their linguistic and social needs. Finally, in study 1 existing teaching materials were analyzed in terms of their appropriateness for the target group.

The main task students had to undertake was different for each of the two groups. As described above, in study 1, learners were distributed in seven heterogeneous groups, consisting of students from both degree programs and international students. and were asked to design teaching materials. They were expected to understand the main concepts of the project, consider migrants' needs, critically analyze teaching materials, and finally apply what they had learnt to create new teaching materials. In study 2, learners, organized in eight groups, focused on the trajectories of low-literacy migrants. After reading a text, selected for its appropriateness to the students' knowledge and assignment objectives (see Adami, 2008), learners had to turn the written information into a digital product. To do this, they had to identify the main ideas, explain them in their own words, and illustrate them with examples. In this case, learners were expected to be able to analyze and synthesize the information in the article, to present it using their own words, accompanied by relevant pictures and other visual cues. As for technical and digital elements, they were required to include subtitles and narrate the resulting text themselves in voice-over. Both contents and technical aspects were evaluated. In both studies, the final products had to be uploaded to the online platform used in the course.

The interventions followed the guidelines of the Leaning-by-Design framework (Yelland et al., 2008), which promotes the use of problem-solving and higher-order thinking skills, and is based on the Pedagogy of Multiliteracies (New London Group, 1996; Cope and Kalantzis, 2000). In both cases, learners worked in groups to make decisions and collaborate, in order to successfully complete the task. They had to compromise to reach agreements within their groups, but also to put themselves in the shoes of adult migrants and try to understand migrants' reality and difficulties so that they could fully grasp their educational needs (in study 1), whereas in study 2 they also had to mediate the written text and transform it into a multimodal audiovisual product.

The RSEE was administered before and after the interventions. Besides, once the interventions had finished, the participants in study 1 were asked to complete a reflection log to ponder on the difficulties encountered and positive aspects they had experienced during the project. In study 2, an in-depth semi-structured interview was conducted. Discussion was prompted by a predetermined set of questions which led to a more open exchange among the participants.

2.3.2 Data collection

Quantitative data was collected via *Google Forms,* where participants had to self-generate a unique code to protect anonymity. Apart from the answers to the RSEE, the form collected demographic and other relevant information, such as age, gender, nationality, or volunteering experience. The RSEE items follow a *Likert* format with responses ranging from 1 = strongly disagree, to 6 = strongly agree. Later, the final grades obtained in the allotted task were added to the database.

Following the administration of the scale, qualitative information was collected to better understand participants' experiences. This approach makes it possible to describe subjectively perceived phenomena at the individual and group level in greater detail and to explore the links between the themes mentioned by the participants (Mezmir, 2020). Following Mezmir's recommendation to "ensure that a range of different cases, sources, and time periods are reviewed" (Mezmir, 2020, pp. 17–18), two different techniques were applied to obtain the qualitative data: the compilation of logs written by the students in study 1, and in-depth semi-structured interviews with three participants selected from study 2. The use of the reflection logs and the interviews is in line with previous studies that have reported results related to critical thinking "based on qualitative methods, such as an analysis of texts (i.e., reflective reports, blog entries, …)" (Lorencová et al., 2019, p. 8). Thus, the qualitative analysis of the participants' narratives was expected to provide information about the learners' cognitive processes and critical thinking skills, as well as other aspects related to the design of the final products. Finally, students' grades were collected at the end of the intervention.

2.4 Data analysis

2.4.1 Quantitative analysis

The first part of the quantitative analysis consisted in the generation of the descriptive data for all variables, including sex, age, nationality, mother tongue and volunteering experience. Later, the five factors included in the RSEE were analyzed. Factor scores were used to analyze the 5 factors of the RSEE scale. As the RSEE used was not validated for the target population in this study, using factor scores would facilitate the interpretation of the results. The computed factor scores are standardized to a mean of zero. Sex was classified as male and female. Non-parametric tests were used to compare the differences between participants for study 1 and study 2, and sex with the different factors of the RSEE. Spearman correlations and the proposal of a moderation model was intended. Statistical analysis was performed using SPSS software (version 25).

2.4.2 Qualitative analysis

Data from the student logs and transcripts from the in-depth interviews were compiled and imported into the qualitative analysis software *Atlas.ti v.8* after being anonymized.

Coding, searching for themes and clustering were carried out according to the framework of CT skills and sub-skills proposed by Facione (1990, 2020), as well as to other emerging categories identified during the text analysis process. Each of the three researchers independently reviewed the data, generated the initial codes, and refined them collaboratively in a shared codebook, following

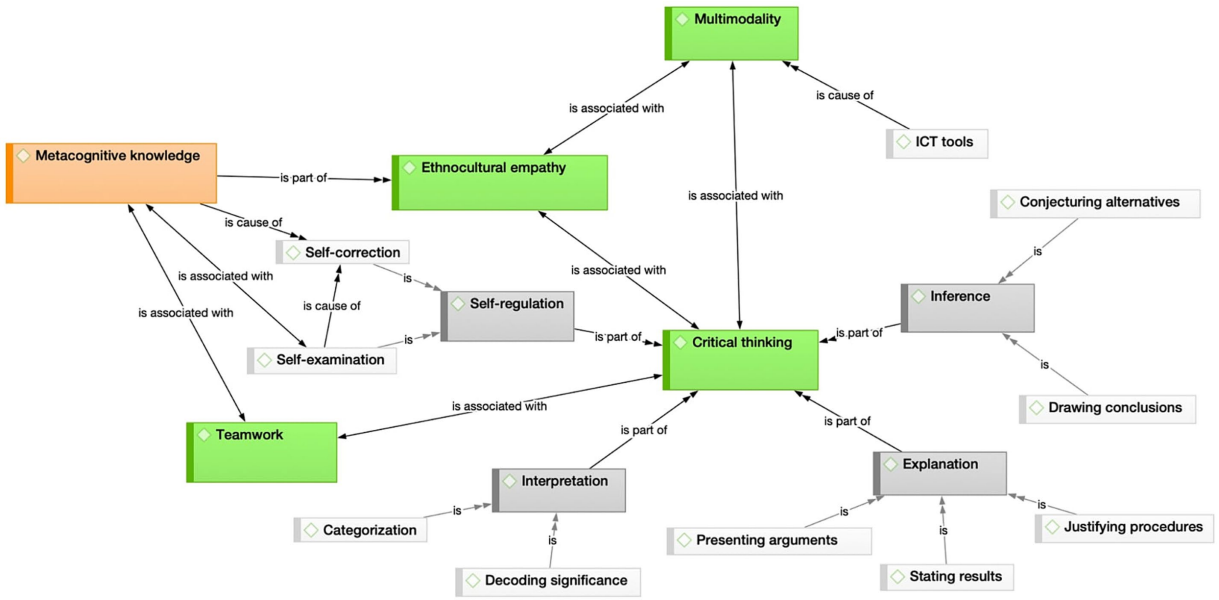

FIGURE 1
Relational patterns between the topics that emerge in the students' logs (study 1).

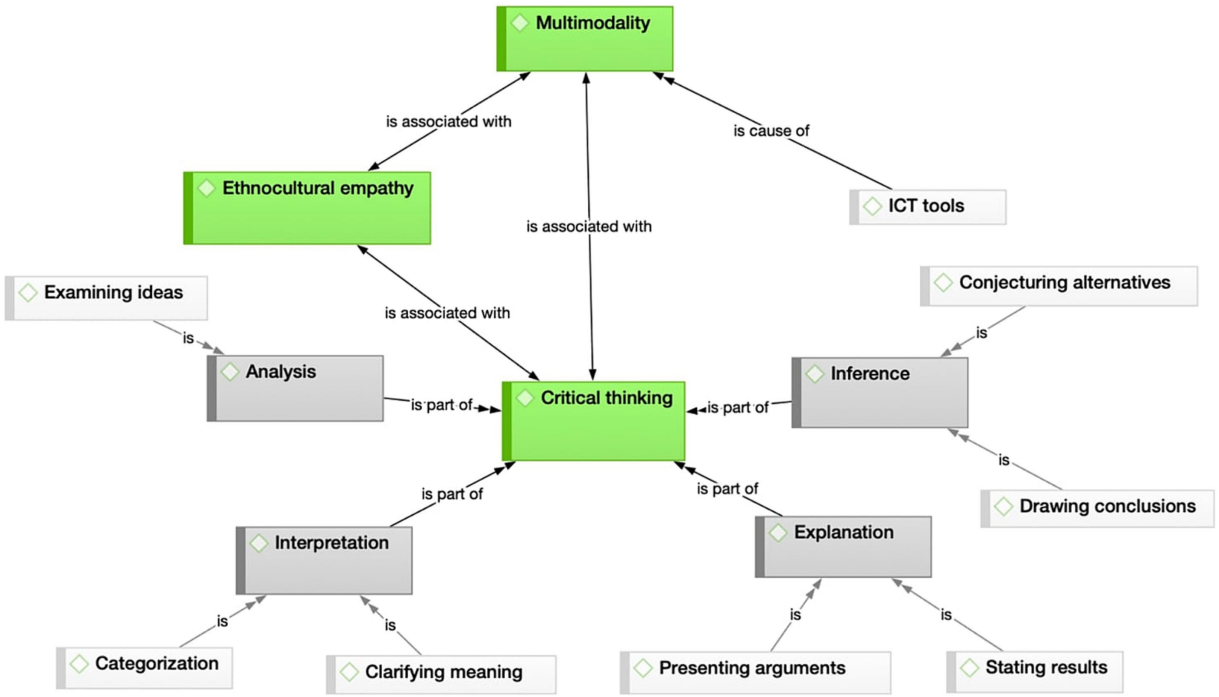

FIGURE 2
Relational patterns between the topics that emerge in the in-depth interviews (study 2).

consensus reached in group discussions to ensure consistent coding practices.

Data reduction was done by grouping the codes into broader categories and overarching themes. Axial coding was then undertaken using the *Atlas.ti* v.8 functionalities to remove overlapping codes and redundancies, revealing the dominant codes, matching them with their sub-categories, and determining the attributes and dimensions of each of them. Finally, the quotations extracted from participants' logs and interviews were assigned the corresponding codes.

In addition, a visual representation of the relationships between codes and categories for each subset was generated (Figures 1, 2) to enhance the understanding of data patterns. Color coding has been used to distinguish the main categories identified. Thus, the thematic nuclei that provide the backbone of this study, and the categories and

subcategories described by Facione (1990, 2020), are shown in green, gray, and white, respectively. In Figure 1, in addition, the color red is added to round off Facione's (1990, 2020) framework with the notion of metacognition, as reflected in the students' logs.

Although the following section will detail the differences, similarities and implications of the inter-group comparison, a preliminary overview reveals a similar underlying structure, but also the greater complexity present in group 1, illustrated by the 'self-regulation' cluster in the top left of Figure 1.

This first visual approximation also provides a means of comparing the CT skills exercised by the two cohorts, which coincided in three of the four categories reported by each group, namely 'inference', 'explanation' and 'interpretation'. Similarly, it is also possible to discern the absence in both groups of the category 'evaluation' that Facione's (1990, 2020) framework includes.

A final consideration evidenced by the exploratory visual contrast between these two figures is that Figure 2 does not feature any allusions to teamwork, an aspect that will also be discussed in the sections below.

3 Results

3.1 Quantitative

Regarding the first research question, a first approximation is made based on quantitative data. Simple statistical analysis was used initially to describe the data that had been collected and variables that will be later analyzed. The factor scores for each of the factors in the RSEE were used to perform the subsequent analyses.

To descriptively compare the differences between before and after the intervention, the minimum and maximum scores registered (Mean = 0) are displayed in Table 3.

As we can see in Table 3, among the studied sample, the lowest scores before the intervention, as well as after the intervention, were obtained in Factor 1 (Cultural Openness). Their highest scores before the intervention were obtained in Factor 4 (Resentment) whilst after the intervention, the highest were obtained in Factor 5 (Anxiety). Overall, the results point in the desired direction. There is a slight improvement in all factors after the intervention, except for cultural openness. In addition, the results indicate a decrease in the lowest scores after the intervention; although they are still negative, in some cases they have improved by one point. However, the differences found before and after the intervention for the whole sample are not statistically significant.

Moving on to the second research question, to know whether ethnocultural empathy unfolds differently depending on the type of multimodal product designed, we aimed to contrast the ethnocultural empathy levels of the two groups of participants who produced different final outcomes during the interventions: study 1 and study 2. Figure 3 shows how the factors differed between the two experimental groups before and after the intervention. From the figure we can observe that the results of study 1 for all factors except for Factor 3 (Empathy) show an

TABLE 3 Descriptive statistics for the total sample in each factor before and after the intervention.

Variable	*N*	Minimum	Maximum	Variable	Minimum	Maximum
PRE_Cultural openness and desire to learn	42	−3.71379	1.09919	POST_Cultural openness and desire to learn	−2.87672	1.06808
PRE_Awareness of contemporary racism	42	−2.73111	1.20204	POST_Awareness of contemporary racism	−2.24118	1.24376
PRE_Empathy	42	−2.64050	1.20254	POST_Empathy	−2.46930	1.34661
PRE_Resentment and cultural dominance	42	−1.40086	2.70647	POST_Resentment and cultural dominance	−1.37548	2.03130
PRE_Anxiety and lack of multicultural self-efficacy	42	−1.02781	2.42113	POST_Anxiety and lack of multicultural self-efficacy	−0.88682	3.30589

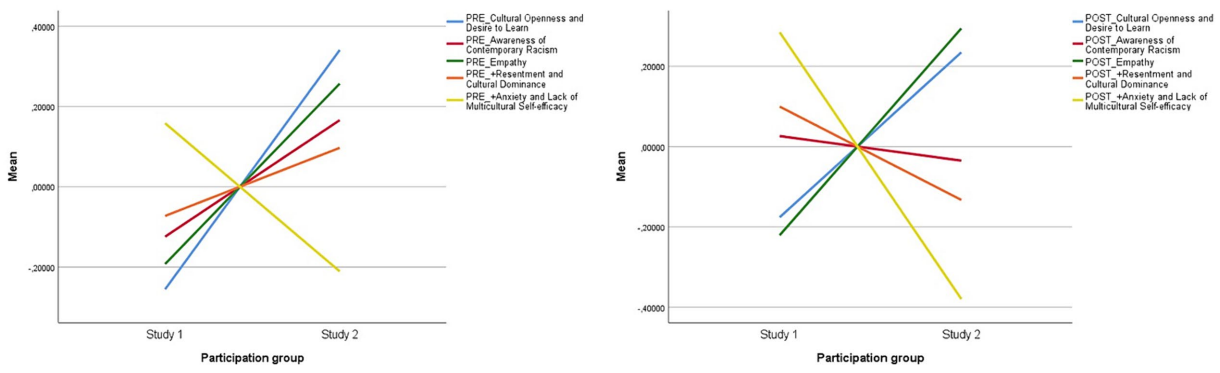

FIGURE 3
Changes between the two experimental groups before and after the intervention.

TABLE 4 Test statistics for the Ethnocultural Empathy Scale factors and the participation group[a].

		Cultural openness and desire to learn	Awareness of contemporary racism	Empathy	Resentment and cultural dominance	Anxiety and lack of multicultural self-efficacy
PRE	Mann–Whitney *U* test	127.5	189.5	148	203	160.5
	Z	−2.25	−0.674	−1.728	−0.33	−1.424
	Sig.	0.024	0.501	0.084	0.741	0.154
POST	Mann–Whitney *U* test	153.5	201	140	176.5	135.5
	Z	−1.589	−0.381	−1.932	−1.004	−2.071
	Sig.	0.112	0.703	0.053	0.315	0.038

[a]Grouping variables: participation group (Study 1 or study 2).

TABLE 5 Test statistics for Factor 3 and Factor 5 of the Ethnocultural Empathy Scale and the participation group.

Course of participation		*N*	Mean rank	Sum of ranks
POST_Empathy	21–22	24	18.33	440.00
	22–23	18	25.72	463.00
	Total	42		
POST_Anxiety and lack of multicultural self-efficacy	21–22	24	24.85	596.50
	22–23	18	17.03	306.50
	Total	42		

increase after the intervention when contrasted with study 2, especially in Factor 2 (Awareness of Racism) and 4 (Resentment). That is, in study 1 there is an increase in Awareness, Anxiety and Resentment. On the contrary, study 2 shows a decrease in Factor 2 (Awareness of Racism), Factor 4 (Resentment) and Factor 5 (Anxiety). However, the changes within each group were not statistically significant.

Non-parametric tests were used (non-normal distribution was found in all factors of the scale) to compare the differences between the levels of ethnocultural empathy of the participants in the two studies. Table 4 shows the results obtained from the preliminary analysis, before and after the intervention.

In Factor 3 (Empathy) and Factor 5 (Anxiety), significant differences were observed between the groups and their post-intervention results, with a p value of 0.053 and 0.038, respectively.

What stands out from Table 5 is the difference between both groups and their mean ranks within the previously mentioned factors post-moment. Interestingly, the results for Factor 3 (Empathy) were higher in study 2 (25.72 in study 2 and 18.33 in study 1), whilst the results for Factor 5 (Anxiety) were higher in study 1 (24.85 in study 1 and 17.03 in study 2).

The effect size r was calculated, obtaining a size effect of 0.625 for Factor 3 (Empathy) and 0.674 for Factor 5 (Anxiety). These results indicate that the significant differences and the size effect between both groups are large (Cohen, 1992, 2016).

Regarding research question 3, different variables were analyzed to determine their relationship with the development of ethnocultural empathy. No statistically significant results were obtained regarding academic performance or involvement in volunteering initiatives. Other socio-demographic variables, such as age or nationality and mother tongue, were discarded due to the homogeneity of the sample for the former and its excessive dispersion and reduced sample for the latter.

However, significant differences were found between the sexes. In this case, non-parametric tests were used (non-normal distribution was found in all factors of the scale). It is noticeable that Factor 3 (Empathy) also showed differences between the sexes (Table 6).

According to the mean ranks in Table 7 for the mentioned factor, empathy levels in females (24.24) were higher than empathy levels in males (15.38).

Due to the small population sample, effect size r analysis was calculated to check the relevance of the differences. A size effect of 0.708 for Factor 3 (Empathy) was obtained, indicating that the significant differences and the effect size between both groups are large (Cohen, 1992, 2016).

Finally, it was sought to establish whether there is a statistical correlation between empathy and CT skills. Thus, the correlations between the CT analysis and factors based on Facione (1990, 2020) and the five factors of the RSEE were tested using non-parametric correlations (non-normal distribution was found in all factors of the scale). As observed in Table 8, no significant differences were found, and, in any case, a negative, small correlation was found between them.

3.2 Qualitative

As this is a mixed-methods study, qualitative data was collected and analyzed to get a more accurate picture and a deeper insight into the affective and cognitive processes that the participants went through. They will also enable us to answer the research questions 4 and 5.

Thus, the narratives contained in the students' diaries, which were written entirely in English, and the accounts expressed during the interviews, conducted in Spanish and translated by the authors, complement the results contained in the statistical analysis above. The theoretically grounded categories and the most recurrent quotes from the respondents frame the structure of the presentation of the findings in this section. For clarity, this section will report the results of each of the cohorts independently hence structured in two separate sub-sections.

TABLE 6 Test statistics for the Ethnocultural Empathy Scale factors and sex of the participants[a].

		Cultural openness and desire to learn	Awareness of contemporary racism	Empathy	Resentment and cultural dominance	Anxiety and lack of multicultural self-efficacy
PRE	Mann–Whitney *U* test	108.5	125	133	171	155.5
	Z	−2.178	−1.728	−1.51	−0.476	−0.906
	Sig.	0.029	0.084	0.131	0.634	0.365
POST	Mann–Whitney *U* test	141.5	126	109	147	167
	Z	−1.279	−1.7	−2.163	−1.13	−0.592
	Sig.	0.201	0.089	0.031	0.259	0.554

[a]Grouping variables: Sex.

TABLE 7 Test statistics for Factor 3 and Factor 5 of the Ethnocultural Empathy Scale and the sex of the participants.

Sex		*N*	Mean rank	Sum of ranks
POST_Cultural openness and desire to learn	Male	13	17.88	232.50
	Female	29	23.12	670.50
	Total	42		
POST_Awareness of contemporary racism	Male	13	16.69	217.00
	Female	29	23.66	686.00
	Total	42		
POST_Empathy	Male	13	15.38	200.00
	Female	29	24.24	703.00
	Total	42		
POST_Resentment and cultural dominance	Male	13	24.69	321.00
	Female	29	20.07	582.00
	Total	42		
POST_Anxiety and lack of multicultural self-efficacy	Male	13	23.15	301.00
	Female	29	20.76	602.00
	Total	42		

3.2.1 Study 1: teaching materials for low-literacy migrant adults

Regarding the first study cohort, where students were arranged into seven work teams, participants' logs reflect on their experiences during the collaborative, multimodal intervention, and how they relate to the development of their empathetic attitudes and their deployment of critical thinking skills.

3.2.1.1 Empathy

Empathy is largely ascribed to emotional states prompted by the realization of the linguistic and cultural hurdles that migrant students must overcome. This overlapping of personal and third-party affective states results in feelings of dismay in the face of adversity (S2), admiration towards the resilience displayed by migrants (S12) and a firm conviction that "emotional factors need to be taken into account when developing a [SL teaching] project" (S22).

One outcome of this empathic development is the enhancement of competences in the crafting of instructional SL materials, spurred by the acknowledgement that they contribute to the successful inclusion of low-literacy migrant adults.

Finally, an increased "awareness of the situation and problems of this collective" (S26) is also cited as being conducive to a higher level of empathy.

3.2.1.2 Critical thinking skills

The salience of the interplay between critical thinking and the adoption of a multimodal approach in the production of the final products is manifest. As S13 relates:

> I have learnt of the importance of employing multimodal materials for teaching and acquiring a successful learning in students. In that sense, for the transmission of content it is essential to work with the visual, audio, gestural, linguistic, and spatial designs.

This reflective process upon completion of the intervention spans the suitability of the materials produced for the Spanish language learners for whom they are intended. For instance, S20 remarks on "being able to choose the right activities for each language level and being able to judge if an activity is good enough or appropriate for the type of learner we had."

In turn, the logs reflect, as expected, a remarkable level of metacognition, operationalized as the analysis of the self-process of learning, the successful self-directed learning strategies adopted, as well as assessments of what favors or hinders their acquisition of skills or competencies.

3.2.1.3 Multimodality

The relevance of multimodality to better respond to the needs of the target audience of these materials is consistently referred to, as a result of which feelings of empathy and commiseration with the hardships experienced by migrants – especially those with languages and cultures of origin distant from the majority in Spain, or those with an incipient level of prior training in languages other than their mother tongue – are expressed.

Moreover, multimodality is widely associated with 'diversity' and 'interculturality,' which further enhances the plasticity of this concept to accommodate the possible heterogeneity of future learners' needs. Multimodality thus stands as a resource for navigating uncertainty and enhancing the adaptability of the trainee teacher.

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TABLE 8 Correlations between the critical thinking analysis and factors based of Facione and the five factors of the Empathy Ethnocultural Scale.

			Critical thinking factors (Facione)	POST_Cultural openness and desire to learn	POST_Awareness of contemporary racism	POST_ Empathy	POST_ + Resentment and cultural dominance	POST_ + Anxiety and lack of multicultural self-efficacy
Spearman's Rho	Critical thinking factors (Facione)	Correlation coefficient	1.000	−0.034	−0.174	−0.119	−0.162	−0.017
		Sig. (two-tailed)		0.875	0.417	0.578	0.449	0.938
		N	24	24	24	24	24	24

3.2.1.4 Teamwork

The process of reflection and monitoring of one's own progress is expressed fundamentally through the contributions of one's own individual work to the group effort. In this regard, S3 reflects:

> Working in a team is ideal for learning about the way colleagues work and the ideas that each of them can contribute, the attitude is much more positive and makes the task more interactive. It also helps to foster the creativity of each team member.

In the same vein, group work is associated with concepts such as 'motivation,' 'brainstorming' and 'enriching' practices, both from an affective and a cognitive perspective. Thus, S19 comments on her sense of fulfillment by saying: "I took many ideas from my classmates, reformulated some others and had the feeling of being listened to regarding my own ideas."

Similarly, the benefits that the collaborative approach can unlock for soft skills are identified: "I think that working in a group is always beneficial as you get to know other points of view and work on adaptation and mediation" (S17).

In contrast, the collective approach is not unanimously considered in the records analyzed. The preference for individual work is rooted in factors such as time management and productivity (S2), workload allocation (S7), coordination (S8, S21, and S24) or the reconciliation of conflicting ideas (S22), which would be undermined by group work.

3.2.2 Study 2: video about three low-literacy adult migrants

As for the second group, during the in-depth interviews, students verbalized their reflections, attesting to their critical thinking skills. These, in turn, shed light on the ways in which digitally-based multimodal language teaching is deemed to better meet the needs of migrant learners.

3.2.2.1 Empathy

The most prominent component of empathy in this group is cognitive in nature, taking the form of being able to understand or explain something to somebody who is culturally distant. Moreover, for this approach, empathy is perceived as a two-way street, as empathizing more with immigrants will "make it possible for them to understand us too" (S28).

3.2.2.2 Critical thinking skills

Interviewees' critical thinking encompasses, among others, making inferences. As S29 elaborates:

> In a primary school it would be very complicated to have to explain bureaucracy to [migrant] children. But in secondary school and perhaps beyond it would be much simpler, although it would still be a slightly more complex task than explaining it to an adult. But maybe some workshops could be held in which they could be given an explanation.

The video-based intervention also enabled participants to hone their skills in making interpretations based on the information available, as exemplified by S28 stating that:

> It would have been the same [if] I had had to go to Germany when I was a child, I suppose, and possibly my classmates would have ignored me and not helped me, it would have upset me, because what could I have done without having someone to lend me a helping hand? So I think that teachers themselves should raise awareness among their students.

Similarly, the ability to provide explanations is evident in interview excerpts, such as this one, about the interplay between multimodal and traditional approaches to teaching:

> I believe that joining forces goes a long way, because if you are constantly reading one thing or you are always doing the same thing, even if it is audiovisual, in the end, it is going to end up being monotonous. But if there is a change [...] a perfect balance can be achieved and it becomes, firstly, more impactful for the student [...], and secondly, it makes it much more memorable [...]. So I think the right compromise between both types of education is the right approach that will lead to much more progress for the learner. (S29)

Finally, in contrast to the participants in group 1, group 2 interviewees exhibited analytical CT, embodied in the examining of the ideas of their peers. The following is the S28's reaction to S29's remark above:

> I share your view because I believe that a variety of approaches is what brings about the right outcome, since doing the same thing on a daily basis, as you have pointed out, eventually becomes monotonous.

3.2.2.3 Multimodality

Multimodality, enabled by digital tools, is believed to be instrumental in cultivating competencies that could not be otherwise acquired by the intended recipients of the learning materials:

> In other words, when you ask a student to write a text commentary, you are assessing their ability to express themselves, to reason... […] and submit them in writing. However, the moment you screen a video, perhaps so that they can elicit information, other types of skills come into play, such as being able to interpret what they are viewing and how to attribute meaning to it. (S30)

In this regard, as Peña-Acuña and Cislowska (2023) point out, multimodal resources enable multilevel learning, where learners incorporate knowledge about a particular digital tool alongside the appreciation of how such tool "changes the way of interacting among equals and with the world and for what other purposes the learned tools can be useful" (p. 278).

3.2.3 Final products

As for the end products participants designed in study 1, all seven work teams identified topics of interest for the target population, such as, shopping at the supermarket, buying food, daily routines, applying for a job, and moving around the city; except for one group that suggested creating a blog about cities to visit -a regular theme in mainstream textbooks. Full integration of multimodal elements was achieved to varying degrees, apart from written language elements, three of the seven teams only included simple visual support; in other cases, visual aids were used to facilitate comprehension and enhance the language learning process. Four groups included digital resources and suggested the use of digital technologies in the learning process (*Kahoot*, *Tiktok* and mobile phones); three groups added audiovisual elements and used digital-based apps to create the materials; finally, one group recorded their own audio files for the teaching unit. In general, although many of the groups designed attractive and thoughtful, and generally well sequenced tasks, in most of the cases activities were too difficult for the low-literacy adult learners they were intended for.

It is noteworthy that two groups included a third language, that of the target population they had selected, which in both cases was Ukrainian. This choice is in line with the findings of Ávila-López and Rubio-Alcalá (2023), who claim that, to fully empower individuals, "multimodal modes should definitely include the linguistic repertoires that migrants bring to the social equation" (p. 182).

Turning to study 2, student teachers were asked to produce a video containing the main ideas of an article about the acculturation process of migrants. As explained above, participants were required to transform the written article in a digital multimodal product, a video file with several elements: they had to add images, subtitles, and their own voices to narrate the contents; and at the end of the video, three comprehension questions would help viewers to check what they had learnt watching the video. Half of the groups managed to design and create elaborated videos that fulfill, to varying degrees, all of the criteria. Two of the groups performed even beyond expectations. In general, students identified key concepts and defined them using their own words, adapted contents and language to make ideas more accessible, selected a wide variety of elements to support and illustrate their ideas, added subtitles and their own voices, paying special attention to intonation in order to attract the audience's attention. The rest of the groups accomplished the task moderately well, including most of the elements required. Lower attainment was due to limited variety of digital elements and in 2 cases, also a lack of cognitive effort as participants mainly summarized the contents of the reading. In most of the groups there is, however, an important display of cognitive abilities and CT skills. Student teachers showed a good understanding and analysis of the text, identifying key information; they managed to draw relevant conclusions from the reading and presented their ideas in the video supporting them with sound arguments and illustrating them with multimodal elements. Thus, the text mediation competences, as described in the Companion Volume of the Common European Framework of Reference for Languages (Council of Europe, 2020), were extensively demonstrated in the final products. There is a clear effort on the part of the participants to make high-quality attractive videos.

4 Discussion

As stated at the beginning of this work, this study set out to compare how effective two digital multiliteracy interventions were in developing future language teachers' ethnocultural empathy and cognitive abilities when appraising the educational needs of low-literacy migrants. The analysis of the quantitative and qualitative data has provided answers to the research questions posed at the beginning of the study, which aimed to assess the potential for developing the ethnocultural empathy of student teachers via the design of multimodal products.

Data has shown that student teachers' ethnocultural empathy can be developed by introducing multimodal tasks in their training courses, which is in line with Rasoal et al.'s (2011a) assertions that ethnoculturally

empathic stances are amenable to learning and training. However, it seems that the nature of the final products created by participants, leaning more towards either affective or cognitive perspective-taking (Jiang and Gao, 2020) in each of the two groups featured in this work, has significantly impacted the extent of such development.

This allows us to address the second research question, quantitatively, it has been possible to establish significant differences between groups after the interventions, with a sizable effect. Such differences have been found in Factor 3 (Empathy) and Factor 5 (Anxiety), together with the high effect sizes obtained. This strongly implies that the type of multimodal product that participants are invited to create significantly impacts on the development of ethnocultural empathy and that these results can be generalized. Accordingly, depending on the type of final product expected of them and the type of evaluation they anticipated would be applied, participants would potentially develop greater or lesser anxiety and empathy levels after the intervention. Hence, we have ascertained that the group participating in study 2 showed higher levels of empathy and the participants of study1, lower levels of anxiety according to the factors obtained in the Revised Ethnocultural Empathy Scale.

With regards to the third research question, another significant finding of this study is the gender differences revealed. Quantitative results show higher levels of empathy in females, which is consistent with previous studies (Cundiff and Komarraju, 2008; Rasoal et al., 2011b; Pinzón Corredor, 2018). It is, however, worth noting that the large size effect counterbalances the small population sample size in terms of generalizability. No other demographic variables analyzed, however, produced statistically significant results.

The quantitative data have not provided the anticipated results, not relating participants' cognitive and affective empathy levels to one another in a significant manner. This may be due to the fact that in the Spanish version of the RSEE, cognitive and affective empathy are merged into one single factor, possibly rendering its distribution of factors inadequate for a population of prospective L2 teachers of migrant learners. It seems necessary to verify whether the tool operates well with such a population, hence a study with a larger sample is needed. Thus, the small sample size is insufficient to draw robust comparable results. However, the participants' contributions are rich in insights and nuances at the qualitative level, which allows us to answer research questions 4 and 5.

As to the fourth research question, pertaining to the cognitive processes/capabilities and CT skills that are promoted when designing multimodal products intended for adult immigrants, the findings presented in this paper are consistent with the conclusions of Peña-Acuña and Navarro-Martínez (2024), whose study on the training of student teachers in the use of multimodal storytelling applications found an increase in trainees' mental flexibility (p. 15). In addition, the adoption of the multimodal approach seems to have elicited a considerable degree of metacognition in the students. Despite not being statistically supported, it is an interesting finding, since it might point to the need to extend Facione's (1990, 2020) CT framework. Along the same lines, Dwyer et al. (2014) integrative framework articulates this metacognitive capacity in terms of 'reflective judgment' and 'dispositional factors', both of which "ultimately dictate how well each thinking process will be carried out" (p. 49).

As for the fifth research question, the data collected in the reflection logs and interviews sheds light on the participants' perceptions gained from their experience during the production of the multimodal outputs. In terms of cognitive processes and CT skills, qualitative data suggest a diverging activation of CT skills dependent on the required multimodal task. Some inter-group differences have been observed, as in the view of the participants in group 1, the interventions carried out enabled them to deploy their CT skills and to hone their competencies to work in teams or in collaboration with their peers in the pursuit of a common goal. This echoes previous studies linking cognitive and action-oriented tasks (Dwyer et al., 2014), where learners are expected to jointly deliver a multimodal final product that also relies on mediation and problem-solving skills. In group 2, however, the participants showed a more analytical approach to working collaboratively, engaging their CT skills to offer feedback to the arguments held by their peers. While empathy and cognitive perspective-taking are both valuable in promoting understanding and collaboration among diverse groups, their exclusive focus may overlook the complexity of emotional responses and interpersonal dynamics in intergroup relations.

As for the relationship between ethnocultural empathy and CT skills in prospective teachers of Spanish as an L2, this study has provided valuable qualitative insights into the role that digital technology-based multimodal interventions have the potential to fulfill. Thus, in the first group, responsible for the production of instructional materials, the participants exhibited a higher level of complexity in their CT skills, especially in the area of self-regulation. This group also demonstrated effective learning strategies that facilitated, to varying degrees, successful task finalization and the cultivation of ethnocultural empathy, underscoring the importance of empathy in the design of learning materials. Along these lines, ethnocultural empathy seems to reconcile cognitive and affective elements, where knowledge and understanding of the challenges faced by migrants are added to the emotional triggers through which empathetic stance-taking arises. However, some difficulties have been identified. Although integrating multimodal elements appears to be manageable for most of the groups, the requirement to consider the entry level of the prospective audience has been the most challenging element for the trainee teachers. That is, although they were more conscious of migrants' needs, not all of them succeeded in transferring that knowledge into a fairly novel task for them. In line with Zhang-Leimbigler's (2014) remarks, the multiliteracies approach fostered participants' observing and analyzing skills, but maybe the task was beyond their zone of proximal development (Macy, 2016), hindering the transferability of knowledge. Misalignments in the level of competence such as this may happen when applying new pedagogical theories in teacher education courses. In fact, as some participants reported, this type of tasks may require more time, or the inclusion of facilitating preparatory tasks. They would have also liked to "put the activities into practice with migrants" (S8) in order to check their effectiveness.

The high level of self-awareness, as shown by constant references to self-regulation skills, together with the probably overwhelming novelty of the assignment could also explain the higher levels of anxiety pre-post in study 1. Prioritizing perspective-taking towards oneself, as Wallace-Hadrill and Kamboj (2016) recall, may attenuate positive emotions. This explains how the intervention in study 1 made future teachers fully aware of their detachment from the situation and needs of migrants, which in turn led them to doubt their multicultural self-efficacy and experience higher levels of anxiety.

The second group, engaged in the creation of a video presentation, demonstrated their CT skills and acknowledgement of the advantages of a multimodal digital approach to language teaching for migrant learners during the in-depth interviews. Their reflections drew attention to the benefits of incorporating a variety of modalities in the creation of

educational content to better serve the needs of low-literate adult migrants. Similarly to what Wang et al. (2014) report, in this group empathy is operationalized primarily as cognitive understanding of culturally distant individuals, facilitating both mutual appreciation and reciprocal consideration. However, the absence of the category 'evaluation' in their CT skills as described in Facione's (1990, 2020) framework suggests areas of further development in terms of their metacognitive processing and self-regulation. Unlike participants in study 1, these learners seem to be faced with a more manageable task that allows them to activate their CT skills and, even more so, to make the most of their digital abilities. The introduction of audiovisual multimodal elements appears to have facilitated the successful completion of the task. On the other hand, the higher levels of empathy and lower levels of anxiety in study 2 show that this multiliteracies design significantly improves the ethno-cultural empathy of the prospective teachers of migrant pupils; as they are more familiar with the reality of the target population and feel more capable of carrying out the required task, their anxiety and lack of multicultural self-efficacy levels decrease.

In general, although not supported by quantitative data, participants' narratives indicate a change in their perspectives and beliefs about migrants and their own future jobs. Trainees verbalize their awareness-raising process 'before this I was not so aware of the difficulty migrants have because of not knowing the language of the country they are arriving in' (S8). Besides, many of them admitted to being motivated by working on tasks that could be useful for their future work. There was also a sense of pride in the effort they had put in and the product they had created.

We agree with Gouthro and Holloway (2013) when they affirm that in teacher education "we need to be committed to strategies to carefully prepare and support teachers to use both critical lifelong learning and multiliteracies approaches in their own teaching practices" (p. 57). Multiliteracies practices in technology-mediated settings enhance teacher education, as they help teacher students become critically reflective educators who can prepare their own learners for the challenges of an ever more plurilingual multicultural and digital society. Our findings also corroborate the claims of Warner and Dupuy (2018) about future language teachers having fixed conceptions of language learning and teaching, and when confronted with situations that do not reflect their experiences and ideas tensions arise. As suggested by the authors, the interventions presented here enhanced students' reflection, which is necessary to go through the transformation process specific to the multiliteracies framework. In this way, this study contributes to filling the gap identified by Paesani and Allen (2020) when they advocate for language teacher programs that enhance the understanding of the multiliteracies framework. Thus, the findings in this study support the value of integrating digital media, CT skills and ethnocultural empathy development into teacher education programs to equip future language teachers with the skills and awareness necessary to function effectively in diverse educational settings and meet the needs of multicultural learner populations.

The authors acknowledge the limitations present in this work, mainly in three respects. Firstly, given that the instrument used to collect quantitative data is the RSEE, which has been calibrated on the basis of a scale validated in a Colombian sample but not in a Spanish one, and in view of the low statistical significance observed in most of the factors examined in this study, a broader population survey would be required in order to check its validity. Secondly, the uneven ratio of female and male subjects may have influenced the results obtained. Thus, a more representative sampling of men and women in the study group might refine the reported figures. Finally, the reluctance of students to participate in qualitative research, especially their unwillingness to respond to in-depth interviews, casts doubt on the generalizability of the data obtained. Follow-up studies would be necessary to confirm the reported results.

Despite the small sample size, the study certainly adds to our understanding of the impact of multimodal tasks involving critical thinking skills on trainees' cognitive and affective abilities. Besides, it adds to the growing body of research that emphasizes the desirability of embedding multimodal digitally-based content creation tasks in training curricula for future language teachers. Those multiliteracy tasks appear to enhance future teachers' ethnocultural empathy, particularly among females, reduce their anxiety and perceived lack of multicultural self-efficacy, and foster the deployment of learners' CT skills, as well as their awareness of and interest in their future teaching practice.

Data availability statement

The raw data supporting the conclusions of this article will be made upon request by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

AF-C: Formal analysis, Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Conceptualization, Funding acquisition. EC-B: Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Formal analysis, Data curation. PF-A: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Abrami, P. C., Bernard, R. M., Borokhovski, E., Wade, A., Surkes, M. A., Tamim, R., et al. (2008). Instructional interventions affecting critical thinking skills and dispositions: a stage 1 metaanalysis. *Rev. Educ. Res.* 78, 1102–1134. doi: 10.3102/0034654308326084

Adami, H. (2008). The role of literacy in the acculturation process of migrants. Council of Europe. Available at: https://rm.coe.int/CoERMPublicCommonSearchServices/DisplayDCTMContent?documentId=09000016802fc1b7

Ávila-López, J., and Rubio-Alcalá, F. D. (2023). Multiliteracies and multilingualism in adult migrants: a systematic review. *Eur. J. Lang. Policy* 15, 167–189. doi: 10.3828/ejlp.2023.10

Baynham, M. (2006). Agency and contingency in the language learning of refugees and asylum seekers. *Linguist. Educ.* 17, 24–39. doi: 10.1016/j.linged.2006.08.008

Canales, L. I., and Rovira, G. (2016). La importancia de la autorregulación y la empatía en la formación docente. *Movimento* 22, 157–172.

Carlsen, C. H., Rocca, L., and Sheils, J. (2023). Education for integration–the case of adult migrants. Quality and Equity in Education. A Practical Guide to the Council of Europe Vision of Education for Plurilingual, Intercultural and Democratic Citizenship, 180–202

Cohen, J. (1992). Quantitative methods in psychology: a power primer. *Psychol. Bull.* 112, 155–1159. doi: 10.1037/0033-2909.112.1.155

Cohen, J. (2016). "A power primer" in *Methodological issues and strategies in clinical research*. ed. A. E. Kazdin. *4th* ed (Washington DC: American Psychological Association), 279–284.

Cope, B., and Kalantzis, M. (2000). *Multiliteracies: literacy learning and the design of social futures*. London: Routledge.

Council of Europe (2020). *Common European framework of references for languages: Learning, teaching, assessment – Companion volume*. Strasbourg: Council of Europe Publishing.

Cundiff, N. L., and Komarraju, M. (2008). Gender differences in Ethnocultural empathy and attitudes toward men and women in authority. *J. Leadersh. Organ. Stud.* 15, 5–15. doi: 10.1177/1548051808318000

D'Agostino, M., and Mocciaro, E. (2021). Literacy and literacy practices: Plurilingual connected migrants and emerging literacy. *J. Second. Lang. Writ.* 51:100792. doi: 10.1016/j.jslw.2021.100792

de Vignemont, F., and Singer, T. (2006). The empathic brain: how, when and why? *Trends Cogn. Sci.* 10, 435–441. doi: 10.1016/j.tics.2006.08.008

Decety, J., and Jackson, P. L. (2004). The functional architecture of human empathy. *Behav. Cogn. Neurosci. Rev.* 3, 71–100. doi: 10.1177/1534582304267187

DeTurk, S. (2001). Intercultural empathy: myth, competency, or possibility for alliance building? *Commun. Educ.* 50, 374–384. doi: 10.1080/03634520109379262

Diminescu, D. (2008). Connected migrants: an epistemological manifesto. *Soc. Sci. Inf.* 47, 565–579. doi: 10.1177/0539018408096447

Dwyer, C. P., Hogan, M. J., and Stewart, I. (2014). An integrated critical thinking framework for the 21st century. *Think. Skills Creat.* 12, 43–52. doi: 10.1016/j.tsc.2013.12.004

Facione, P. A. (1990). *Critical thinking: A statement of expert consensus for purposes of educational assessment and instruction—The Delphi report*. Millbrae, CA: California Academic Press.

Facione, P. A. (2020). *2020 critical thinking: What it is and why it counts. Measured reasons LLC*.

Fernández-Corbacho, A. (2018). Desarrollo de destrezas lectoras en una lengua extranjera en educación primaria. Perfil del lector con dificultades. Tejuelo: Didáctica de la Lengua y la Literatura, 28, 91–126. Available at: http://hdl.handle.net/10662/7984

Finck, C., Gómez, Y., Castro, J. N., Mogollón, E. Y., Marcelo, N., and Hinz, A. (2021). Adaptation and validation of a Spanish instrument for assessing multicultural competencies and empathy. *Int. J. Intercult. Relat.* 83, 163–176. doi: 10.1016/j.ijintrel.2021.06.007

Fonseca-Mora, M. C. (2023). "Emotion in language education and pedagogy" in *Language and emotion: an international handbook*. eds. G. Schiewer, J. N. Altarriba and B. Chin, vol. *3* (Boston: DeGruyter Mouton), 2195–2217.

Froehlich, L., Mok, S. Y., Martiny, S. E., and Deaux, K. (2022). Stereotype threat-effects for Turkish-origin migrants in Germany: taking stock of cumulative research evidence. *Eur. Educ. Res. J.* 21, 330–354. doi: 10.1177/1474904118807539

García-Barroso, L., and Fonseca-Mora, M. C. (2023). Multiliteracies for adult language learners: a narrative review. Porta Linguarum. *Int. J. Foreign Lang. Teach. Learn.* 40, 199–213. doi: 10.30827/portalin.vi40.26661

Gonzalves, L. (2021). Development of copying skills in L2 adult English learners with emergent print literacy. *J. Second Lang. Writ.* 51:100790. doi: 10.1016/j.jslw.2021.100790

Gouthro, P. A., and Holloway, S. M. (2013). Preparing teachers to become lifelong learners: exploring the use of fiction to develop multiliteracies and critical thinking. *Lang. Liter.* 15, 50–68. doi: 10.20360/G2588T

Hanna, H. (2023). A critical review of international research into pre-service teachers' beliefs and practices when teaching migrant learners. *Lond. Rev. Educ.* 21, 1–20. doi: 10.14324/lre.21.1.21

Hanushek, E.A., Piopiunik, M., and Wiederhold, S. (2014), The value of smarter teachers: international evidence on teacher cognitive skills and student performance. Program on education policy and governance. Working papers no. 14-06, Harvard Kennedy School.

Haznedar, B., Peyton, J. K., and Young-Scholten, M. (2018). Teaching adult migrants: a focus on the languages they speak. *Crit. Multiling. Stud.* 6, 155–183.

Hemmerechts, K., Agirdag, O., and Kavadias, D. (2017). The relationship between parental literacy involvement, socio-economic status and reading literacy. *Educ. Rev.* 69, 85–101. doi: 10.1080/00131911.2016.1164667

Himmler, O., and Jäckle, R. (2018). Literacy and the migrant–native wage gap. *Rev. Income Wealth* 64, 592–625. doi: 10.1111/roiw.12299

Holloway, S. M., and Gouthro, P. A. (2020). Using a multiliteracies approach to foster critical and creative pedagogies for adult learners. *J. Adult Continuing Educ.* 26, 203–220. doi: 10.1177/1477971420913912

Holloway, S. M., and Qaisi, R. (2022). Composing meaning through multiliteracies and multimodality with adult and adolescent learners. *Lang. Liter.* 24, 85–106. doi: 10.20360/langandlit29587

Jiang, L., and Gao, J. (2020). Fostering EFL learners' digital empathy through multimodal composing. *RELC J.* 51, 70–85. doi: 10.1177/0033688219898565

Joyce, S. (2019). Strengthening skills expert review of Australia's vocational education and training system. [report] commonwealth of Australia, Department of the Prime Minister and Cabinet. Available at: https://www.pmc.gov.au/sites/default/files/resource/download/strengthening-skills-independent-review-australia-vets_1.pdf

Kapıkıran, N. A. (2023). Sources of Ethnocultural empathy: personality, intergroup relations, affects. *Curr. Psychol.* 42, 11510–11528. doi: 10.1007/s12144-021-02286-2

Klimecki, O. M. (2019). The role of empathy and compassion in conflict resolution. *Emot. Rev.* 11, 310–325. doi: 10.1177/1754073919838609

Klimecki, O. M., Vétois, M., and Sander, D. (2020). The impact of empathy and perspective-taking instructions on proponents and opponents of immigration. *Huma. Soc. Sci. Commun.* 7, 1–12. doi: 10.1057/s41599-020-00581-0

Lee, S. C. (2019). Integrating entertainment and critical pedagogy for multicultural pre-service teachers: film watching during the lecture hours of higher education. *Intercult. Educ.* 30, 107–125. doi: 10.1080/14675986.2018.1534430

Leone, P. E., Krezmien, M., Mason, L., and Meisel, S. M. (2005). Organizing and delivering empirically based literacy instruction to incarcerated youth. *Exceptionality* 13, 89–102. doi: 10.1207/s15327035ex1302_3

Lincoln, D., and Kearney, M. L. (2019). Promoting critical thinking in higher education. *Stud. High. Educ.* 44, 799–800. doi: 10.1080/03075079.2019.1586322

Lorencová, H., Jarošová, E., Avgitidou, S., and Dimitriadou, C. (2019). Critical thinking practices in teacher education programmes: a systematic review. *Stud. High. Educ.* 44, 844–859. doi: 10.1080/03075079.2019.1586331

Macy, L. (2016). Bridging pedagogies: Drama, multiliteracies, and the zone of proximal development. *Educ. Forum* 80, 310–323. doi: 10.1080/00131725.2016.1173750

Mallinckrodt, B., Miles, J. R., Bhaskar, T., Chery, N., Choi, G., and Sung, M.-R. (2014). Developing a comprehensive scale to assess college multicultural programming. *J. Couns. Psychol.* 61, 133–145. doi: 10.1037/a0035214

Marin, L., and Halpern, D. F. (2011). Pedagogy for developing critical thinking in adolescents: explicit instruction produces greatest gains. *Think. Skills Creat.* 6, 1–13. doi: 10.1016/j.tsc.2010.08.002

Martínez-Otero Pérez, V. (2011). La empatía en la educación: estudio de una muestra de alumnos universitarios. *Revist. Electrón. Psicol. Iztacala* 14:174.

Mercer, S. (2016). "Seeing the world through your eyes: empathy in language learning and teaching" in *Positive psychology in SLA*. eds. P. MacIntyre, T. Gregersen and S. Mercer (Bristol: Multilingual Matters), 91–111.

Meskill, C. (2005). Infusing English language learners issues throughout professional educator curricula: the training all teachers project. *Teach. Coll. Rec.* 107, 739–756. doi: 10.1177/016146810510700407

Mezmir, E. A. (2020). Qualitative data analysis: an overview of data reduction, data display, and interpretation. *Res. Humanit. Soc. Sci.* 10, 15–27. doi: 10.7176/RHSS/10-21-02

Minuz, F., Kurvers, J., Schramm, K., Rocca, L., and Naeb, R. (2022). *Literacy and second language learning for the linguistic integration of adult migrants: reference guide*. Strasbourg Cedex: Council of Europe.

New London Group (1996). A pedagogy of multi-literacies: designing social futures. *Harv. Educ. Rev.* 66, 60–93. doi: 10.17763/haer.66.1.17370n67v22j160u

OECD (2017). *Why are immigrants less proficient in literacy than native-born adults? Adult skills in focus*. Paris: OECD Publishing.

Paesani, K., and Allen, H. W. (2020). Teacher development and multiliteracies pedagogy: challenges and opportunities for postsecondary language programs. *Second Lang. Res. Pract.* 1, 124–138.

Peña-Acuña, B., and Cislowska, A. I. (2023). The chroma key perceived as a multimodal and multiliteracies teaching tool. *Eur. J. Lang. Policy* 15, 273–297. doi: 10.3828/ejlp.2023.14

Peña-Acuña, B., and Navarro-Martínez, Ó. (2024). The promotion of originality perceived in two multimodal storytelling applications: storybird and scratch. *Educ. Sci.* 14:21. doi: 10.3390/educsci14010021

Pinzón Corredor, D.M. (2018). Actitud intercultural y empatía etnocultural en la socialización académica de los estudiantes de medicina. Doctoral Dissertation. Universidad de Bogotá.

Rasoal, C., Eklund, J., and Hansen, E. (2011a). Toward a conceptualization of ethnocultural empathy. *J. Soc. Evol. Cult. Psychol.* 5, 1–13. doi: 10.1037/h0099278

Rasoal, C., Jungert, T., Hau, S., and Andersson, G. (2011b). Ethnocultural versus basic empathy: same or different? *Psychology* 2, 925–930. doi: 10.4236/psych.2011.29139

Rodríguez, S., Valle, A., Martins Gironelli, L., Guerrero, E., Regueiro, B., and Estévez, I. (2020). Performance and well-being of native and immigrant students. Comparative analysis based on PISA 2018. *J. Adolesc.* 85, 96–105. doi: 10.1016/j.adolescence.2020.10.001

Rokita-Jaśkow, J. (2023). Agencia de profesores de inglés como lengua extranjera en la mediación de la socialización de estudiantes multilingües [EFL teacher agency in mediating the socialisation of multilingual learners]. *Glottodidactica* 50, 191–212. doi: 10.14746/gl.2023.50.1.10

Salamatina, Y. V. (2019). Using digital technologies for forming empathy of would-be school teachers. In Proceedings of the international scientific and practical conference on digital economy (ISCDE 2019).

Snyder, L. G., and Snyder, M. J. (2008). Teaching critical thinking and problem solving skills. *Delta Pi Epsilon Journal* 50, 90–99.

Tutkun, T. (2019). Examining and predicting Ethnocultural empathy of preservice classroom teachers. *Univ. J. Educ. Res.* 7, 963–972. doi: 10.13189/ujer.2019.070407

Underhill, A. (2013). "The inner workbench: learning itself as a meaningful activity" in *Meaningful action: Earl Stevick's influence on language teaching*. eds. J. Arnold and T. Murphey (Cambridge: Cambridge University Press), 202–218.

Wallace-Hadrill, S. M. A., and Kamboj, S. K. (2016). The impact of perspective change as a cognitive reappraisal strategy on affect: a systematic review. *Front. Psychol.* 7, 1–14. doi: 10.3389/fpsyg.2016.01715

Wang, Y.-W., Davidson, M. M., Yakushko, O. F., Savoy, H. B., Tan, J. A., and Bleier, J. K. (2003). The scale of Ethnocultural empathy: development, validation, and reliability. *J. Couns. Psychol.* 50, 221–234. doi: 10.1037/0022-0167.50.2.221

Wang, C. S., Tai, K., Ku, G., and Galinsky, A. D. (2014). Perspective-taking increases willingness to engage in intergroup contact. *PLoS One* 9, 1–8. doi: 10.1371/journal.pone.0085681

Warner, C., and Dupuy, B. (2018). Moving toward multiliteracies in foreign language teaching: past and present perspectives and beyond. *Foreign Lang. Ann.* 51, 116–128. doi: 10.1111/flan.12316

Warren, C. A. (2018). Empathy, teacher dispositions, and preparation for culturally responsive pedagogy. *J. Teach. Educ.* 69, 169–183. doi: 10.1177/0022487117712487

Warren, A. N., and Ward, N. A. (2019). Equitable education for English learners through a pedagogy of multiliteracies. *Kappa Delta Pi Rec.* 55, 89–94. doi: 10.1080/00228958.2019.1580989

Whitford, D. K., and Emerson, A. M. (2019). Empathy intervention to reduce implicit Bias in pre-service teachers. *Psychol. Rep.* 122, 670–688. doi: 10.1177/0033294118767435

Yang, Y., Cox, C., and Cho, Y. (2019). Development and initial validation of cultural competence inventory–preservice teachers. *J. Psychoeduc. Assess.* 38, 305–320. doi: 10.1177/0734282919848890

Yelland, N., Cope, B., and Kalantzis, M. (2008). Learning by design: creating pedagogical frameworks for knowledge building in the twenty-first century. *Asia Pac. J. Teach. Educ.* 36, 197–213. doi: 10.1080/13598660802232597

Zhang-Leimbigler, Sheri (2014). A pedagogy of multiliteracies: second language and literacy acquisition. Online submission. Available at: https://www.semanticscholar.org/paper/A-Pedagogy-of-Multiliteracies%3A-Second-Language-and-Leimbigler/c0478b4dcbeff95d5f1d649e44380186cf3b3346

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Corrigendum: Ethnocultural empathy development of future language teachers through digital multiliteracy resources for low-literacy adult migrants

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Exploring the factors influencing high school students' deep learning of English in blended learning environments

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Exploring deep learning and its influencing factors is receiving increasing attention. This study examines influencing factors (i.e. self-efficacy, learning engagement, and teacher-student interaction) of high school students' English deep learning in blending courses. Research hypotheses are proposed, and a structural equation model (SEM) of influencing factors of deep learning is built. A sample size of 225 participants was recruited on a voluntary and anonymous basis from a high school in Southwestern China for this study. We find: (1) self-efficacy, learning engagement and teacher-student interaction all predict and have positive impacts on English deep learning; (2) self-efficacy has a positive impact on learning engagement and teacher-student interaction; (3) teacher-student interaction has a positive impact on learning engagement. The findings underscore the importance of self-efficacy, learning engagement, and teacher-student interaction for EFL high school learners to achieve deep learning in a blending context. Drawn from these findings, pedagogical implications for promoting these learners' deep learning are provided.

KEYWORDS

blending courses, deep learning, influencing factors, SEM, high school students

1 Introduction

As a symbol of high-level learning and a method that is conducive to improving learners' learning ability, deep learning has attracted more and more attention from researchers (Fullan et al., 2018). *Horizon Report* issued by New Media Consortium (NMC) in 2017 and *Chinese higher education vision of Horizon Report* aiming at the application status of higher education technology in China delivered by Smart Learning Institute of Beijing Normal University both mention that key tendency of the application of technology is turning from the tangible learning forms and learning spaces to intangible innovation and deep learning (Gao and Huang, 2017).

How can traditional education model further promote students' deep learning? In accordance with *Action Plan of Educational informatization 2.0*, issued by Ministry of Education of the People's Republic of China in 2018, educational informatization is the core and symbol of education modernization—We should wield the advantage of technology and transform the traditional model to accelerate the deep integration between new technology and education. The action plan aims to promote the implementation of "Internet + Education." Tech-enhanced blending courses then have emerged. With the support of hardware and information technology such as smart devices and mobile learning apps, the blending courses, characterized by "Internet-accessible smart devices + traditional classroom teaching," can realize the sharing of high-quality teaching resources and improve the effectiveness of teaching and learning. According to *Action Plan of Educational informatization 2.0*, smart education development and innovation action is one of its most important contents and integrated technology education that aims to promote deep learning is the core pillar of smart education.

The blending courses teaching environment based on the smart education pays more attention on the integration of physical environment of smart classroom and innovative smart teaching. The cramming strategy, for the traditional high-school English teaching in China, makes students likely to choose a shallow learning method, that is, one that does not require too much effort, and does not require too much understanding to easily obtain kind of "success," which is the so-called high score. Blending courses aim to provide students more humanistic learning environment in which teachers, armed with technology, are able to design a variety of classroom activities and adopt multiple teaching strategies through smart devices to encourage students to participate more in the process of teaching and learning. So, can high school students in these blending courses truly achieve English deep learning? What factors affect students' deep learning?

So far, a great number of studies have been done on favorable effects of the use of new Internet technology in a learning process in terms of facilitation and enhancement of learning (Allen, 2011). In previous studies, some researchers tested the relationship between only a single influencing factor and deep learning, or explored the reasons why students' deep learning did not happen from the perspective of teachers by focusing on post-secondary setting, or analyzed and summarized the influencing factors of deep learning, but there is either a lack of data-based analysis or a theoretical framework for analysis. We need to conduct in-depth discussions on the influencing factors and mechanism of English deep learning in blending courses. To this end, this research draws on the existing research results, analyzes and discusses the factors (learning engagement, self-efficacy, and teacher-student interaction) that affect the English deep learning of high school students in the blending courses, and proposes a theoretical hypothesis model. The model is validated using measurement data, which reveals the impacts of influencing factors on English deep learning and their interrelationships.

Blending teaching assisted by smart devices mixes online learning with traditional face-to-face classroom instruction, offering a novel approach for achieving the deep learning of students. The research questions are as follows:

(1) How do those influencing factors (i.e., learning engagement, self-efficacy, and teacher-student interaction) affect the English deep learning in blending course?
(2) What are the relationships between the various influencing factors?

2 Literature review

2.1 Research on deep learning in blending courses

As a future education trend and learning idea, deep learning is an in-depth progression of the blending courses model. Blending learning (B-learning) is a teaching model that combines the benefits of traditional classroom teaching (Face-to-Face) and network teaching (e-Learning) (Delialioglu and Yildirim, 2007). Its starting point is to increase students' in-depth understanding and the fundamental goal is to allow students to go from shallow to deep learning, develop their low-level cognition to a higher one (Zhu, 2016), with the goal of assisting students in achieving optimal learning and promoting students to reach the level of deep learning (Zhang and Wang, 2014). Furthermore, the blending courses teaching model and deep learning processes adapt to and complement one another. Deep learning consisted of three processes: "acquiring information (understanding of shallow learning level)—developing skills (ability to analyze and reflect)—deep learning (problem solving, application of inventive capacity)." This basically matched the process of blending courses teaching model. In the pre-class stage of blending courses, students obtained the basic information of knowledge points online using smart devices, and then in the face-to-face teaching stage in the classroom, students reflected on knowledge and established their own knowledge framework through interaction with teachers. Finally, students addressed practical issues based on the knowledge they have gained in order to achieve internalization and consolidation of knowledge. The blending courses teaching model combined the benefits of online and offline teaching, and according to cognitive load theory, the overall burden in teaching is fairly divided in three stages: pre-class, in-class, and after-class stage, making it easier for students to achieve deep learning (Zhang and Wang, 2014). As a result, we can see that blending courses teaching and deep learning are tightly linked, and the two are interdependent, making it possible for us to increase the effectiveness of English instruction. Scholars have been studying the actual teaching effects in the blending courses of deep learning, and they have proven, through theoretical and practical studies, that it can actually promote deep learning (e.g., He et al., 2019; Tan, 2019).

When Akyol and Garrison (2011) investigated the issues of cognitive presence in pure online and blending inquiry-based communities, they discovered that in blending inquiry-based communities, cognitive presence and perceptual and factual learning outcomes were higher than in pure online learning, and learners were more likely to reach deep learning. According to Nazarenko (2015), a blending format promoted the development of students' professional and informational capabilities in a case study research based on the experience of applying a blending learning approach. Wang et al. (2017) analyzed the behavior of deep and shallow learners in a blending learning environment using the learning behavior analysis approach and discovered that deep learners were more likely to actively participate in classroom activities. In terms of the further effects of blending learning practice, Du and Fu (2016) investigated the learning effects of MOOC blending teaching and found that the design of MOOC blending teaching can increase teaching quality and meet the intended in-depth learning goals. To deepen the learning depth of blending learning, Peng and Yang (2017) proposed that it was necessary to start from the construction of blending learning field, improvement of teachers' teaching design capabilities, and training of blending learning control capabilities to fully leverage the power of big data analysis skills in order to form synergies. As a result, we may assume that the blending courses teaching model seeks deep

learning to some level, which is a potential prerequisite of blending teaching.

2.2 Influencing factors of English deep learning in blending courses

2.2.1 Learning engagement

Learning engagement refers to the level of behavioral participation and emotional experience students have when they begin and complete learning activities. Learning engagement is a pleasant and continuous emotional state demonstrated by learners during the course of learning activities, with the key characteristics of activity, attentiveness, and devotion (Gao et al., 2015). Activity referred to the level of effort and persistence learners put into learning; attentiveness referred to the degree to which the learner is attentive in the learning process and devotion primarily referred to learners' pride and excitement for learning activities, as well as their willingness to overcome the problems faced in learning (Schaufeli et al., 2002). Engagement consists of behavioral, emotional, and cognitive components; behavioral engagement refers to actively participating in professional and social activities; emotional engagement refers to academic aspirations and a sense of belonging to the school; and cognitive engagement refers to the methods and strategies used to improve learning efficiency (Fredricks et al., 2004).

"Engagement" can be embodied through behaviors such as beginning, participating, working hard, persistence, continuing to try in the face of difficulties or failures, and positive emotional experiences (such as positivity, optimism, enthusiasm, happiness, curiosity, and interest), and can be demonstrated through reflection of behavior toward the goal of struggle. Learning engagement had been proven in studies to be an essential indication of students' learning in school and to have a direct and stable association with the learning successes that students may attain (Bresó et al., 2011). A higher degree of learning engagement was beneficial for learners in achieving their learning objectives and obtaining desirable learning outcomes (Ronimus et al., 2014). Besides, when students were studying, behavioral engagement was an important observation index of their learning engagement, and it was an explicit feature of learning engagement. That is to say, they would have a serious and committed attitude, actively communicated with teachers and classmates, paid attention to information comprehension and problem solving, and built creativity and cooperation abilities. As a result, behavioral engagement was a prerequisite for deep learning, a key element influencing academic performance and results (Johnson and Sinatra, 2013), and an essential indicator of educational progress (Kim et al., 2016). According to Liu and Wang (2017), behavioral engagement can lessen the negative effects of cognitive load on students, prevent shallow learning, enhance the development of students' collaborative and metacognitive abilities, and complete deep learning capacity training in a virtual reality context. Zhao et al. (2013) also discovered that learning engagement encouraged critical thinking and cooperative communication, as well as deep learning. In other words, the level of students' learning engagement determined the quality of CALL to a large extent. Thus, in the novel blending courses teaching model, students' learning engagement can be assumed to have a big influence on deep learning promotion and specifies the quality of teaching that can be accomplished by employing the model.

2.2.2 Self-efficacy

An individual's self-efficacy is defined as his/her belief, judgment, or subjective self-experience about his/her ability to complete a task. It's a crucial cognitive factor that influences self-regulated learning (Bandura, 1998).

Researchers discovered that self-efficacy predicted and explained academic accomplishment (Vayre and Vonthron, 2017). Self-efficacy could improve learning effectiveness and was an essential component influencing learning motivation and predicting learning outcomes (Yin and Xu, 2011; Tsai, 2012). People with high self-efficacy, according to the findings of the aforementioned studies, had a stronger potential to improve their own abilities, so as to achieve higher level learning. Deep learning was linked to self-efficacy, according to Papinczak et al. (2008), and students with strong self-efficacy can attain higher levels of deep learning. In an intelligent device-assisted teaching environment, Lee and Choi (2017) investigated the influencing elements of deep learning and discovered that students' self-efficacy and evaluation methods influenced the level of deep learning. Furthermore, studies have shown that self-efficacy can predict learning engagement (Bresó et al., 2011). When faced with a difficult or challenging task, individuals with higher self-efficacy were able to persevere on the task for longer periods of time and are less likely to give up in the middle (Chouinard et al., 2007). According to Bandura's theory of social cognition, if learners wished to maintain a high level of learning engagement, they have a strong sense of self-efficacy in order to retain a decent level of motivation to commit themselves to learning activities. We can deduce that self-efficacy will have a positive impact on high school students' learning engagement based on this. The relevant findings from the study on self-efficacy and teacher-student interaction revealed that increasing students' self-efficacy had a significant impact on the frequency and degree of teacher-student interaction (Huang et al., 2015). The research of Dong (2015) further demonstrated that high school students' chemistry classroom participation was significantly influenced by their chemistry learning self-efficacy. The better the students' chemistry learning self-efficacy, the greater their classroom participation and academic success in chemistry. Self-efficacy determines the content and nature of the learner's imaginal realization of future learning scenarios or processes, which affects the individual's motivational psychology in the implementation of learning activities, and thus has an impact on actual learning activities, directly or indirectly. Thus, this study infers that self-efficacy has a beneficial influence on teacher-student interaction in a blending English course.

2.2.3 Teacher-student interaction

The different forms, qualities, and degrees of interaction and their impacts between teachers and students in the classroom

teaching environment are referred to as "teacher-student interaction".

In the specific learning environment of the blending courses, smart devices and information technology have substantially enhanced the opportunities and means of interactions between teachers and students. Compared to that in the conventional classroom, the interaction between teachers and students in the blending courses teaching model includes the following features: first, the teacher-student interaction forms exhibit a tendency of variety and flexibility with the use of smart technologies. The advancement of information technology lessens the sensation of distance in online virtual interactions while simultaneously increasing the flexibility of real-world interactions in classrooms. Second, the content of teacher-student interaction is more open, and is no longer limited to specific textbook knowledge and problem solving in classrooms. In reform-based blending courses teaching, students have a variety of possibilities to communicate with teachers and share their thoughts and learning experiences (Rimmkaufman et al., 2015). On the research of college students' learning engagement, Zhu (2010) discovered that the interaction between teachers and students in the school had an important impact on learning engagement. Among them, teacher-student interaction in classroom was the most significant factor. After performing an investigation in a university classroom in China, Ma et al. (2011) developed a model of the influence of teacher-student interaction on teaching quality. According to the findings of the study, the influence of teacher-student interaction on students' learning behavior is primarily achieved through learning motivation, and teachers' teaching concept, teaching level, and teaching strategy all have significant impacts on students' learning motivation; teachers can stimulate students by increasing the degree of learning participation, thereby transforming students from passive to active learners. Thus, this study assumes that in the blending courses, teacher-student interaction will have a positive influence on students, encouraging them to have more active learning beliefs and behaviors, deepen their learning engagement, and finally achieve the standards of deep learning.

3 Methods

3.1 Participants

There were 225 second-year high school students from a key middle school in Southwestern China participated in the questionnaire survey, with 107 males and 118 females, and the ages of them were from 16 to 18.

This middle school began to explore the reform of a blending courses teaching model in 2018, first conducting pilot teaching in the three subjects of Chinese, Mathematics and English. The school combines advanced and mature educational informatization research results and information technology methods with the actual situation and needs of the school's teaching and learning, and draws on the experience of building smart classrooms in universities and colleges, and proposes a design for blending courses construction from eight aspects to build a three-in-one construction model of "the integration of resource space, physical space, interactive space, and multi-dimensional data collection and application" (He and Huang, 2018). Through 3 years of construction and development, with the support of smart devices and information technology, the school's blending courses teaching model has achieved significant results. It can be seen that the students in this middle school already have the experience of learning in a blended classroom, and they are quite appropriate to be selected as the research participants of this study.

3.2 Questionnaire

The questionnaire consists of four subscales, including the deep learning scale, the learning engagement scale, the teacher-student interaction scale and the self-efficacy scale. It is a five-point Likert scale (1–5 respectively indicate "totally disagree," "basically disagree," "neural," "basically agree" and "totally agree").

(1) deep learning scale

This scale is adapted from the deep learning subscale constructed by the NSSE-China research group of the Institute of Education of Tsinghua University (Shi et al., 2011).

(2) learning engagement scale

It was formed on the basis of the Utrecht Work Engagement Scale-Student scale (UWES-S) (Zhang and Gan, 2005).

(3) self-efficacy scale

The scale uses the Chinese version of the General Self-Efficacy Scale (GSES) compiled by Schwarzer et al. (Wang et al., 2001).

(4) teacher-student interaction scale

The scale is the Chinese version of the teacher-student interactive questionnaire developed by Kang (Zhang, 2019).

3.3 Data collection

Before the questionnaires were formally distributed, the researcher attended several classes accompanied by the English teachers of the tested classes. In order to comply with the ethical requirements of the university being studied and maintain anonymity, detailed information of all participants has been omitted. Before seeking their consent, participants were informed of the research objectives and confidentiality of the study before the administration of questionnaires and then ensured that the responses to the questionnaires would be treated confidentially and could be withdrawn at any time. All participants consented to be involved in the study voluntarily. A total of 225 questionnaires were sent to all classes. The 225 surveys were all gathered. The questionnaire recovery rate was 100%. The researchers excluded questionnaires with questions forgotten to answer and all questions of the same answers. A total of 216 valid surveys were gathered, and the questionnaire's valid rate was 96%. Throughout

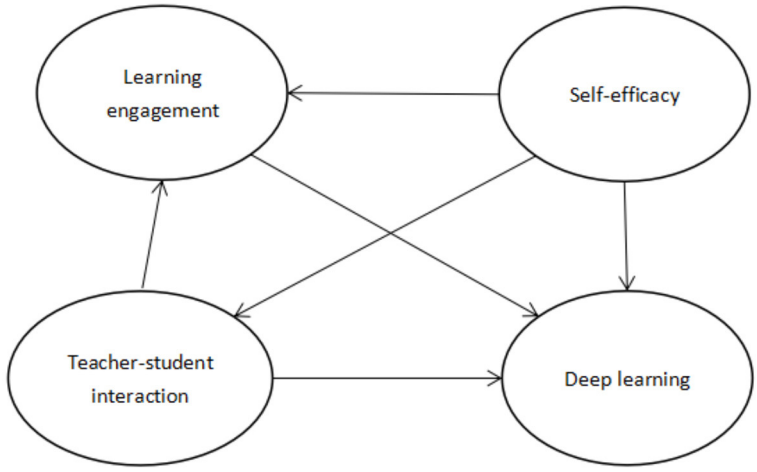

FIGURE 1
Theoretical model of influencing factors of English deep learning in blending courses.

the data collection process, the researchers strictly followed ethical standards.

3.4 Theoretical research model and hypothesis

Based on the previous research on the influencing factors of English deep learning of high school students in blending courses, the following research hypotheses are made:

H1: Learning engagement, self-efficacy and teacher-student interaction all predict and have positive effects on deep learning.

H2: Teacher-student interaction has a positive effect on learning engagement and self-efficacy has a positive effect on both learning engagement and teacher-student interaction.

Based on the above hypotheses, this research constructs a theoretical research model of influencing factors of English deep learning of high school students in blending courses, as shown in Figure 1.

4 Results

4.1 Reliability and validity of the questionnaire

SPSS26.0 was used to test the reliability and validity of the model. The reliability test is generally based on the Cronbach's alpha, and the validity test is generally based on the Value of KMO and Bartlett's. As shown in Table 1, the coefficients of each scale are >0.8, indicating that the internal consistency of the questionnaire is high. The questionnaire's overall reliability coefficient is 0.924, suggesting that the consistency and stability of the questionnaire's items are quite good. As a result, all of the data obtained in this study's questionnaire have extremely high reliability.

As shown in Table 2, The entire scale's KMO value is greater than 0.8, indicating that there is no significant difference between items in terms of correlation, and the Bartlett's Test of Sphericity result $p = 0.000$, which reaches a significant level, suggesting that the items of the questionnaire are not independent, and the questionnaire is valid.

In summary, both reliability and validity of the entire scale are generally high in this study, and the test findings fulfill the relevant particular requirements, suggesting that the data are acceptable for factor analysis.

TABLE 1 Cronbach's alpha coefficient of the questionnaire.

Scale	Cronbach's alpha coefficient	Distribution of Items
Self-efficacy	0.859	1–5
Learning engagement	0.827	6–10
Teacher-student interaction	0.893	11–15
Deep learning	0.877	16–20
Overall	0.924	

4.2 Verification and modification of structural equation model

The fitness index is used to verify the structural equation model. Various indicators use certain values as the foundation for their assessment as the primary measure of the degree of fit between the model and the data. Table 3 shows the acceptable standard for the commonly used fitness index values in structural equation models and the fitness index summary of the original model after using AMOS25.0

In terms of the influencing factor model's fitness index, when compared to the reference standard for the value of the fitness index, the original model has to be altered and modified to some amount. AGFI = 0.791, which was less than the acceptable standard

TABLE 2 KMO and Bartlett's test of the entire scale.

Kaiser–Meyer-measure of sampling adequacy		0.900
Bartlett's Test of Sphericity	Approx. Chi-Square	2538.542
	df	190
	Sig.	0.000

TABLE 3 Acceptable standard and summary of fitness index of the original model.

Name of index	Acceptable standard value	Value of the model
CMIN/DF	≤5	2.674
GFI	≥0.80	0.837
AGFI	≥0.80	0.791
CFI	≥0.90	0.883
PNFI	≥0.50	0.714
PGFI	≥0.50	0.654
PCFI	≥0.50	0.762
RMR	≤0.10	0.064
RMSEA	≤0.08	0.088

TABLE 4 Summary of modified model fitness index.

Name of index	Acceptable standard value	Value of the modified model
CMIN/DF	≤5	2.317
GFI	≥0.80	0.869
AGFI	≥0.80	0.826
CFI	≥0.90	0.911
PNFI	≥0.50	0.715
PGFI	≥0.50	0.654
PCFI	≥0.50	0.762
RMR	≤0.10	0.070
RMSEA	≤0.08	0.078

value of 0.8; CF1 = 0.883, which was smaller than the acceptable standard value of 0.9; and RMSEA = 0.088, which was greater than the standard value of 0.08. All of these values did not satisfy the level of fitness. The remaining indicators have all attained the standard value.

The fitness index in Table 3 shows that the fitness effect of the structural equation model is not ideal, indicating that the original model has to be modified to some extent. After modification for 4 times, the influencing factor model of English deep learning for high school students in the blending courses finally meets the standard of fitness index. All data of the modified model's fitness are shown in Table 4 and the modified model diagram is obtained as shown in Figure 2.

4.3 Test results and interpretation of hypotheses

The path coefficient map of the modified model is shown in Figure 3.

The model of influencing factors of high school students' English deep learning in blending courses, as shown in Figure 3, contains four latent variables: self-efficacy, learning engagement, teacher-student interaction, and deep learning. The relationship between the four latent variables can be analyzed and explained through this structural equation model: self-efficacy, learning engagement and teacher-student interaction all predict and have direct positive impacts on deep learning. Among them, the influence effect of self-efficacy is 0.37, the influence coefficient of learning input factor is 0.38, and the influence coefficient of teacher-student interaction factor is relatively small, 0.19; Learning engagement is directly influenced by self-efficacy and teacher-student interaction, of which the influence coefficient of self-efficacy is 0.22, and the influence coefficient of teacher-student interaction is 0.45; Finally, teacher-student interaction is influenced by self-efficacy, with an influence coefficient of 0.47.

The researcher validates the hypotheses proposed in this study using the analysis described above. Theory-based research hypotheses are confirmed, by using AMOS25.0, through confirmatory factor analysis between the theoretical model and the questionnaire data, the fitness test of the model fitness index and the model modification. To some extent, the model is scientific, and it serves as a reference for high school to carry out blending courses teaching and to increase high school students' English deep learning.

5 Discussion

5.1 Effect of self-efficacy

5.1.1 Effect of self-efficacy on English deep learning

In this study, students' self-efficacy has a significant positive effect on their English deep learning in the blending courses, which is consistent with the conclusion drawn by the previous studies (Papinczak et al., 2008; Yin and Xu, 2011; Tsai, 2012; Lee and Choi, 2017). It indicates that increasing students' self-efficacy will result in an increase in students' English deep learning.

In the blending courses, students' positive feelings or beliefs in the face of various English learning activities and learning scenarios have a major influence on English deep learning. The more confident students are in English learning under a variety of learning activities and circumstances in blending courses, the deeper their English learning may be. If students believe they can have gains in the blending courses, they will be more active in studying relevant course content; if students believe they will not learn much in blending courses, they will devote less energy to learning assignments. Nilsen's action research points out that students' self-efficacy significantly affects students' motivation to learn deeply. The more self-confidence students have in their ability to learn, the more time they will dedicate to learning assignments, and vice versa (Nilsen, 2009). Zhang's research on the relationship

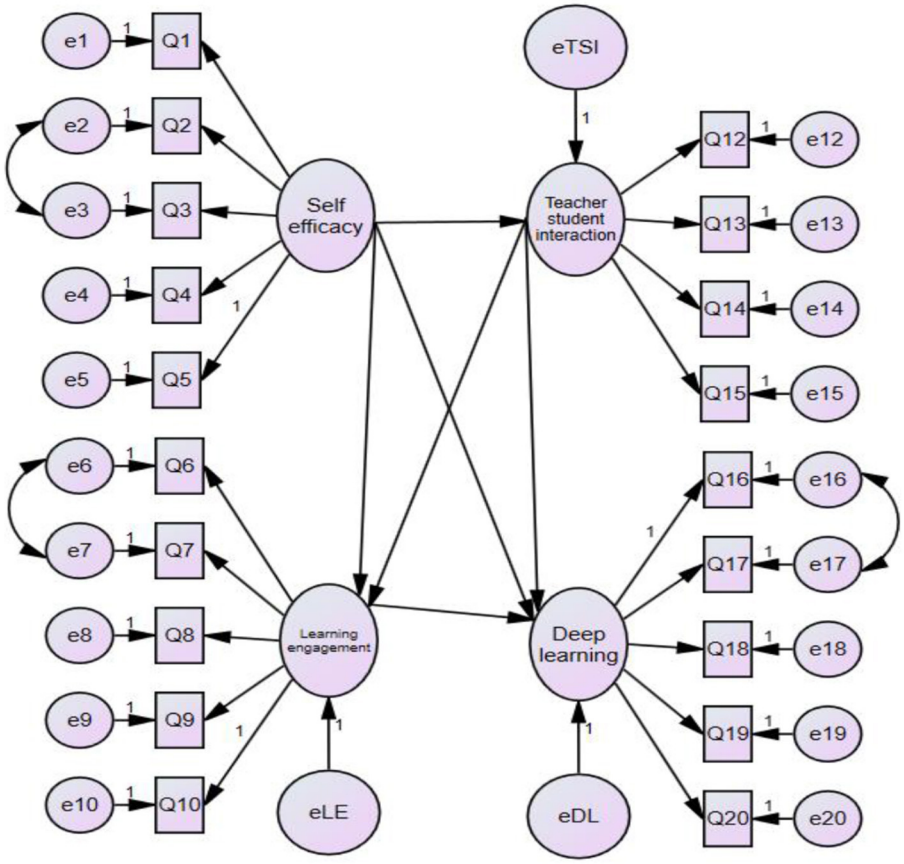

FIGURE 2
Modified model diagram of influencing factors.

between college students' self-efficacy and deep learning in a digital environment discovers that online self-efficacy may predict deep learning significantly. Her research also suggests that increasing online self-efficacy encourage learners to employ more diverse learning techniques (Zhang, 2015), which is consistent with the fact that in this study, self-efficacy has a substantial impact on students' English deep learning, and students with a higher level of self-efficacy are more likely to have greater self-confidence, gain a stronger potential to improve their own abilities, be able to control over their behaviors to get desired results, and persevere on the task for longer periods of time, so as to achieve higher level learning.

5.1.2 Effect of self-efficacy on learning engagement

Students' self-efficacy positively affects their learning engagement in the blending course. As we have mentioned previously, in this blending context the overall burden in teaching and learning is fairly divided in three stages: pre-class, in-class, and after-class stage, making it easier for students to learn. Students in this context are more likely to have a lower level of learning load, and they are also provided with more humanistic learning environment, and teachers are able to design a variety of classroom activities and adopt multiple teaching strategies through smart devices and information technology, thus students tend to get a higher level of self-efficacy, to be motivated and encouraged to participate more in the process of teaching and learning. According to Bandura's theory of social cognition, if learners wished to maintain a high level of learning engagement, they have a strong sense of self-efficacy in order to retain a decent level of motivation to commit themselves to learning activities, which was also confirmed by Dong's (2015) research. Students will gradually develop more committed attitude, actively communicate with teachers and classmates, pay attention to information comprehension and problem solving, and build creativity and cooperation abilities, resulting in more and more intense learning engagement, and will also further improve their own learning efficacy so as to create a virtuous circle. For high school students, full and active learning enthusiasm enables them to generate learning motivation, hone their perseverance, and improve their learning ability; the improvement of learning ability and the spirit of continuing to pay for learning enable students to obtain a good learning self-experience, and then go all out to devote themselves to learning.

5.1.3 Effect of self-efficacy on teacher-student interaction

In the blending course, students' self-efficacy positively affects teacher-student interaction, demonstrating that increasing

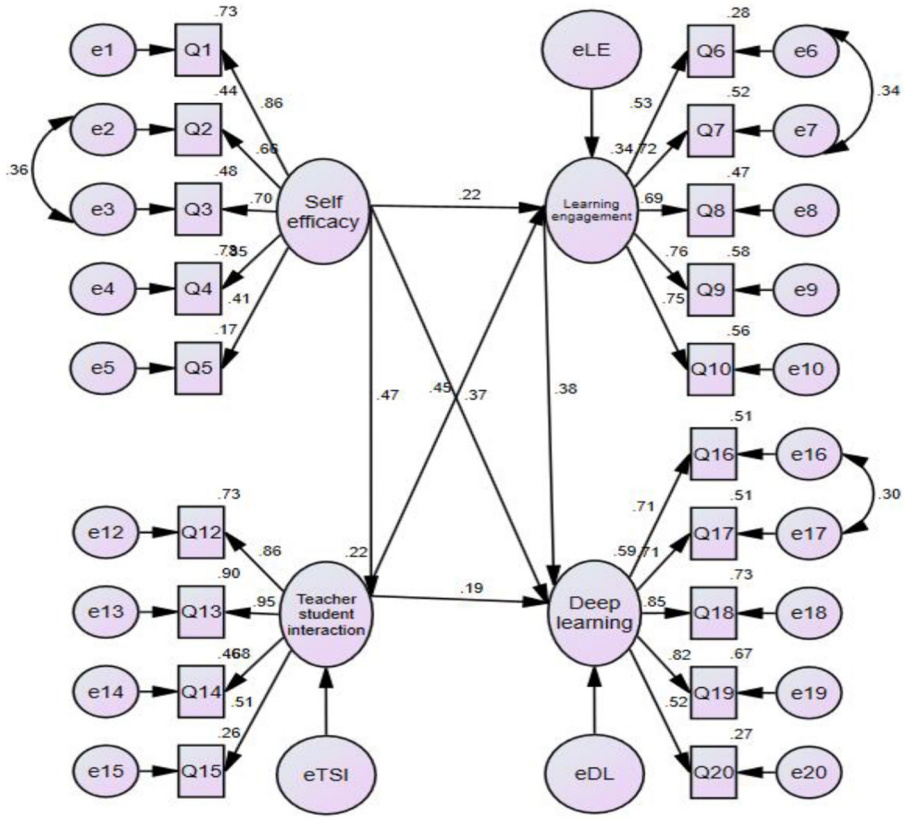

FIGURE 3
Modified model path coefficient.

students' self-efficacy can increase the frequency and degree of interaction between students and teacher. This finding is in line with findings of previous studies of Huang et al. (2015) and Dong (2015). According to self-efficacy theory, students with varying skill levels choose to perform the same learning activity in various ways and to varying degrees. The greater the student's sense of self-efficacy, the more likely they are to engage in a certain action. In the blending context, with various online and offline activities, students get more access to communicate with teachers, and when they feel they have abilities to complete a task, they will be eager to undertake difficulties and more willing to seek help from teachers. When they fail to reach their learning goals, they will increase their efforts and attribute their failures in favor of success. Thus, more teacher-student interaction will be seen under this circumstance, and with more and more communications between teachers and students, students could be more confident or less anxious to achieve success.

5.2 Effect of teacher-student interaction

5.2.1 Effect of teacher-student interaction on English deep learning

In the blending course, teacher-student interaction has a positive impact on the deep learning of English. It can be shown that increasing the frequency and degree of interaction between students and teachers will result in an improvement in students' English deep learning level, which are also found by Ma et al. (2011)'s investigation in a university classroom. In the blending courses, the traditional teacher-centered interaction is replaced by student- and knowledge-centered interaction—students are at the center of teaching and students interact with teacher on an equal basis thus forming a special partnership in order to achieve common goals.

The forms of interaction between students and teachers are varied through the blending courses teaching model which combines online learning with traditional classroom teaching. During the pre-class preparation stage, teachers use the intelligent software platform to assign a series of specific shallow learning tasks and upload pre-class learning materials, such as micro-videos of learning courses and exercises on relevant knowledge. The goal is to guide students in understanding and applying some basic English core knowledge, and then teachers use the teaching software platform to create personalized written reports for students and conduct diagnostic evaluations for students, while also realizing real-time learning supervision and management of each student via the smart learning platform. When they face difficulties, students may also communicate with teachers via the software learning platform and ask for teachers' feedback and clarification. The software learning platform captures each student's frequent difficulties. After summarizing, it is shown on the teacher's smart device terminal, allowing teachers to provide professional and thorough responses to students in the classroom. Teachers'

professional expertise, as well as their support and responsiveness to students in various situational tasks, might enable students to receive timely assistance. Students can promote their own deep learning strategies and abilities to use rules, methods, skills, and so on to solve problems in the learning process, and also to master core knowledge content, develop critical thinking, problem-solving, cooperative communication, and other skills in the interaction with teachers. All these can contribute to students' deep learning.

5.2.2 Effect of teacher-student interaction on learning engagement

Teacher-student interaction has a positive influence on students' learning engagement in the blending course. It was confirmed by Zhu (2010) who discovered that the interaction between teachers and students had an important impact on learning engagement. The interaction between teachers and students is to enhance the development of students' cognition and abilities. It may nurture students' abilities to recall, interpret, apply, analyze, synthesize, and evaluate through their interaction with teachers, and realize the shift from ignorance to knowledge so as to create a distinct cognition. Moreover, teacher-student interaction may influence the relationship between the two, as well as students' emotions in English learning, which in turn has an impact on students' dedication to learning. With more interactions between teachers and students, and when they get more feedback from teachers, students will be more willing to communicate, develop more interest in learning, and become more actively involved in learning activities.

5.3 Effect of learning engagement

Students' learning engagement has a positive influence on their English deep learning in the blending course. The behavior and cognition of students actively engaged in learning provide the foundation for English deep learning in the blending courses. As Johnson and Sinatra (2013) found, behavioral engagement was a prerequisite for deep learning, a key element influencing academic performance and results. Students who were highly engaged behaviorally and cognitively tended to gain support for meaningful learning outcomes. The finding of the present study also echoes the findings of Liu and Wang (2017) and Zhao et al. (2013), who claimed that behavioral engagement could lessen the negative effects of cognitive load on students, prevent shallow learning, enhance the development of students' critical thinking, collaborative and metacognitive abilities, and complete deep learning capacity training in a virtual reality context. Previous research has demonstrated that the learning engagement theory is congruent with the key principles of deep learning, and that learning behavior and cognitive engagement match the requirements of the deep learning mechanism.

6 Conclusions and implications

This study investigated the factors that influence high school students' English deep learning in the blending course. We found that students' self-efficacy and engagement predicted and had strong positive influences on English deep learning. Self-efficacy had considerable beneficial influences on students' learning engagement and teacher-student interaction. Teacher-student interaction positively impacted English deep learning and students' learning engagement.

Drawn from these findings, we get some pedagogical implications for promoting EFL learners' deep learning in the blending courses. To increase students' English deep learning level in the blending courses, it is vital to strengthen students' self-efficacy and improve students' learning engagement. When design instructional activities, teachers could thoroughly analyze students' need and match the level of classroom tasks to students' existing learning capacity. The online platform can provide accurate data to analyze the needs and current level of students. Teachers can follow the change of students' learning process and better satisfy students' needs by using online sources. During the online learning phase, students can continue to accrue "successful experience" by performing acceptable minor tasks, and with constant repetition, steadily enhance their English learning, and eventually accomplish the aim of tackling greater learning tasks. The goal of blending teaching is not only to give information and resources, but also to develop students' abilities to learn and update knowledge and integrate resources on a continual basis. In the face-to-face teaching stage, teachers could engage students actively by carrying out various classroom tasks and providing care and support to students through encouragement and verbal persuasion. Students' perceptions of their own abilities are heavily impacted by the opinions of those around them. Teachers could assist students in developing a right vision of learning and personal values, as well as promote students' concentration on knowledge and ability development rather than just completing academic requirements.

Increasing the frequency and degree of interaction between students and teachers can promote the growth of students' English deep learning. It is suggested that teachers coordinate "dual-line" teaching activities (online learning and face-to-face classroom teaching) to enhance the interaction between teachers and students. Teachers could thoroughly examine the benefits of "dual-line" teaching activities in order to maximize interaction between teachers and students. Although different strategies are used to increase the occurrence of deep learning online and offline in blending courses, online and offline cannot be independent of one another, but should complement and coordinate with each other to form synergy in terms of learning content, learning tasks, learning process and evaluation.

The English curriculum layout of blending courses teaching model should take the dual channels of "shallow learning + deep learning" as the teaching purpose, which should run through all phases of English teaching. As for the pre-class stage, teachers could fairly plan a succession of specialized shallow learning activities, and establish a common learning community for teachers and students, where teachers and students can discuss and exchange learning experiences. Teachers can also initiate challenging learning tasks in the learning community to motivate students to participate, and students can complete learning tasks through cooperation and interaction with teachers. Then, through the student's individualized report and the diagnostic assessment provided by the learning platform,

teachers could design the following tasks. During the face-to-face teaching stage, due to the individual counseling that cannot be completed by an online learning platform, teachers can complete it using face-to-face ways. Teachers could change teaching arrangements as needed in response to students' previews and reviews, create a variety of learning settings and possibilities, and provide prompt feedback. After class, teachers assign personalized learning courseware and activities to students, track the accomplishment of students' work in real time, give timely feedback to students, and encourage students to actively interact with teachers so that their deep learning can be improved.

Besides, it is suggested that we enrich evaluation methods and promote students' learning reflection. The assessment should evaluate students not just on their academic success, but also on their growth of diverse talents and emotional input. The inter-group assessment, peer assessment and self-assessment can be used integratively online and offline. Finally, improving IT support could benefit students' deep learning. The effective use of technology can transform teaching and learning practices, making them more important and interesting, while being able to connect more closely with students, which in turn can fundamentally change the quality of the student learning experience and enhance their deep learning (Malliarakis et al., 2014). The fast growth of information technology and smart devices has enabled the advent of the blending courses. Online learning platforms, which created a multitude of learning resources for students, can be tailored to meet the learning characteristics of students. The use of smart touch devices, virtual reality, intelligent technology, etc., provides students with a variety of learning avenues that allow them to interact with teachers and learning content at any time. Thus, frequent updating of online learning resources, maintenance of the learning platform, development of the campus network, and a variety of additional information technology support all play a significant part in students' deep learning.

This study focused on a single group English learners in a single school. Future studies could explore other influencing variables of deep learning of students with varied learning capacities in schools at different levels of education. Simultaneously, this study focused on quantitative data without qualitative insights and relied solely on self-reported data from a single source. Future researchers can employ interviews, classroom observations, and journals, to make more in-depth and complete research, and combine students' and teachers' perspective to have a holistic view of deep learning and underlying mechanisms of student interactions and learning processes.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by the China University of Petroleum. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

HS: Conceptualization, Methodology, Project administration, Supervision, Writing—review & editing. PL: Conceptualization, Data curation, Investigation, Writing—original draft, Writing—review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Akyol, Z., and Garrison, D. R. (2011). Understanding cognitive presence in an online and blended community of inquiry: assessing outcomes and processes for deep approaches to learning. *Br. J. Educ. Technol.* 42, 233–250. doi: 10.1111/j.1467-8535.2009.01029.x

Allen, I. (2011). Going the distance: online education in the United States. *Sloan Consortium* 18:44. doi: 10.1111/1467-8659.1450275

Bandura, A. (1998). Perceived self-efficacy in cognitive development and functioning. *Educ. Psychol.* 28, 117–148. doi: 10.1207/s15326985ep2802_3

Bresó, E., Schaufeli, W. B., and Salanova, M. (2011). Can a self-efficacy-based intervention decrease burnout, increase engagement, and enhance performance? A quasi-experimental study. *Higher Educ.* 61, 339–355. doi: 10.1007/s10734-010-9334-6

Chouinard, R., Karsenti, T., and Roy, N. (2007). Relations among competence beliefs, utility value, achievement goals, and effort in mathematics. *Br. J. Educ. Psychol.* 77, 501–517. doi: 10.1348/000709906X133589

Delialioglu, O., and Yildirim, Z. (2007). Students' perceptions on effective dimensions of interactive learning in a blended learning environment. *J. Educ. Technol. Soc.* 10, 133–146.

Dong, X. (2015). A survey and research on the current status of self-efficacy in chemistry learning among high school seniors. *Chem. Educ*. 55–58.

Du, S., and Fu, Z. (2016). Blended learning and its empirical research based on MOOC. *China Educ. Technol.* 12, 129–133.

Fredricks, J. A., Blumenfeld, P. C., and Paris, A. H. (2004). School engagement: potential of the concept, state of the evidence. *Rev. Educ. Res.* 74, 59–109. doi: 10.3102/00346543074001059

Fullan, M., and Quinn, J., and McEachen, J. (2018). *Deep Learning: Engage the World, Change the World.* Thousand Oaks, CA: Corwin Press.

Gao, J., Li, M. J., and Zhang, W. L. (2015). The relationship between proactive personality and online learning engagement: the perspective of self-determination motivation theory. *e-Educ. Res.* 36, 18–29.

Gao, Y., and Huang, R. H. (2017). Interpretation and implications of 2017 NMC technology outlook of higher education in China: A horizon project regional report. *China Educ. Technol.* 38, 15–22.

He, L., Tang, L., and Liu, J. (2019). Design and practice of MOOC blended teaching based on deep learning. *Comput. Educ.* 1, 150–157.

He, Z., and Huang, T. (2018). The construction concept, model, and application prospects of smart classrooms in universities: taking Central China Normal University as an example. *Mod. Educ. Technol.* 28, 54–60.

Huang, F., and Wang, Q. H. X., and Peng, H. (2015). A survey of high school students' classroom participation and its influencing factors—Taking high school chemistry class as an example. *Theor. Prac. Educ.* 35, 55–57.

Johnson, M. L., and Sinatra, G. M. (2013). Use of task-value instructional inductions for facilitating engagement and conceptual change. *Contemp. Educ. Psychol.* 38, 51–63. doi: 10.1016/j.cedpsych.2012.09.003

Kim, D., Park, Y., Yoon, M., and Jo, I. H. (2016). Toward evidence-based learning analytics: using proxy variables to improve asynchronous online discussion environments. *The Int. Higher Educ.* 30, 30–43. doi: 10.1016/j.iheduc.2016.03.002

Lee, J., and Choi, H. (2017). What affects learner's higher-order thinking in technology-enhanced learning environments? the effects of learner factors. *Comput. Educ.* 115, 143–152. doi: 10.1016/j.compedu.2017.06.015

Liu, Z. Y., and Wang, Z. J. (2017). The empirical study of behavior engagement influence on deep learning: exemplified with video learning in virtual reality (VR) environment. *J. Dist. Educ.* 35, 72–81.

Ma, Z. Y., Meng, J. Z., and Yan, J. P. (2011). An empirical study on effects of classroom interaction on teaching quality: a case of a local university in Shanghai. *Fudan Educ. Forum* 2, 51–56.

Malliarakis, C., Satratzemi, M., and Xinogalos, S. (2014). *Technology Integration in the Most Favorable Conditions: Findings From a Professional Development Training Program*. New York, NY: Springer Publishing.

Nazarenko, A. L. (2015). Blended learning vs traditional learning: What works? (a case study research). *Proc.- Soc. Behav. Sci.* 200, 77–82. doi: 10.1016/j.sbspro.2015.08.018

Nilsen, H. (2009). Influence on student academic behavior through motivation, self-efficacy and value expectation: An action research project to improve learning. *Issues Inf. Sci. Inf. Technol.* 6, 545–556. doi: 10.28945/1080

Papinczak, T., Young, L., Groves, M., and Haynes, M. (2008). Effects of a metacognitive intervention on students' approaches to learning and self-efficacy in a first year medical course. *Adv. Health Sci. Educ. Theor. Pract.* 13, 213–232. doi: 10.1007/s10459-006-9036-0

Peng, F. X., and Yang, W. (2017). How to deepen the depth of learning in blended learning—How to supported learning analysis with education Big Data. *Modern Dist. Educ.* 2, 31—39.

Rimmkaufman, S. E., Baroody, A. E., Larsen, R., Curby, T. W., and Abry, T. (2015). To what extent do teacher-student interaction quality and student gender contribute to fifth graders' engagement in mathematics learning?. *J. Educ. Psychol.* 107, 170–185. doi: 10.1037/a0037252

Ronimus, M., Kujala, J., Tolvanen, A., and Lyytinen, H. (2014). Children's engagement during digital game-based learning of reading: the effects of time, rewards, and challenge. *Comput. Educ.* 71, 237–246. doi: 10.1016/j.compedu.2013.10.008

Schaufeli, W. B., Salanova, M., Gonzálezromá, V., and Bakker, A. B. (2002). The measurement of engagement and burnout: a two sample confirmatory factor analytic approach. *J. Happ. Stu.* 3, 71–92. doi: 10.1023/A:1015630930326

Shi, J., Tu, D., Wang, S., Lv, Z., and Zhao, L. (2011). Annual report of national college education survey 2009. *Tsinghua J. Educ.* 32, 9–23.

Tan, S. (2019). Construction of "blending teaching" model in colleges pointing to Deep Learning. *China Higher Educ*. 6, 51—53.

Tsai, C. C. (2012). The development of epistemic relativism versus social relativism vi a online peer assessment, and their relations with epistemological beliefs and internet self-efficacy. *Educ. Technol. Soc.* 15, 309–316.

Vayre, E., and Vonthron, A. M. (2017). Psychological engagement of students in distance and online learning: effects of self-efficacy and psychosocial processes. *J. Educ. Comput. Res.* 55, 197–218. doi: 10.1177/0735633116656849

Wang, C. K., Hu, Z. F., and Liu, Y. (2001). Evidences for reliability and validity of the Chinese version of general self-efficacy scale. *Chin. J. Appl. Psychol.* 7, 37–40.

Wang, H. B., Li, J. H., and Yang, X. M. (2017). Research on differences of learning behaviors between deep learners and surface learners in blend learning in higher Education. *e-Educ. Res*. 12, 44—50.

Yin, R., and Xu, D. (2011). Relationship between online learning environment and undergraduates' self-efficacy. *Distance Educ. China* 31:53.

Zhang, J. H. (2019). The current situation and effect of teacher-student interaction in college teaching. *Res. Educ. Dev*. 23, 10—17.

Zhang, Q. (2015). A study on the correlation between self-efficacy and deep learning among college students in the e-learning environment. *E Educ. Res*. 55–61.

Zhang, Q. L., and Wang, A. C. (2014). The design of new blended learning model based on flipped classroom. *Modern Educ. Technol.* 24, 27–32.

Zhang, Y. W., and Gan, Y. Q. (2005). The Chinese version of Utrecht work engagement scale: an examination of reliability and validity. *Chin. J. Clin. Psychol.* 3, 268–281.

Zhao, Z., Wang, X., and Song, W. (2013). A study on the level of deep learning among college students and related factors: analysis based on the survey of academic situation at Ocean University of China. *Educ. Res. Exp*. 73–77.

Zhu, H. (2010). The relationship between student engagement and college student achievement—the analysis of 2010 annual data set of Beijing college student survey. *Tsinghua J. Educ.* 31, 35–43.

Zhu, Z. T. (2016). New developments of smarter education: from flipped classroom to smart classroom and smart learning space. *Open Educ. Res.* 1, 18–49.

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An isochronic substitution benefit study of the effects of screen time on the cognitive abilities of 3–6 children

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Purpose: To investigate the impact of substituting screen time with other activities on children's cognitive ability.

Method: A total of 583 children (299 males and 284 females), aged 3–6 years, were selected as participants. Correlation, regression, and isochronic substitution analyses were used.

Results: Screen entertainment time on TV (SET_TV) was negatively associated with children's math ability. However, screen learning time on other electronic devices besides TV (SLT_OED) and non-screen learning time by learning alone (NSLT_LA) were positively associated with math ability and language ability. After controlling for gender, age, and family socio-economic status, SET_TV remained negatively associated with math ability, while NSLT_LA remained positively correlated. Furthermore, substituting 10 min of SET_TV with NSLT_LA resulted in an increase of 0.55 in language ability and 0.87 in math ability. Similarly, substituting SLT_OED, sleeping at home, and exercising outside of kindergarten for 10 min of SET_TV resulted in an increase of 0.90, 0.43, and 0.61 in math ability, respectively.

Conclusions: There are cognitive benefits when screen recreation time is replaced with screen learning time, non-screen learning time, sleep time, and exercise time, with the highest benefits observed when screen recreation time is substituted with NSLT_LA.

KEYWORDS

screen time, cognitive ability, isochronous substitution benefit, preschoolers, language ability, math ability

1 Introduction

Since the introduction of television in the twentieth century, people's senses of hearing and sight have been expanded to infinity. Television has brought every corner of the world together and continues to play a significant role in people's daily lives, particularly for young children and the elderly. However, with the rapid development and constant updates of electronic products such as computers, cell phones, and tablets, there is a growing trend of these devices replacing television as the primary source of entertainment and information. As people become increasingly dependent on electronic devices, their screen time also continues to increase. This has led to a steep rise in the number of people with "low head" posture and screen addiction, a phenomenon that is now spreading to preschool-aged children. Shockingly, 24% of children begin using screens before age 1, and 76% before age 2. Even among 3-year-old children who have just entered kindergarten, a

staggering 78.6% spend more than the recommended daily screen time which is no more than 60 min per day (Wang et al., 2024).

Screen time, also known as screen exposure, screen-based behavior, or screen viewing behavior, is inconsistently named or translated in current research. Numerous studies have shown that excessive screen time is associated with negative effects on early childhood development, including physiological (Foreman et al., 2021; Xie and Chen, 2022; Liu et al., 2023), motor (André and Cochetel, 2022), cognitive (Li et al., 2022; Vanderloo et al., 2022b), emotional (Li and Liu, 2022; Xiang et al., 2022), and social aspects (Chang and Wang, 2022; Li and Liu, 2022; Xiang et al., 2022; Wang et al., 2024), and can even have a detrimental impact on children's physical and mental health in the long term (Ennemoser and Schneider, 2007; Vanderloo et al., 2022a). Many countries and organizations have issued guidelines related to screen time, suggesting that people should reduce screen time in early childhood (Cliff et al., 2017; Tremblay et al., 2017), and some guidelines even point out that the less screen time the better (Guan et al., 2020). For a while, screen time has been like a scourge, and parents and educators have been actively working on various strict programs to limit children's screen time. Of course, many scholars take a different view: Kostyrka-Allchorne et al. (2017) systematically reviewed the literature on the relationship between television viewing and children's executive functioning, academic performance, attention, language, and play, and showed that viewing high-quality educational content predicted preschool children's academic performance later in life. Empirical studies have also further suggested that the frequency of educational screen activities (puzzle games, online learning, etc.) moderates the negative predictive effect of screen time on children's early literacy skills (Li et al., 2022). A recent cohort study using a large population (15,965 preschoolers) showed that children's mental health risk increased significantly when screen time exposure exceeded 1 h per day, regardless of the type of screen content viewed by preschoolers, and that the risk increased over time; for the same amount of screen time viewed, children who watched entertainment and non-children's programs were at greater risk of mental health problems than those who watched educational programs. Children's mental health risk is higher when they watch entertainment and non-children's programs compared to educational programs (Wang et al., 2024).

At the same time, numerous scholars have identified key factors that significantly influence the cognitive abilities of preschool children. For example, Ma et al. (2022) conducted a comprehensive search of databases such as PubMed, Web of Science, Eric, SPORT Discus, Academic Search Premier, MEDLINE, CNKI, Wanfang, and Wipro, and analyzed 43 empirical studies to conclude that physical activity has a positive impact on the cognitive development and academic performance of young children. Similarly, Xing et al. (2018) found that longer sleep duration is associated with better brain development and executive function in toddlers and children, with nighttime sleep ratio being a significant predictor of executive function after 3 months. Executive function is considered to be the most advanced process of human cognitive activity, encompassing a wide range of cognitive functions that develop rapidly in early childhood (Luan et al., 2013). In fact, it is widely recognized as the highest level of cognitive activity in humans during this stage of development. Moreover, recent guidelines for preschoolers' daily activities and related studies have revealed a strong connection between physical activity, sleep, and screen time. It is important to note that the total amount of time spent on physical activity, sleep, and sedentary behavior, including screen time, make up a 24-h day. This highlights the need for researchers to adopt a holistic perspective when studying the effects of screen time (Chang et al., 2020a). In other words, researchers must consider the overall balance of a child's daily activities when examining the impact of screen time.

In summary, while there has been extensive research on the relationship between screen time and preschool children's cognitive ability, the focus has been primarily on the associations between physical activity, screen time, and sleep, with fewer studies examining these factors together. Existing studies have also primarily looked at the different effects of various types of screen activities on cognitive ability, but there is a lack of specific strategies for how to allocate screen time in a balanced way (Chang and Wang, 2022). It is often suggested that screen time for learning should be increased while screen time for entertainment should be decreased, but this overlooks the fact that screen time is just one aspect of a child's daily life and can be adjusted to other activities such as sleep, exercise, and study time. Parents should be provided with information on how to adjust screen time rules and find alternative activities for their preschoolers (De Decker et al., 2012). However, previous statistical tools have limited scholars from considering these variables holistically and have also caused issues with covariance (Chang and Wang, 2022). With the development of new statistical tools, this problem can now be addressed (Chang et al., 2020a). This study aims to explore the cognitive benefits of different types of screen time substitutions and how adjusting screen time to other parts of a child's day, such as sleep, exercise, or study time, can impact cognitive ability. This is referred to as isochronous substitution benefits in this study. Research hypothesis: (1) There is a negative correlation between screen time and cognitive abilities in children aged 3–6 years old. However, there is a positive correlation between learning time and exercise time and cognitive abilities in this age group. (2) Replacing screen entertainment time with screen learning time can have a positive impact on cognitive abilities. (3) Replacing screen time with non-screen learning activities, particularly screen entertainment time, can have a positive effect on cognitive abilities. (4) Replacing screen time with sleep and exercise, especially screen entertainment time, can have a positive impact on cognitive abilities.

2 Materials and methods

2.1 Participants

Based on Tsinghua University's survey program on the developmental status of children aged 3–6, the 2020 "Early Childhood Development Data System Collection" project was carried out in seven kindergartens in Changsha, SanYu Group. A total of 900 children were randomly selected from each of the kindergarten's three classes (junior, middle, and senior), with 702 children participating in the study due to practical constraints.

TABLE 1 Basic information about the study subjects.

		Grade			Total
		Junior class	Middle class	Senior class	
Sex	Male	75	129	95	299
	Female	101	97	86	284
Total		176	226	181	583

After the questionnaire stage, 630 valid data were obtained, and after the cognitive ability test, 650 valid data were obtained, resulting in a total of 583 participants (299 males and 284 females; see Table 1). This study obtained ethical approval from the Ethics Review Committee (HR342-2024).

2.2 Materials

2.2.1 Questionnaire on screen time and related factors for preschoolers

The questionnaire focuses on investigating the screen time, exercise time, sleep time, and study time of preschool children. It is completed by the primary caregiver of the child and is based on the "Home Scale" from the China Urbanization and Children Development Survey (CUCDS) at Tsinghua University. The Home Scale has been modified to suit the characteristics of preschool children. The primary caregiver is asked to report the average daily time spent on various activities in the past month, recording the hours and minutes. If the time is a whole number of hours, the minutes should be 0. If there is no such activity, please also fill in 0. The questionnaire includes the following components: ① Screen Entertainment Time (SET), which includes using the TV for entertainment (SET_TV) and using other electronic devices besides TV, such as mobile phones and tablets, etc., for entertainment (SET_OED); ② Screen Learning Time (SLT), which includes using the TV for learning (SLT_TV) and using other electronic devices besides TV, such as mobile phones and tablets, etc., for learning (SLT_OED); ③ Non-Screen Learning Time (NSLT), which includes learning alone without the use of electronic devices, such as doing homework, reading, studying, drawing, and playing the piano (NSLT_LA) and learning with parents, such as reading bedtime stories (NSLT_LWP); ④ Sleep Time at Home (STH), which includes both nighttime and daytime sleep; and ⑤ Exercise Time Outside Kindergarten (ETOK), which refers to physical activity to improve physical health. Generally, exercise should last for at least 20 min and result in shortness of breath and sweating. The total screen time (TST) is calculated by adding SET and SLT, and the total learning time (TLT) is calculated by adding SLT and NSL. Each component has two subcomponents for weekdays and weekends, and the final assessment time is calculated as "(Weekday Time*5+Weekend Time*2)/7."

2.2.2 Cognitive ability test for 3–6-year-old

The cognitive ability test in this study, also known as the learning ability test or academic ability test, was derived from the China Urbanization and Children Development Survey (CUCDS) of Tsinghua University, which was designed by Professor Houcan Zhang of Beijing Normal University and applies to Chinese children between the ages of 3 and 12 years old (Yan, 2017; Shen, 2019; Zhu and Liu, 2019). In this study, the Language Ability Test (LAT) and the Mathematics Ability Test (MAT) were utilized to evaluate the cognitive ability of children aged 3–6 years old. While cognitive ability encompasses more than just language and math skills, these two areas have commonly been used in previous studies as indicators of children's overall cognitive development (Yan, 2017; Shen, 2019).

2.2.3 Questionnaire on family's socio-economic status

The SES questionnaire was developed mainly regarding Yuan et al. (2009)'s SES questionnaire from the Institute of Developmental Psychology, Beijing Normal University. The study examined the impact of parents' literacy, occupation, and economic income on adolescents. To gather information on family income, the researchers used a questionnaire that was designed to account for the fact that adolescents may not have accurate knowledge of their family's income. However, since the questionnaire was filled out by parents in this study, the indicator of family economic income was directly chosen. The researchers then used the Program for International Student Assessment (PISA) method to calculate the SES of the families (OECD, 2003). This involved four steps and the SES was divided into three levels based on a standard deviation of 1. The occupational classification was determined using the scoring criteria from the International Classification of Occupations and the Socio-Economic Status Index (ISEI) developed by Ganzeboom and Treiman (1996).

2.3 Process

The first stage is pre-testing. A sample of 30 children and 30 parents were selected to participate in the cognitive ability test and questionnaire completion, based on which adjustments were made to form a formal program of action for the study, while informed consent was obtained from the parents of all the children participating in the study.

In the second stage, formal testing was conducted. First, an online questionnaire was used to survey preschool children's screen time and related factors, as well as their family's socio-economic status. Due to the large number of items assessed by parents in this study, a full tracking and control measurement was used for quality control. Parents were informed of the importance of accurately assessing their child's screen time during a centralized

meeting before the test. This emphasized the positive impact it could have on later home-based co-education strategies. During the test, monitoring was carried out through secondary information. Parents were provided with tips and methods for accurately assessing their child's screen time and were reminded to review their completed assessment to minimize errors. Any assessment data that seemed unreasonable, such as zero sleep time, were excluded from the analysis. Doubtful data were also verified with the parents of the subjects in question. Next, the Cognitive Ability Test for 3–6-year-olds was administered. The test was conducted individually in a quiet, well-lit room. The child (subject) was given 20 min to complete the test, with 10 min each for the language and math portions. The question-and-answer session had to be stopped immediately after the allotted time. Finally, five parents were randomly selected from the junior class, middle class, and senior class to participate in the interview. The questions were designed based on the survey results, particularly any findings that were inconsistent with previous studies. Some examples of questions asked were: (1) Which do you think is more important, independent learning or accompanied learning? Why? (2) Which do you value more, learning through screens or non-screen methods? How do you balance your child's time between these two types of learning? (3) How much screen time do you think is appropriate for your child, and how do you see different types of screen time impacting your child? Interviews were also conducted with kindergarten directors, teachers, and parents to ensure an accurate interpretation of the findings.

2.4 Statistics

First, to determine the normality of continuous variables, histograms, skewness, and kurtosis were considered comprehensively. Basic descriptive statistics were then performed on the collected data. Secondly, the independent samples *t*-test was used to analyze differences between the two groups, while one-way ANOVA was used for differences between more than two groups. Correlation and regression analyses were also conducted to explore the relationship between screen time, related factors, and cognitive ability (Chang et al., 2020b). Finally, isochronous substitution analysis, a popular method in the fields of public health and physical education, was used to examine the impact of substituting different types of screen time and other activities on preschoolers' cognition. This method utilizes a multiple linear regression model that includes all time-use components of interest, with one component removed at a time and used as an explanatory variable. The unstandardized regression coefficients of the included components are then interpreted as the change in the outcome variable due to a change in time spent on the excluded components (Mekary et al., 2009). Specifically, four models were constructed for the isochronous substitution analysis in this paper.

Model 1:

Y1 = (b2) SET_OED + (b3) SLT_TV + (b4) SLT_OED + (b5) NSLT_LA + (b6) NSLT_LWP + (b7) STH + (b8) ETOK + (b9) TOTAL TIME + (b10) SES + (b11) AGE.

Model 2:

Y2 = (b1) SET_TV + (b3) SLT_TV + (b4) SLT_OED + (b5) NSLT_LA + (b6) NSLT_LWP + (b7) STH + (b8) ETOK + (b9) TOTAL TIME + (b10) SES + (b11) AGE.

Model 3:

Y3 = (b1) SET_TV + (b2) SET_OED + (b4) SLT_OED + (b5) NSLT_LA + (b6) NSLT_LWP + (b7) STH + (b8) ETOK + (b9) TOTAL TIME + (b10) SES + (b11) AGE.

Model 4:

Y4 = (b1) SET_TV + (b2) SET_OED + (b3) SLT_TV + (b5) NSLT_LA + (b6) NSLT_LWP + (b7) STH + (b8) ETOK + (b9) TOTAL TIME + (b10) SES + (b11) AGE.

3 Results

3.1 Basic information on screen time and related factors for preschoolers

TLT was significantly smaller for boys than girls ($t = -2.45$, $p = 0.015$), and NSLT was significantly smaller for boys than girls ($t = -2.27$, $p = 0.023$) but there was no gender difference in both SLT ($t = -0.52$, $p = 0.601$) and TST ($t = 0.96$, $p = 0.336$) were not gender-specific; girls spent more time on studying than boys,

TABLE 2 Basic information on screen time and related factors in preschool children.

		N	SET	SLT	NSLT	STH	ETOK
Sex	Male (x)	299	62.09 ± 46.17	37.83 ± 31.07	67.57 ± 38.42$^{x<y}$	570.74 ± 45.12	72.43 ± 41.69
	Female (y)	284	55.89 ± 40.31	39.21 ± 32.51	72.89 ± 36.23	577.09 ± 41.48	68.61 ± 38.33
Age	<4 (1)	170	57.28 ± 40.51	36.00 ± 32.81	66.39 ± 36.62	582.23 ± 43.01$^{1>3}$	70.92 ± 39.87
	4 (2)	210	62.80 ± 48.24	37.59 ± 30.80	69.21 ± 35.54	578.28 ± 41.83$^{2>3}$	71.50 ± 42.00
	>4 (3)	203	56.72 ± 40.57	41.88 ± 31.69	74.30 ± 39.73	562.20 ± 43.25	69.32 ± 38.53
SES	Low (a)	69	65.31 ± 38.14$^{a>c}$	39.41 ± 34.64	77.33 ± 52.85$^{a>c}$	561.40 ± 37.76$^{a<b,c}$	73.04 ± 43.17
	Medium (b)	420	60.44 ± 43.91$^{b>c}$	39.54 ± 32.13	70.69 ± 35.12	574.64 ± 44.57	70.13 ± 39.55
	High (c)	94	48.35 ± 43.95	33.24 ± 27.37	62.55 ± 32.77	579.35 ± 41.03	70.71 ± 40.55
Total		583	59.07 ± 43.49	38.51 ± 31.76	70.16 ± 37.44	573.83 ± 43.47	70.57 ± 40.10

SET is Screen Entertainment Time, SLT is Screen Learning Time, NSLT is Non-Screen Learning Time, STH is Sleeping Time at Home, and ETOK is Exercise Time Outside of Kindergarten; SES is the socio-economic status of the family, SES = (0.707*Z literacy level + 0.747*Z occupation + 0.717*Z family income)/1.572; * represents the difference between genders, a, b, and c represent low, medium, and high levels of SES in that order, and < or > represents the direction of significant difference.

TABLE 3 Basic cognitive skills of preschool children.

		N	Language ability	Math ability
Sex	Male (x)	299	99.89 ± 13.69	$100.77 \pm 14.95^{x>y}$
	Female (y)	284	97.51 ± 15.60	97.13 ± 14.80
Age	<4 years (1)	170	$90.50 \pm 11.94^{1<2<3}$	$89.09 \pm 9.95^{1<2<3}$
	4 years old (2)	210	98.37 ± 13.01	95.93 ± 11.52
	>4 years old (3)	203	106.00 ± 14.73	110.46 ± 14.21
SES	Low (a)	69	98.44 ± 15.60	96.99 ± 15.76
	Medium (b)	420	98.51 ± 14.65	98.95 ± 14.93
	High (c)	94	99.91 ± 14.25	101.28 ± 14.32
Total		583	98.73 ± 14.69	98.99 ± 14.98

SES stands for family socioeconomic status.

which is generally consistent with previous studies (Jiang et al., 2014), girls often have more patience and sit still than boys in online classes, watching learning videos, and playing puzzle games, which is reflected in their higher sedentary time compared to boys (Chang et al., 2020b).

The amount of time spent on screens was found to be significantly higher for children from low and middle socioeconomic status (SES) families compared to those from high SES families, $F = 4.14$, $p = 0.016$). Similarly, SET was significantly higher for low and middle SES children than high SES children ($F = 3.81$, $p = 0.023$). On the other hand, NSLT was significantly higher for low SES children compared to high SES children ($F = 3.27$, $p = 0.039$), and STH was significantly lower for low SES children compared to middle and high SES children ($F = 3.69$, $p = 0.026$). Families with low SES children were characterized by a pattern of "double highs and one low," with high screen time and study time, but low sleep time.

Children in the learning time of "<4-year-old group" and "4-year-old group" are both less than the ">4-year-old group ($M_{<4}$ =107.60 ± 58.73, M_4 =109.66 ± 55.72, $M_{>4}$ =125.16 ± 58.05, $F = 5.47$, $p = 0.004$)," but there was no age difference in screen time ($F = 0.77$, $p = 0.464$); Sleep time at home in the "<4-year-old group" and "4-year-old group" of preschool children are both greater than the ">4-year-old group" ($F = 11.97$, $p < 0.001$). As young children progress through the grades, especially into senior class, parents may plan more for their children's school time to prepare for elementary school enrolment (see Table 2).

3.2 Basic cognitive skills of preschool children

The study found that boys had better math ability ($t = 2.95$, $p = 0.003$) than girls. Additionally, both language ability ($F = 62.45$, $p < 0.001$) and math ability ($F = 154.21$, $p < 0.001$) were lower in the "<4-year-old group" compared to the "4-year-old group." Children in the "4-year-old group" also had higher cognitive ability than those in the ">4-year-old group." These findings support the idea that cognitive ability increases rapidly with age.

Different SES groups had no significant difference in language ability ($F = 0.36$, $p = 696$) or math ability ($F = 1.20$, $p = 0.301$). While previous studies have shown that SES can impact cognitive ability, this study did not find a significant relationship between SES and language or math ability. This suggests that cognitive ability is influenced by multiple factors (see Table 3).

3.3 Correlations of screen time and related factors with cognitive ability in preschoolers

Language ability was significantly and positively correlated with both SLT_OED ($r = 0.099$, $p < 0.05$) and NSLT_LA ($r = 0.126$, $p < 0.01$), while math ability was also significantly and positively correlated with SLT_OED ($r = 0.105$, $p < 0.05$), NSLT_LA ($r = 0.146$, $p < 0.001$), math ability was significantly negatively correlated with SET_TV ($r = -0.108$, $p < 0.01$; see Table 4).

3.4 Effects of screen time and related factors on cognitive ability with control variables

After controlling for gender, age, and family socioeconomic status, SET_TV was negatively associated with math ability (B = −0.04, $p = 0.004$) and positively associated with NSLT_LA ($B = -0.05$, $p = 0.011$; see Table 5).

3.5 Effects on cognitive ability after substituting different activity times for each other

After controlling for the effects of variables such as gender, age, and SES, language ability increased by 0.55 after NSLT_LA substituted for SET_TV 10 min/d; math ability increased by 0.90, 0.87, 0.43, and 0.61 after SLT_OED, NSLT_LA, sleep time at home, and exercise time outside kindergarten respectively substituted for SET_TV 10 min/d. Additionally, when SLT_OEP and NSLT_LA replaced NSLT_LWP 10 min/d, math ability increased by 0.88 and 0.85, respectively (see Table 6).

For boys, language ability increased sequentially by 1.03 and 0.51, respectively after replacing SET_TV with SLT_TV and sleep time at home for 10 min/d, and by 0.90 after replacing exercise time outside kindergarten with SLT_TV for 10 min/d; and after replacing SET_TV with SLT_TV, SLT_OED, NSLT_LA, sleep time at home, and exercise time outside kindergarten for 10 min/d math ability rose 0.96, 1.23, 0.86, 0.61, and 0.70, respectively. For girls, NSLT_LA substituted for SET_TV for 10 min/d to increase math ability by 0.75 sequentially (see Supplementary material 1).

4 Discussion

The present study utilized traditional multiple regression analysis and isochronous alternative analysis to examine the relationship between screen time and cognitive ability. Consistent

TABLE 4 Correlation of screen time and related factors with cognitive ability in preschool children.

	ChZ	MaZ	SET_TV	SET_OED	SLT_TV	SLT_OED	NSLT_LA	NSLT_LWP	STH
ChZ	–								
MaZ	0.690***	–							
SET_TV	−0.057	−0.108**	–						
SET_OED	0.019	0.015	0.158***	–					
SLT_TV	0.057	0.036	0.218***	0.209***	–				
SLT_OED	0.099*	0.126**	0.029	0.360***	0.329***	–			
NSLT_LA	0.105*	0.146***	−0.019	0.058	0.074	0.126**	–		
NSLT_LWP	−0.012	−0.026	−0.040	0.134**	0.168***	0.169***	0.210***	–	
STH	−0.071	−0.105*	−0.138**	−0.091*	−0.117**	−0.139**	−0.107**	−0.003	–
ETOK	0.002	0.040	0.000	−0.097*	0.072	−0.046	0.096*	0.148***	−0.052

SET_TV is screen entertainment time, which includes watching cartoons and other entertainment programs on TV, SET_OED is screen entertainment time which includes using other electronic devices besides TV for entertainment, SLT_TV is screen learning time which includes watching educational programs on TV, SLT_OED is screen learning time which includes using other electronic devices besides TV for learning, NSLT_LA is learning alone without the use of electronic devices, NSLT_LWP is learning with parents without the use of electronic devices, STH is sleep time at home, ETOK is exercise time outside of kindergarten, ChZ stands for language ability, MaZ stands for math ability.

*Stands for $p < 0.05$.

**Stands for $p < 0.01$.

***Stands for $p < 0.001$.

with previous research, the results support the negative impact of screen time for entertainment, particularly television (SET_TV), on the cognitive ability of 3–6-year-olds. Furthermore, the association between screen time and cognitive ability was found to be influenced by the type of screen time used. When screen time was used for learning, the association with cognitive ability was weakened or even partially positive. This study also revealed several key findings.

First, the negative impact of TV use on children is relatively higher than the use of other electronic devices. Academic research on children's screen time began in the 1980's, and by the beginning of the twenty-first century, the composite concept of "screen time" emerged. This concept includes the use of computers, game consoles, and other electronic products, and has gradually replaced "television exposure" as a hot research topic in the field of children's health (Xie and Chen, 2022). The present study follows the historical development of TV screen time and other electronic product screen time. Through this examination, it was found that TV screen time has a significantly negative impact on children. This may be attributed to the fact that the use of other electronic products not only involves screen time but also includes time spent playing electronic games. The associations between different types of electronic games and cognitive development may vary, particularly in the case of puzzles. It is important to note that the association between different types of video games and children's cognitive development may also differ, especially in the case of educational video games, which may have a positive impact on children's cognitive abilities (Li and Liu, 2022). Educational video games may be positively associated with children's cognitive abilities. Some scholars have further revealed that action video games can promote the development of individual cognitive ability, educational games can improve learning motivation and academic performance, and pro-social video games can reduce individual aggression and improve individual pro-social behavior (Niu et al., 2014).

Secondly, SET can have cognitive benefits when it is converted to SLT, NSLT, STH, and ETOK. The highest cognitive benefits were observed when screen recreation time was converted to NSLT_LA. This study explores various ways in which screen time can be converted. Firstly, simply adjusting the amount of screen time can have cognitive benefits, such as converting SET to SLT. Secondly, the greatest cognitive benefits were seen when SET was converted to NSLT. It is important to note that children's learning and cognitive development are closely intertwined. Interestingly, this study also found that NSLT_LA has a stronger correlation with cognitive ability than NSLT_LWP. Generally speaking, children in early childhood have weak autonomy and require parents to accompany them in learning and provide timely control and guidance (Wang, 2024). Therefore, education experts often recommend that parents spend more time with their children at an early age, particularly in early reading. Theoretically, NSLT_LWP should have significant cognitive benefits. However, the present study does not support this view. There are three possible reasons for this: (1) Through interviews, it was found that kindergartens place great emphasis on children's independent learning after class, and advocate for parents to allow children to explore independently in related learning activities after leaving the kindergarten without seeking help. Therefore, most parents believe that while accompanying learning is important, cultivating their children's independent learning habits is more important. (2) Independence is a crucial factor in early childhood learning and has a significant impact on cognitive development (Peng, 2020), this viewpoint is supported by the fact that the cognitive benefits of converting other periods into NSLT_LA are relatively highest in this study. (3) Research has shown that children often lack quality parental accompaniment, and low-quality parental accompaniment, such as a lack of verbal activities, has been linked to an increase in screen time (Supanitayanon et al., 2020). Finally, converting SET to either STH or ETOK also showed cognitive benefits. Interestingly, the cognitive benefit of converting to ETOK

TABLE 5 Effect of screen time and related factors on cognitive ability with control variables.

Variant	Regression coefficient	ChZ	MaZ
SET_TV	B (95% CI)	−0.02 (−0.05, 0.01)	**−0.04 (−0.07, −0.01)**
	P	0.188	0.004
SET_OED	B (95% CI)	0.01 (−0.05, 0.07)	0.01(−0.05, 0.06)
	P	0.761	0.871
SLT_TV	B (95% CI)	0.03 (−0.02, 0.09)	0.02 (−0.03, 0.07)
	P	0.204	0.464
SLT_OED	B (95% CI)	0.05 (−0.02, 0.10)	0.05 (−0.003, 0.10)
	P	0.162	0.063
NSLT_LA	B (95% CI)	0.03 (−0.01, 0.07)	**0.05 (0.01, 0.08)**
	P	0.114	0.011
NSLT_LWP	B (95% CI)	−0.001 (−0.06, 0.06)	−0.01 (−0.06, 0.04)
	P	0.978	0.779
STH	B (95% CI)	0.0004 (−0.03, 0.03)	−0.003 (−0.03, 0.02)
	P	0.973	0.831
ETOK	B (95% CI)	0.003 (−0.02, 0.03)	0.02 (−0.01, 0.04)
	P	0.814	0.152

SET_TV is screen entertainment time, which includes watching cartoons and other entertainment programs on TV, SET_OED is screen entertainment time which includes using other electronic devices besides TV for entertainment, SLT_TV is screen learning time which includes watching educational programs on TV, SLT_OED is screen learning time which includes using other electronic devices besides TV for learning, NSLT_LA is learning alone without the use of electronic devices, NSLT_LWP is learning with parents without the use of electronic devices, STH is sleep time at home, ETOK is exercise time outside of kindergarten, ChZ stands for language ability, MaZ stands for math ability; Bolding indicates that the regression is significant.

was slightly higher than that of STH, which aligns with current published guidelines.

Third, the association between screen time and cognitive ability varies by discipline and gender. Screen time was more strongly associated with math ability than language ability. Although previous studies have supported the negative associations of language ability and math ability with children's screen time, the relationship between screen time and cognition in early childhood has been controversial (Hu et al., 2020; Supanitayanon et al., 2020). Individual characteristics, parental behavior, and situational factors may influence the association, especially in early childhood when brain networks are rapidly developing (Kostyrka-Allchorne et al., 2017; Hutton et al., 2020). The impact of screen time on cognition in early childhood has been a topic of debate. Some studies suggest that passive screen time, such as watching television or playing video games that do not involve problem-solving or physical activity, may have a negative effect on math achievement and executive functioning in Chinese preschoolers. On the other hand, active screen time, such as playing educational video games or engaging in physical activities, may have a positive impact on their receptive language skills (Hu et al., 2020). The fact that the present study did not examine active screen time may have contributed to this finding. In addition, the variability in the associations between language and math skills and cognitive abilities in the present study may be due to the research instrument, as language and math skills tests have more instruments with different reliability and validity in early childhood. Therefore, although the present study revealed a stronger association between children's screen time and math ability, the present study still suggests that the association between screen time and language ability will show more positive associations due to the differences in the instruments used to measure them. In fact, this study also found some evidence to support the reverse correlation between screen time and children's language ability. For example, an increase in screen time is negatively correlated with boys' language ability, but not for girls. This gender difference may be because girls have a greater advantage in the left brain compared to boys, which is responsible for speech (Han, 2004).

There are some limitations to this paper. First, this study is based on a single sample of children in a large city, and the findings cannot be generalized to the whole country. It can only be said that it has some reference significance in understanding the association between screen time and cognitive development among preschoolers in large cities, and it still needs to be verified in multiple fields based on more sample data in the future. Second, this study is a cross-sectional study rather than a longitudinal analysis, and the association between screen time and cognitive development may show different associations with age and changes in schooling. Finally, the data were collected during the epidemic, and this particular period may have a certain impact on the results of the study, future scholars need to pay attention to this issue.

5 Conclusion

This study examined the association between screen time and cognitive ability in 3–6-year-old children from the perspective of balancing time use. The research results not only reinforced existing research findings that the association between screen time and cognitive ability is closely related to the use of screen time, but also

TABLE 6 Changes in preschool children's cognitive abilities after screen time and related factor time were substituted for each other for 10 min/d.

	SLT_TV		SLT_OED		NSLT_LA		NSLT_LWP		STH		ETOK	
	B (95% CI)	*P*	B (95% CI)	*P*	B (95% CI)	*P*	B (95% CI)	*P*	B (95% CI)	*P*	B (95% CI)	*P*
ΔChZ												
Model 1 (replaces SET_TV)	0.61 (−0.11, 1.33)	0.096	0.55 (−0.16, 1.26)	0.128	**0.55** (0.05, 1.05)	0.033	0.01 (−0.64, 0.65)	0.988	0.27 (−0.11, 0.65)	0.157	0.26 (−0.15, 0.68)	0.213
Model 2 (alternative to SET_OED)	0.38 (−0.53, 1.30)	0.410	0.32 (−0.75, 1.39)	0.553	0.32 (−0.46, 1.10)	0.417	−0.22 (−1.14, 0.70)	0.636	0.05 (−0.66, 0.75)	0.896	0.04 (−0.65, 0.72)	0.917
Model 3 (replaces SLT_TV)	–	–	−0.06 (−1.06, 0.94)	0.906	−0.06 (−0.77, 0.65)	0.864	−0.61 (−1.48, 0.27)	0.176	−0.34 (−0.97, 0.29)	0.296	−0.35 (−1.02, 0.32)	0.310
Model 4 (replaces SLT_OED)	0.06 (−0.94, 1.06)	0.906	–	–	−0.002 (−0.80, 0.80)	0.995	−0.55 (−1.47, 0.38)	0.249	−0.28 (−0.97, 0.42)	0.434	−0.29 (−0.99, 0.42)	0.424
ΔMaZ												
Model 1 (replaces SET_TV)	0.65 (−0.0008, 1.29)	0.050	**0.90** (0.26, 1.54)	0.006	**0.87** (0.42, 1.33)	<0.001	0.02 (−0.55, 0.60)	0.933	**0.43** (0.09, 0.77)	0.014	**0.61** (0.24, 0.99)	0.001
Model 2 (alternative to SET_OED)	0.20 (−0.62, 1.02)	0.638	0.45 (−0.51, 1.42)	0.928	0.43 (−0.27, 1.12)	0.232	−0.42 (−1.25, 0.41)	0.316	−0.02 (−0.65, 0.62)	0.957	0.16 (−0.45, 0.78)	0.600
Model 3 (replaces SLT_TV)	–	–	0.26 (−0.64, 1.16)	0.574	0.23 (−0.41, 0.87)	0.483	−0.62 (−1.41, 0.17)	0.123	−0.21 (−0.78, 0.35)	0.459	−0.03 (−0.63, 0.57)	0.918
Model 4 (replaces SLT_OED)	−0.26 (−1.16, 0.64)	0.574	–	–	−0.03 (−0.75, 0.69)	0.937	**−0.88** (−1.71, −0.04)	0.039	−0.47 (−1.09, 0.15)	0.138	−0.29 (−0.92, 0.34)	0.371

Row variables are substituted variables and column variables are substitutes. Bold represents significant changes after substitution. SET_TV is screen entertainment time, which includes watching cartoons and other entertainment programs on TV, SET_OED is screen entertainment time which includes using other electronic devices besides TV for entertainment, SLT_TV is screen learning time which includes watching educational programs on TV, SLT_OED is screen learning time which includes using other electronic devices besides TV for learning, NSLT_LA is learning alone without the use of electronic devices, NSLT_LWP is learning with parents without the use of electronic devices, STH is sleep time at home, ETOK is exercise time outside of kindergarten, ChZ stands for language ability, MaZ stands for math ability.

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further indicated that the negative impact of SET_TV on children's cognition is relatively higher than SET_OED, and there are cognitive benefits when SET is replaced with SLT, NSLT, STH, and ETOK, with the highest benefits observed when SET is substituted with NSLT_LA. Future scholars should explore the direction of adjusting children's screen time from a holistic perspective, not only focusing on the internal structural adjustments of screen time, such as adjusting part of screen entertainment time to screen learning time but also focusing on time outside of screen time, such as sleep time and exercise time.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

This study has received ethical approval from the Human Subject Protection Committee of East China Normal University, with approval number HR342-2024. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin. Written informed consent was obtained from the individual(s), and minor(s)' legal guardian/next of kin, for the publication of any potentially identifiable images or data included in this article.

Author contributions

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

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References

André, A., and Cochetel, O. (2022). Temps d'exposition aux écrans et grapho-motricité des enfants de 5 à 6 ans. *Sante publique* 34, 21–44. doi: 10.3917/spub.221.0021

Chang, Z. Y., and Wang, S. M. (2022). Isochronic substitution benefits of exercise and rest behaviors on children's mental health from 3 to 6 years old. *J. Tianjin Sports Inst.* 37, 366–372. doi: 10.13297/j.cnki.issn1005-0000.2022.03.018

Chang, Z. Y., Wang, S. M., and Zhang, X. H. (2020a). Progress of research on the relationship between exercise and rest behavior and health in preschool children. *J. Shandong Inst. Phys. Educ.* 36, 83–90. doi: 10.14104/j.cnki.1006-2076.2020.03.017

Chang, Z. Y., Wang, S. M., and Zhang, X. H. (2020b). Relationships between physical activity, sedentary behavior, and physical fitness in preschool children. *Res. Presch. Educ.* 3, 42–56. doi: 10.13861/j.cnki.sece.2020.03.004

Cliff, D. P., McNeill, J., Vella, S. A., Howard, S. J., Santos, R., Batterham, M., et al. (2017). Adherence to 24-hour movement guidelines for the early years and associations with social-cognitive development among Australian preschool children. *BMC Publ. Health* 17:857. doi: 10.1186/s12889-017-4858-7

De Decker, E., De Craemer, M., De Bourdeaudhuij, I., Wijndaele, K., Duvinage, K., et al. (2012). Influencing factors of screen time in preschool children: an exploration of parents' perceptions through focus groups in six European countries. *Obes. Rev.* 13(Suppl.1), 75–84. doi: 10.1111/j.1467-789X.2011. 00961.x

Ennemoser, M., and Schneider, W. (2007). Relations of television viewing and reading: findings from a 4-year longitudinal study. *J. Educ. Psychol.* 99, 349–368. doi: 10.1037/0022-0663.99.2.349

Foreman, J., Salim, A., Praveen, A., Fonseka, D., Ting, D., He, M. G., et al. (2021). Association between digital smart device use and myopia: a systematic review and meta-analysis. *Lancet Digit. Health* 3, e806–e818. doi: 10.1016/S2589-7500(21)00135-7

Ganzeboom, H. B. G., and Treiman, D. J. (1996). Internationally comparable measures of occupational status for the 1988 international standard classification of occupations. *Soc. Sci. Res.* 25, 201–239. doi: 10.1006/ssre.1996.0010

Guan, H. Y., Zhao, X., Qu, S., Wu, J. X., and Yang, Y. F. (2020). Exercise guidelines for preschool children (3–6 years old). *Chin. J. Child Health* 28, 714–720. doi: 10.11852/zgetbjzz2020-0982

Han, Y. W. (2004). Analysis of gender differences in language acquisition. *J. Nanjing Univ. Technol.* 4, 101–104. doi: 10.3969/j.issn.1671-7287.2004.04.023

Hu, B. Y., Johnson, G. K., Teo, T., and Wu, Z. (2020). Relationship between screen time and Chinese Children's Cognitive and Social Development. *J. Res. Childh. Educ.* 34, 183–207. doi: 10.1080/02568543.2019.1702600

Hutton, J. S., Dudley, J., Horowitz-Kraus, T., DeWitt, T., and Holland, S. K. (2020). Associations between screen-based media use and brain white matter

integrity in preschool-aged children. *J. Am. Med. Assoc. Pediatr*. 174:e193869. doi: 10.1001/jamapediatrics.2019.3869

Jiang, X. X., Hardy, L. L., Ding, D., Baur, L. A., and Shi, H. J. (2014). Recreational screen-time among Chinese adolescents: a cross-sectional study. *J. Epidemiol.* 24, 397–403. doi: 10.2188/jea.JE20140006

Kostyrka-Allchorne, K., Cooper, N. R., and Simpson, A. (2017). The relationship between television exposure and children's cognition and behavior: a systematic review. *Dev. Rev*. 44, 19–58. doi: 10.1016/j.dr.2016.12.002

Li, M. Y., Wang, S. Q., and Zhang, Y. (2022). Is the screen a friend or a foe—the effect of screen time on preschoolers' early literacy and the moderating role of educational screen activities. *J. Educ*. 18, 87–98. doi: 10.14082/j.cnki.1673-1298.2022.01.010

Li, W. Y., and Liu, A. R. (2022). Quantity versus quality of screen exposure: the relationship between screen exposure and preschool children's noncognitive abilities. *J. Educ*. 18, 99–112. doi: 10.14082/j.cnki.1673-1298.2022.01.011

Liu, W. W., Lou, H. Q., Fu, L., and Dai, Q. Q. (2023). Quality of survival of preschool children with overweight and obesity and the factors affecting it. *Chin. J. Child Health* 2023, 1–5. doi: 10.11852/zgetbjzz2022-0890

Luan, W. S., Wang, J. M., and Lu, Y. J. (2013). A review of research on preschool children's executive function. *Early Childh. Educ.* 6, 81–85. doi: 10.3969/j.issn.1004-4604.2013.07.020

Ma, L., Tang, Y., Hu, X. Q., Xin, F., and Zhang, D. Y. (2022). A systematic review of the effects of physical activity on cognitive development and academic performance in young children. *Chin. Sports Sci. Technol.* 58, 18–27. doi: 10.16470/j.csst.2021128

Mekary, R. A., Willett, W. C., Hu, F. B., and Ding, E. L. (2009). Isotemporal substitution paradigm for physical activity epidemiology and weight change. *Am. J. Epidemiol*. 170, 519–527. doi: 10.1093/aje/kwp163

Niu, Y. B., Wen, G. H., and Cao, X. C. (2014). Effects of video games on individual development. *Chin. J. Child Health* 22, 620–622. doi: 10.11852/zgetbjzz2014-22-06-19

OECD (2003). *PISA 2003 Technical Report (390)*. ISBN:9789264010536.

Peng, D. H. (2020). Essential connotation, factor structure and learning effects of children's early learning qualities. *Res. Presch. Educ.* 3, 57–71. doi: 10.13861/j.cnki.sece.2020.03.005

Shen, J. (2019). The effect of health on children's cognitive ability—a comparative household and urban-rural analysis based on a national survey. *Youth Stud.* 2, 14–26.

Supanitayanon, S., Trairatvorakul, P., and Chonchaiya, W. (2020). Screen media exposure in the first 2 years of life and preschool cognitive development: a longitudinal study. *Pediatr. Res*. 88, 894–902. doi: 10.1038/s41390-020-0831-8

Tremblay, M. S., Chaput, J. P., Adamo, K. B., Aubert, S., Barnes, J. D., Choquette, L., et al. (2017). Canadian 24-hour movement guidelines for the early years (0–4 years): an integration of physical activity, sedentary behavior, and sleep. *BMC Publ. Health* 17:874. doi: 10.1186/s12889-017-4859-6

Vanderloo, L. M., Janus, M., Omand, J. A., Keown-Stoneman, C. D. G., Borkhoff, C. M., Duku, E., et al. (2022a). Children's screen use and school readiness at 4-6 years: prospective cohort study. *BMC Publ. Health* 22:8. doi: 10.1186/s12889-022-12629-8

Vanderloo, L. M., Omand, J., Keown-Stoneman, C. D. G., Janus, M., Tremblay, M. S., Maguire, J. L., et al. (2022b). Association between physical activity, screen time and sleep, and school readiness in canadian children aged 4 to 6 years. *J. Dev. Behav. Pediatr*. 43, 96–103. doi: 10.1097/DBP.0000000000000986

Wang, H., Zhao, J., Yu, Z., Pan, H., Wu, S., Zhu, Q., et al. (2024). Types of on-screen content and mental health in kindergarten children. *J. Am. Med. Assoc. Pediatr*. 178, 125–132. doi: 10.1001/jamapediatrics.2023.5220

Wang, N. (2024). From extrinsic coercion to intrinsic autonomy—towards a socialization model of "autonomy support" for children and adolescents. *Youth Inq.* 1, 32–42. doi: 10.13583/j.cnki.issn1004-3780.2024.01.003

Xiang, H., Lin, L., Chen, W., Li, C., Liu, X., Li, J., et al. (2022). Associations of excessive screen time and early screen exposure with health-related quality of life and behavioral problems among children attending preschools. *BMC Publ. Health* 22:2440. doi: 10.1186/s12889-022-14910-2

Xie, Q. W., and Chen, R. J. (2022). A review of research on children's screen exposure in the context of digitalization and post-epidemic era. *Contemp. Youth Stud.* 381, 87–96.

Xing, S. F., Li, Q. Q., Gao, X., Ma, Y. Y., and Fu, R. (2018). Differential effects of different sleep duration parameters on executive functioning in preschool children. *Psychol. J.* 50, 1269–1281. doi: 10.3724/SP.J.1041.2018.01269

Yan, B. H. (2017). Rural-urban mobility and children's cognitive development: an analysis based on data from the 2012 China Urbanization and Labor Migration Survey. *Society* 37, 59–89. doi: 10.15992/j.cnki.31-1123/c.2017.04.003

Yuan, X. J., Fang, X. Y., Liu, Y., and Li,. Z. R. (2009). The relationship between educational placement styles and migrant children's urban adjustment. *J. Beijing Norm. Univ.* 5, 25–32. doi: 10.3969/j.issn.1002-0209.2009.05.004

Zhu, M. J., and Liu, J. M. (2019). Effects of parenting styles on children's academic competence. *Soc. Dev. Res*. 6, 43–62.

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The integration of psychology and medicine: an empirical study of curriculum reform from the perspective of China

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Under the background of new medicine, innovative reform of medical education is mushrooming in Mainland, China. New medicine advocates an innovative training mode supported by medicine + X discipline. In the present study, we made use of the advantages of medical colleges to reform the curriculum of applied psychology and constructed an innovative curriculum system by integrating medicine with psychology. This study aimed to evaluate the effects of the innovative curriculum system on the curriculum satisfaction of applied psychology and investigate the key factors that impact students' curriculum satisfaction. The class of 2018–2022 college students from the Department of Applied Psychology who were under different course training systems were selected to complete the curriculum evaluation questionnaire to evaluate students' curriculum satisfaction. The results demonstrated that curriculum satisfaction of the innovative curriculum system was significantly higher than that the one prior to the curriculum reform ($P < 0.001$), curriculum design, and teaching effect are the significant predictors affecting curriculum satisfaction. The results of this research provide innovative ideas for curriculum reform in psychology and strategies for the integration and development of medicine and psychology.

KEYWORDS

new medicine, applied psychology, curriculum reform, integration of medicine and psychology, curriculum satisfaction

1 Introduction

The curriculum is highly cultural and political since it determines the vision of a society by deciding what kind of knowledge and skills are most valuable for its people and what knowledge is worth passing on (Gouëdard et al., 2020). A curriculum reflects a broader social and political agreement (Stabback, 2016), as society evolves and changes, so should the curriculum. Curriculum reform is an important and necessary measure to make students better adapt to a fast-changing world (Gouëdard et al., 2020), and curricular reform should follow the current wisdom of educational innovation and change strategy as much as possible (Reis, 2018).

In 2020, the government of China put forward a strategic initiative to expedite the innovative development of medical education which should be led by the construction of new

engineering, new medicine, new liberal arts, and new agriculture, that is, "four innovations" (Wang and Ma, 2022; Hu and Wang, 2022). New medicine advocates an innovative education model supported by interdisciplinary subjects such as medicine + literature, medicine + engineering, medicine + science, and medicine + X discipline (Gu et al., 2018; Qin et al., 2022), aiming at cultivating high-level medical innovative talents who can adapt to the new generation of technological revolution represented by artificial intelligence and solve frontier problems in the medical field by using interdisciplinary knowledge (Gu et al., 2018), which coincides with the goal of interdisciplinary education (IPE) advocated by World Health Organization (2010).

According to the Center for the Advancement of Interprofessional Education (CAIPE), a key goal of IPE at the undergraduate level is to develop interprofessional knowledge, skills and attitudes that will promote interprofessional team behaviors and competence (Zheng et al., 2023a; Buring et al., 2009). Universities are increasingly offering interdisciplinary subjects and programs as an alternative to or alongside disciplinary subjects (Shay and Peseta, 2019). The glut of information and rapid spread in the contemporary world calls for students to think critically (Haapaniemi et al., 2021). Critical thinking not only helps them to sift and analyze the huge amount of information from different sources and identify the authenticity and reliability of the information but also prompts them to look at the problem from multiple perspectives, by educating integrative thinkers, schools aim to equip students with the competences necessary to connect seemingly scattered information and form a wider perspective of a whole (Haapaniemi et al., 2021; Blackshields et al., 2014). IPE transcends siloed teaching and learning approaches by emphasizing integrated learning and mutual respect between different professions in response to the new demands of health systems (Abu-Rish et al., 2012; Noll Gonçalves et al., 2021; Noll Gonçalves et al., 2023). IPE and interprofessional collaborative practice (IPCP) are intertwined movements that are reshaping educational approaches and targeted outcomes in health professional training (Lamparyk et al., 2021). It can be said that the new medicine strategy is a concrete practice of IPE.

Among the 14 disciplines in China (Ministry of Education of China, 2020b), applied psychology as a major is classified as natural science (Li Xue, 理学) (Ministry of Education of China, 2020a). In the same way, medicine is also one of the 14 disciplines. Ever since 2001, when the Ministry of Education approved the first batch of applied psychology majors in nine medical colleges in China (Yin, 2007), more than 80 medical colleges and universities have set up applied psychology majors. In view of the close relationship between medicine and psychology, as well as medical colleges and universities have exceptional advantages and resources in the field of medicine, particularly in education and teaching (Xu et al., 2015). Thus, following the "new medicine" policy and the inspiration from the medicine + X discipline concept (Gu et al., 2018; Qin et al., 2022; Yan et al., 2021), at Guangzhou Medical University, we have integrated medicine and psychology into the applied psychology curriculum to create an innovative system that reflects the unique features of a medical college.

According to Rabin et al. (2019), we focus on learner satisfaction as a learner-centered success measure (Zheng et al., 2023b), and examine the factors that impact this subjective success measure. The satisfaction of college students with the curriculum is an important factor in evaluating the success of curriculum content reform, particularly in the context of education and teaching reform (Zheng et al., 2023b). This study selected students in the context of different curriculum systems making curriculum evaluations, aimed to evaluate the effects of innovative curriculum systems on the learner satisfaction of applied psychology and identify key factors contributing to students' curriculum satisfaction which can provide us with better support to form a long-term plan for reforming the curriculum system in new medicine context.

2 The context of curriculum reform of applied psychology in China

2.1 Existing problems in the curriculum system

Applied psychology has been launched as an independent degree program since 1993 in China (Wang et al., 2022a), it has been offered in nearly 300 colleges and universities so far (The Network Essential for College Students, 2024), one quarter of which are medical colleges and universities, which have provided talent reserves for the development of mental health services (Xu et al., 2015; Lü et al., 2020; Zhao, 2019). The "Outline of the Healthy China 2030 Plan" has put forward the objectives and requirements for the prevention and treatment of mental illness (Xinhuanet, 2016), which shows that the government attaches great importance to mental health services and also means that psychological professionals should meet higher requirements to meet the needs of society (Zhang et al., 2022). High-quality professionals are inseparable from high-level training and cultivating (Zhao et al., 2022). The specialty construction of colleges and universities always reflects the needs of economic and social development and employment most sensitively (Xu et al., 2015). However, there are still several problems in the applied psychology curriculum system (Zhao, 2019; Hang et al., 2020).

Lack of interdisciplinary systematic construction in curriculum setting. Currently, applied psychology still adopts the traditional single-discipline teaching mode. Although courses in other disciplines are integrated into the curricula, the courses in applied psychology are dominant. Moreover, in medical colleges and universities, psychology and medicine are only rigidly pieced together, which fails to reflect the deep integration of psychology and medicine (Wang et al., 2020). According to Zhang et al. (2022) the inadequacy of interaction and connection between curricula limited the expanded perspective of students' knowledge and skills.

Lack of professional characteristics in the curriculum system. Compared with normal universities and comprehensive universities, the applied psychology major in medical colleges has a short running time, and the initial stage mostly follows the teaching mode of normal universities (Hang et al., 2020). In the curriculum system, the interdisciplinary integration between applied psychology and medicine is insufficient, applied psychology is still dominant in the curriculum system; and the value and characteristics of running a school in medical colleges are difficult to reflect compared to normal universities (Gong and Chen, 2019; Hang et al., 2020; Wang et al., 2020).

2.2 Medicine + X discipline talent training mode

Due to the advances in science and technology, medicine and medical technology are developing rapidly, which leads to changes in

medical methods and behaviors (Gu et al., 2018), medical education around the world has changed dramatically as a result (Yan et al., 2021), which is reflected in the updating of the concepts of medical education, the innovation of medical education modes, and the optimization of the structure of medical education and so on. In order to adapt to the new round of scientific and technological revolution and industrial transformation, the new medicine is characterized by cross-integration, no longer relying on a single discipline, and integrates modern means such as big data and artificial intelligence, which has received great attention (Wang et al., 2022b).

The interdisciplinary research of "medicine + X" and the cultivation of "medicine + X" compound talents are the key contents of the new medicine construction (Yang and Wang, 2023). X discipline refers to more emerging and frontier disciplines besides medicine, including but not limited to literature, science, engineering, agriculture, biotechnology, artificial intelligence, data science, etc. The Medicine + X discipline training model promotes innovative development and progress in the medical field and realizes the complementarity and win-win situation between medicine and other disciplines facilitating the integration and application of interdisciplinary knowledge.

The development and advancement of psychology is based on medicine. At the same time, it continues to feedback and enrich the field of medicine, and the two are mutually reinforcing, forming a dynamic and mutually reinforcing cycle. Therefore, an innovative curriculum system integrating medicine and psychology has become an inevitable trend in the reform of applied psychology courses.

2.3 Curriculum reform integrating medicine and psychology

The curriculum reform design is student-centered and competency-based, integrating medicine and psychology to achieve teaching goals based on social demand.

A curriculum system for applied psychology in medical colleges has been developed based on interdisciplinary integration. As shown in Figure 1, in terms of course design, maintained the total class hours unchanged, increased the proportion of practical teaching integrating medicine and psychology, taking advantage of technologies such as big data and cloud computing to optimize the integration of medical and psychological courses, enhance the interaction and connection between courses, realizing the systematicness and integrity of the integration of medical and psychology courses, crossing the boundaries of disciplines, promoting the scientific reorganization and effective integration of medical and science courses, and reducing overlapping and duplication. In conclusion, we developed a curriculum system that embodies professional traits.

During the teaching process, our emphasis is on introducing high-quality interdisciplinary talent both from home and abroad. We encourage our teachers to practice the teaching concept of interdisciplinary integration of medicine and psychology and innovate their teaching methods. Carry out multidisciplinary integration teaching, abandon the traditional indoctrination or visiting teaching method, and give full play to students' main role. Make full use of the new format of internet technology, build a digital teaching platform for interdisciplinary integration of medicine and psychology, develop online courses and build smart classroom to realize interdisciplinary resource sharing and promote the deepening integration of psychology and medicine by using information technology.

The advancement of curriculum should also lead to the improvement of evaluating teaching methods. A singular written test method of assessment is inadequate in fully measuring a student's overall abilities. When it comes to evaluating teaching, a multi-dimensional assessment and evaluation system is effective because it covers various assessment contents and uses different evaluation methods. Assessment content include multi-dimensional assessments of knowledge acquisition, skills, attitudes, creativity, and teamwork abilities. Evaluation methods include Learning Management System (LMS)-based online assessment, formative assessment, program-based assessment, and interdisciplinary competency assessment. The teaching evaluation system plays an important role in improving teaching practices and promoting the development of both teachers and students. By using teaching evaluation system, we can assess students' comprehensive ability, guide the direction of curriculum reform, and improve the overall quality of the curriculum (Zhang, 2022).

In summary, exploring and studying the innovative education model of applied psychology, which integrates medicine and psychology, and creating a multidisciplinary knowledge system for students, can benefit the applied psychology major in medical colleges. By fully integrating the psychological, spiritual, and neurological resources of medical colleges and new medical experimental technologies, it can optimize the characteristic curriculum system and content of the cross-integration of psychology and medicine. This could enhance the professional theoretical knowledge of applied psychology students, as well as their practical application ability in mental health service and psychological crisis intervention. Ultimately, these efforts will fully utilize the advantages of medical colleges.

Finally, through preliminary discussion, scientific demonstration, teaching practice, and gradual revision (Zhang et al., 2022), the research group finally constructed an innovative curriculum system integrating psychology and medicine majors.

3 Methods

3.1 Participants

The Department of Applied Psychology selected college students from the class of 2018–2022 who underwent various course training systems to complete a curriculum evaluation questionnaire. The goal was to assess the satisfaction level of the students with the curriculum. The class of 2018–2019 received training before the curriculum reform, while the class of 2020–2022 received training after the curriculum reform. Applied psychology is a four-year training system, and college students under different training programs are at cross-stage, which provides convenience for us to obtain samples.

3.2 Questionnaire survey

At the end of the semester, students of applied psychology from Guangzhou Medical University underwent a unified curriculum evaluation questionnaire, with the assistance of the Academic Affairs Office. This was done despite their training in different curriculum systems. The questionnaire in Supplementary Table 1 uses a five-point

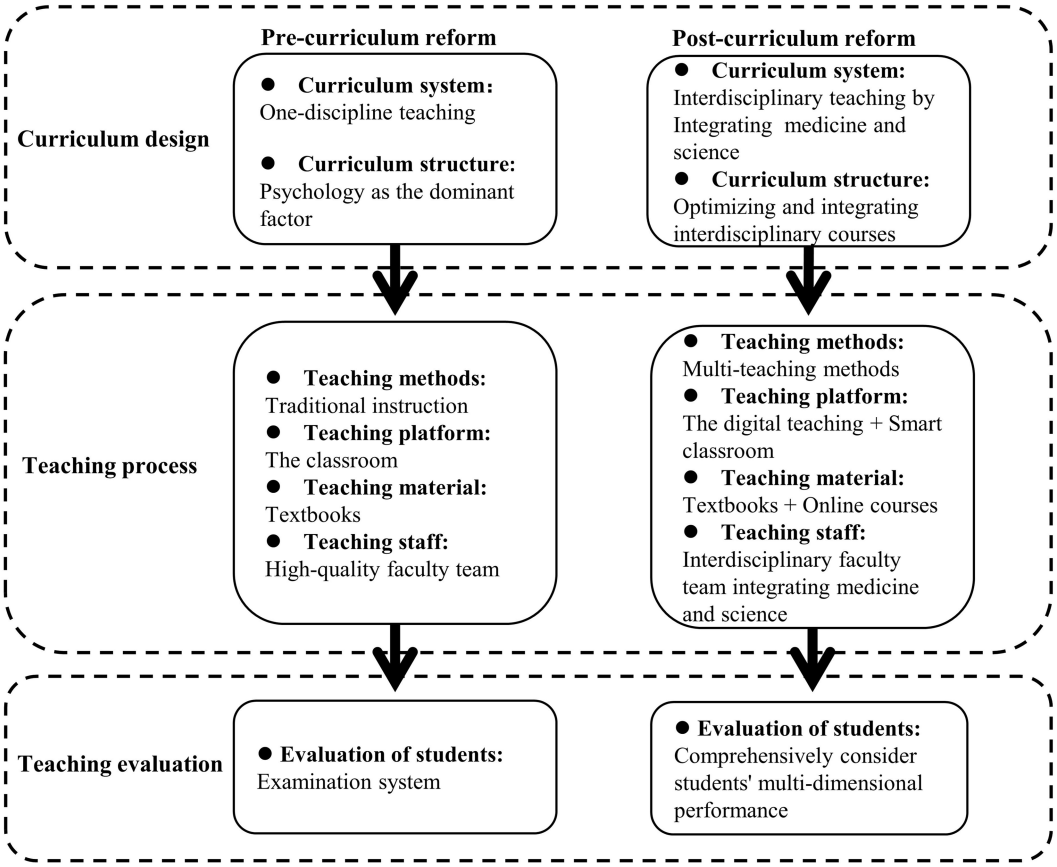

FIGURE 1
Comparison of curriculum systems.

Likert scale with 24 items, ranging from 1 (fully inconsistent) to 5 (fully compliant). A total of 2,474 questionnaires were collected from students who evaluated 12 different courses under different training systems. Out of the total number of questionnaires, 1,268 (51.25%) were collected before the curriculum reform, while 1,206 (48.75%) were collected after the curriculum reform.

3.3 Statistics

The study results were analyzed and processed using SPSS25.0 software. The Mann–Whitney *U*-test was utilized to determine the disparities in students' satisfaction with the curriculum before and after the curriculum reform. Additionally, the multiple stepwise regression analysis was employed to investigate the factors that affect course satisfaction. All the data presented above demonstrated significant differences with a $p < 0.05$.

4 Results

4.1 Descriptive statistical analysis

By using SPSS25.0, we made a descriptive statistical analysis of the results of the questionnaire, results in Table 1. The average total score of the student's curriculum evaluation questionnaire is 103.23 ± 20.53 with a total score of 125. The average range of 24 questions is from 4.01 ± 1.09 to 4.19 ± 0.94 (out of 5). Question 2 received the highest score (4.19 ± 0.94). You think this course is of great use, and what you learn in this course will be of great help to your professional study. This shows that students have a high evaluation score for the teaching effect of the curriculum. Followed by the score of Question 1 (4.18 ± 0.94): generally speaking, you are very satisfied with the course. This indicates that the courses in applied psychology have received high levels of satisfaction from students.

4.2 Mann–Whitney *U*-test

Mann–Whitney *U*-test is a method to test the difference between two groups of ordered variable data without specific distribution. Our questionnaire adopts a five-point scoring method, there may be data distribution deviation, so this test is adopted (MacFarland et al., 2016; McKnight and Najab, 2010). As shown in Table 2, the 12 courses include five required courses and seven optional courses. Through the Mann–Whitney *U*-test, we analyze the course satisfaction of 12 curriculums, respectively. The course satisfaction of four courses after course reform, *Criminal Psychology* ($p < 0.05$), *Social Psychology* ($p < 0.001$), *Psychological History* ($p < 0.01$), and *Biological Psychology* ($p < 0.001$), is significantly higher than before the course reform. No

significant differences were found in the other eight courses. In general, however, curriculum satisfaction after the curriculum reform is significantly better than before ($p < 0.001$).

4.3 Multiple regression analysis

4.3.1 Variables selection

Based on the theoretical cognition and practice of the teaching team on curriculum reform, combined with the main points of the curriculum evaluation questionnaire, the factors affecting students' curriculum satisfaction mainly include 23 factors in 3 aspects: curriculum design, teaching effect, and curriculum implementation. Our study focuses on identifying the primary factors that influence the satisfaction of students with their curriculum. To achieve this, we have selected Question 1 (Generally speaking, you are very satisfied with the course) from the curriculum evaluation questionnaire in Supplementary Table 1 as the dependent variable (Y). From Question 2 onwards, the subsequent questions (Question 2–Question 24) were designated as independent variables (X_1–X_{23}) sequentially.

TABLE 1 Curriculum evaluation questionnaire results ($N = 2,474$).

No.	AVG	*SD*	No.	AVG	*SD*
1	4.18	0.94	14	4.17	0.93
2	4.19	0.94	15	4.12	0.96
3	4.16	0.94	16	4.16	0.93
4	4.02	1.04	17	4.15	0.94
5	4.15	0.94	18	4.12	0.95
6	4.14	0.95	19	4.13	0.94
7	4.14	0.95	20	4.13	0.94
8	4.12	0.95	21	4.09	0.94
9	4.13	0.96	22	4.14	0.92
10	4.11	0.97	23	4.13	0.92
11	4.13	0.95	24	4.12	0.93
12	4.15	0.94	Total scores	103.23	20.53
13	4.15	0.93			

4.3.2 Construct model

This study has a lot of factors on curriculum satisfaction, some variables may not have significant results, and there may be some collinearity among the variables, to avoid the data estimated by the model being inconsistent with reality, the multiple stepwise regression analysis is adopted to screen the factors that affect the course satisfaction. Multiple stepwise regression analysis includes three methods: forward selection method, backward elimination method, and stepwise regression method, in which the stepwise regression method is the synthesis of the first two methods. This study adopted the backward elimination method. Firstly, a model containing all variables is established, and then the variables that contribute the least to the model are gradually eliminated. Once the variable is eliminated, it will not be considered in the next step until the significance level of the remaining variables is <0.05 (Sutter and Kalivas, 1993; Vu et al., 2015). First, we need to build a model containing all variables.

The model (1) of influencing factors of curriculum satisfaction is as follows:

$$\begin{aligned} Y = {} & \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \\ & \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \beta_{11} X_{11} + \beta_{12} X_{12} + \\ & \beta_{13} X_{13} + \beta_{14} X_{14} + \beta_{15} X_{15} + \beta_{16} X_{16} + \beta_{17} X_{17} + \beta_{18} X_{18} + \\ & \beta_{19} X_{19} + \beta_{20} X_{20} + \beta_{21} X_{21} + \beta_{22} X_{22} + \beta_{23} X_{23} + \sigma \end{aligned} \quad (1)$$

4.3.3 Correlation test

Pearson correlation test is applied to verify the correlation between variables, thus laying the foundation for regression analysis. The greater the absolute value of the Pearson correlation coefficient, the greater the degree of linear correlation between variables. The correlation is very strong when the absolute value of R is 0.91–1.00, strong when the absolute value of R is 0.71–0.90, moderate when the absolute value of R is 0.51–0.70, weak when the absolute value of R is

TABLE 2 Curriculum satisfaction before and after curriculum reform.

Course classification	Course name	Pre-curriculum reform	Post-curriculum reform	*z*	*p*-value
Required course	Developmental psychology	4.35 ± 0.89 ($n = 68$)	4.40 ± 0.89 ($n = 158$)	−0.358	0.721
	Social psychology	4.06 ± 0.94 ($n = 94$)	4.48 ± 0.80 ($n = 161$)	−3.617	<0.001
	Psychometrics	4.09 ± 0.94 ($n = 68$)	3.92 ± 1.12 ($n = 74$)	−0.70	0.487
	Counseling psychology	4.32 ± 0.90 ($n = 165$)	4.06 ± 1.10 ($n = 70$)	−1.489	0.136
	Biological psychology	3.87 ± 0.92 ($n = 166$)	4.30 ± 0.91 ($n = 160$)	−4.361	<0.001
Optional course	Psychological disorders and correction in children	4.18 ± 0.93 ($n = 95$)	4.35 ± 0.85 ($n = 74$)	−1.129	0.259
	Criminal psychology	3.89 ± 0.99 ($n = 63$)	4.26 ± 0.92 ($n = 65$)	−2.184	0.029
	Cognitive psychology	4.03 ± 0.93 ($n = 39$)	4.25 ± 0.91 ($n = 73$)	−1.236	0.216
	Psychological history	4.04 ± 0.98 ($n = 164$)	4.30 ± 0.90 ($n = 257$)	−2.718	0.007
	Medical psychology	4.13 ± 0.93 ($n = 158$)	4.34 ± 0.87 ($n = 62$)	−1.458	0.145
	Outline of music therapeutics	3.75 ± 1.29 ($n = 12$)	4.50 ± 0.85 ($n = 14$)	−1.631	0.103
	Human resource management psychology	4.00 ± 0.96 ($n = 176$)	3.92 ± 1.08 ($n = 38$)	−0.325	0.745
	All courses	4.08 ± 0.95 ($n = 1,268$)	4.29 ± 0.93 ($n = 1,206$)	−5.827	<0.001

0.31–0.50, very weak when the absolute value of R is 0.01–0.30, and no correlation when the absolute value of R is 0 (Piaw, 2008). Results are shown in Table 3, we can know that the independent variables X_3 and X_{16} are moderately correlated with Y, and the other independent variables are highly correlated with Y.

4.3.4 Multiple linear regression analysis

From the above analysis, we can see that all variables have passed the correlation test, and then we need to use the backward elimination method to carry out multiple linear regression analysis.

In the first step, 23 variables were substituted into the model (1) for analysis. Then, the variable X_{22} with the highest p-value of 0.951 was eliminated, and model (2) was obtained:

$$\begin{aligned} Y = {} & \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \\ & \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \beta_{11} X_{11} + \beta_{12} X_{12} + \\ & \beta_{13} X_{13} + \beta_{14} X_{14} + \beta_{15} X_{15} + \beta_{16} X_{16} + \beta_{17} X_{17} + \beta_{18} X_{18} + \\ & \beta_{19} X_{19} + \beta_{20} X_{20} + \beta_{21} X_{21} + \beta_{23} X_{23} + \sigma \end{aligned} \quad (2)$$

In the second step, 22 variables are substituted into model (2) for analysis, and the variable X_{21} with the highest p-value of 0.774 is excluded to obtain a new model. Subsequently, the above steps were continuously carried out until step 17, when 14 variables, namely X_3, X_5, X_6, X_8, X_{10}, X_{11}, X_{12}, X_{13}, X_{14}, X_{15}, X_{16}, X_{17}, X_{18}, and X_{23}, were excluded, all the remaining variables had $p < 0.05$, and the results are shown in Table 4.

According to the influence coefficient and significance level of independent variables on dependent variables, it is found that X_1 ($p < 0.001$), X_2 ($p < 0.001$), X_4 ($p < 0.001$), X_7 ($p < 0.01$), X_9 ($p < 0.05$), X_{19} ($p < 0.001$), X_{20} ($p < 0.001$).

After backward elimination of multiple stepwise regression analysis, the model of influencing factors of course satisfaction (3) is as follows:

$$\begin{aligned} Y = {} & \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_4 X_4 + \beta_7 X_7 + \\ & \beta_9 X_9 + \beta_{19} X_{19} + \beta_{20} X_{20} + \sigma \end{aligned} \quad (3)$$

TABLE 3 Correlation test results of variables ($N = 2,474$).

Variables	Y	Variables	Y
Y	1	X_{12}	0.744***
X_1	0.861***	X_{13}	0.737***
X_2	0.820***	X_{14}	0.756***
X_3	0.629***	X_{15}	0.745***
X_4	0.797***	X_{16}	0.674***
X_5	0.768***	X_{17}	0.714***
X_6	0.775***	X_{18}	0.728***
X_7	0.778***	X_{19}	0.741***
X_8	0.771***	X_{20}	0.709***
X_9	0.761***	X_{21}	0.717***
X_{10}	0.779***	X_{22}	0.731***
X_{11}	0.769***	X_{23}	0.727***

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

In Table 4. The R^2 value is 0.797, and the adjusted R^2 value is 0.796, so the fitting degree of the model is good. The F value of the model is 1379.676 ($p < 0.001$), which shows that the model is reliable. Multicollinearity refers to the high correlation between controlled variables. Any analysis can know the existence of multicollinearity by checking the value of the variation spread factor (VIF). When the VIF < 5, multicollinearity is not serious. If VIF > 5, multicollinearity is significant. When the VIF > 10, multicollinearity will be more serious (Ghani et al., 2010). In our study, all VIF values are below 5, which means that there is no significant multicollinearity between independent variables. Finally, the multiple linear regression model of influencing factors of course satisfaction is obtained:

$$\begin{aligned} Y = {} & 0.115 + 0.457 X_1 + 0.168 X_2 + 0.103 X_4 + \\ & 0.062 X_7 + 0.044 X_9 + 0.086 X_{19} + 0.057 X_{20} + \sigma \end{aligned}$$

5 Discussion

The average score of students' satisfaction with courses is 4.18 ± 0.94. Generally speaking, students' satisfaction with courses in applied psychology is at a high level. Through the Mann–Whitney U-test of the overall curriculum satisfaction before and after the curriculum reform, it is found that curriculum satisfaction after the curriculum reform is significantly higher than that before the curriculum reform ($P < 0.001$). At the same time, we also analyzed the differences between the 12 courses before and after the reform, which found that the 4 courses' teaching satisfaction after the curriculum reform was significantly higher than that after the curriculum reform. The course satisfaction of four courses, *Criminal Psychology* ($p < 0.05$), *Social Psychology* ($p < 0.001$), *Psychological History* ($p < 0.01$), and *Biological Psychology* ($p < 0.001$), is significantly higher than before the course reform, which may be because all these four courses are interdisciplinary, which can broaden students' disciplinary horizons and enrich multidisciplinary knowledge and skills. Moreover, according to Zeff (2007), the utilization of diversified teaching methods gives learners various ways of acquiring information and knowledge that enables students to obtain a positive learning experience and enhance their cognition and understanding in the area of psychology whereas the differences in the remaining 8 courses are not significant.

In general, students' satisfaction with the courses of applied psychology specialty after the curriculum reform is higher than that before the curriculum reform, but it is not balanced in the evaluation of the satisfaction of specific courses, which also exposes the problems of insufficient curriculum systematization in the innovative education mode of medicine science integration of applied psychology specialty and insufficient penetration and integration of innovative reform measures in all professional courses.

Through the construction of a stepwise regression model, it is found that the influencing factors of students' satisfaction with curriculum evaluation are in descending order: (1) whether the course is useful and whether the things learned in the course will be of great help to students' professional learning; (2) whether the teaching objectives of the course are clear, and whether the requirements and expectations of the course for students are clear; (3) whether the semester of the course is reasonable; (4) whether the course

TABLE 4 Final results of multiple linear regression analysis.

Predictor variable	β	*SE*	95%CI	*t*	*p*-value	VIF	R^2	*Adj-*R^2	*F*
(constant)	0.115	0.043	(0.030–0.199)	2.663	0.008	–	0.797	0.796	1379.676***
X_1	0.457	0.019	(0.420–0.493)	24.513	< 0.001	4.153			
X_2	0.168	0.020	(0.129–0.208)	8.455	< 0.001	4.806			
X_4	0.103	0.019	(0.065–0.141)	5.333	< 0.001	4.491			
X_7	0.062	0.019	(0.024–0.100)	3.173	0.002	4.617			
X_9	0.044	0.017	(0.010–0.078)	2.508	0.012	3.872			
X_{19}	0.086	0.017	(0.053–0.120)	5.079	< 0.001	3.460			
X_{20}	0.057	0.016	(0.026–0.088)	3.612	< 0.001	2.968			

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

examination improves students' understanding of the course's core concepts; (5) whether students can understand the relationship between the topics (chapters) of the course; (6) whether the learning of the course can enable students to master the knowledge, theory, and skills of the course; (7) course teaching has well stimulated your interest in learning and mobilized your enthusiasm for learning. The coefficient of influence of the above seven factors on course satisfaction is 45.7, 16.8, 10.3, 8.6, 6.2, 5.7, and 4.4% in turn.

Analyzing these factors, we think that curriculum design and teaching effect will have a positive impact on students' curriculum satisfaction. A clear teaching objective of the course affects curriculum satisfaction by 16.8%. According to Soulie and Cosson (2021), a goal-oriented approach to teaching proved essential to determine the overall structure of the teaching program, as well as the content of specific curriculums, and the nature of the examinations. In addition, keeping in mind the ultimate goal is also conducive for students to separate useful knowledge from useless knowledge. Having mastered a certain amount of knowledge, theory, and skills in the course study and what you have learned will be of great help to your professional study with the influence degrees of 5.7 and 45.7%, respectively, on curriculum satisfaction. A study pointed out that learning self-efficacy can promote students' mastery of knowledge and skills (Zheng et al., 2023b). The higher the sense of self-efficacy, the higher the degree of knowledge acceptance of the course content, and the more knowledge they can understand and accept. Correspondingly, curriculum satisfaction will be improved. The course teaches stimulates students' interest and enthusiasm for learning, which shows that teaching innovation makes students feel "pleasantly surprised" (Mayhew et al., 2021), and new teaching approaches were applied to get rid of traditional ideas and existing procedures (Cao et al., 2022), therefore students have a pleasant learning experience and enjoy the classroom, with an influence of 4.4% on curriculum satisfaction. The term of the course is reasonable, that is, the course content conforms to the student's professional knowledge background at the corresponding learning stage, and the chapters of the course content are closely connected and reasonable, which can reduce the students' understanding cost, reduce the learning difficulty and improve the learning effect to a certain extent. That is consistent with Oliver et al. (2008), the context of learning should be closely connected which can promote students to better internalize what they have learned and improve their teaching satisfaction, with the influence degrees of 10.3 and 6.2%, respectively. Reasonably designed course examinations can deepen students' understanding of core concepts. As Leung et al. (2008) mentioned it is also necessary to forcibly memorize some knowledge so that students can build their knowledge framework, thus better consolidating the teaching effect and improving their learning experience and satisfaction, with an impact of 8.6%.

6 Conclusion and limitation

6.1 Conclusion

This study assessed the effectiveness of an innovative curriculum system based on the integration of medicine and psychology in the context of the new medical science, using learner satisfaction as the main indicator and exploring its influencing factors. In conclusion, curriculum design is the basis of teaching, and scientific curriculum design can help teachers organize teaching activities effectively and improve the teaching effect. The teaching mode of the integration of medicine and psychology promotes students' active participation and interest in learning and improves the teaching effect and satisfaction by clarifying the teaching objectives and contents, rationally planning the teaching progress and forms, and choosing appropriate diversified teaching methods and multi-dimensional evaluation methods. It is still necessary to strengthen the systematic construction of curriculum reform, deeply integrate and infiltrate curriculum innovation and reform measures, and promote the comprehensive and balanced development of professional courses.

6.2 Limitations of this study and future work

The questionnaire is a curriculum evaluation questionnaire for all majors in university. Although it can reflect some problems in curriculum reform, it is not a targeted investigation of the education mode of the integration of medicine and psychology for applied psychology majors, and it fails to reflect more comprehensive and in-depth issues.

Curriculum innovation should lead to the innovation of curriculum evaluation. Given the specific measures of education mode of applied psychology, we should formulate targeted curriculum evaluation questionnaires, innovate and expand the methods of curriculum evaluation, expand the survey objects, and formulate multi-dimensional curriculum evaluation questionnaires for students and teachers, respectively.

With the development of social economy and culture, the enrichment of subject fields, and the expansion of subject frontiers, the continuous improvement and optimization of the curriculum system requires a longer-term plan to carry out. As this study is a cross-sectional study, the long-term and short-term longitudinal study can be used to continuously evaluate and evaluate curriculum satisfaction, and adjust the strategies and plans of curriculum reform in time, to promote the rapid development of the discipline.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by the Ethics Committee of Guangzhou Medical University (Approval number: 202309010). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

XM: Investigation, Writing – original draft, Methodology. YW: Investigation, Writing – original draft, Methodology. YP: Writing – original draft, Data curation. HS: Writing – review & editing, Conceptualization. HZ: Writing – review & editing, Supervision, Data curation. XZ: Project administration, Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2024.1469067/full#supplementary-material

References

Abu-Rish, E., Kim, S., Choe, L., Varpio, L., Malik, E., White, A. A., et al. (2012). Current trends in interprofessional education of health sciences students: a literature review. *J. Interprof. Care* 26, 444–451. doi: 10.3109/13561820.2012.715604

Blackshields, D., Cronin, J., Higgs, B., Kilcommins, S., Mccarthy, M., and Ryan, A. (2014). Integrative learning: International research and practice. London: Routledge.

Buring, S. M., Bhushan, A., Broeseker, A., Conway, S., Duncan-Hewitt, W., Hansen, L., et al. (2009). Interprofessional education: definitions, student competencies, and guidelines for implementation. *Am. J. Pharm. Educ.* 73:59. doi: 10.1016/S0002-9459(24)00554-0

Cao, C., Chen, B., Yang, S., Zheng, X., Ye, Y., and Yue, X. (2022). Exploring the impact of individual and social antecedents on Teachers' teaching innovation: perspective of goal-oriented behavior and social identity. *Front. Psychol.* 13:924052. doi: 10.3389/fpsyg.2022.924052

Ghani, I. M. M., Ahmad, S. J. P.-S., and Sciences, B. (2010). Stepwise multiple regression method to forecast fish landing. *Proc. Soc. Behav. Sci.* 8, 549–554. doi: 10.1016/j.sbspro.2010.12.076

Gong, H., and Chen, L. (2019). Rational thinking on the development of advantages and characteristics of university discipline under the construction of "double first-class". *Modern Educ. Manage.* 60–65. doi: 10.16697/j.cnki.xdjygl.2019.07.010

Gouëdard, P., Pont, B., Hyttinen, S., and Huang, P. (2020). "Curriculum reform: A literature review to support effective implementation", In *OECD Education Working Papers*. No. 239, Paris: OECD Publishing.

Gu, D., Niu, X., Guo, X., and Hu, Y. (2018). Defining and developing a roadmap for"new College of Medicine". *China Higher Medical Educ.* 17–18. doi: 10.3969/j.issn.1002-1701.2018.08.008

Haapaniemi, J., Venäläinen, S., Malin, A., and Palojoki, P. J. J. O. C. S. (2021). Teacher autonomy and collaboration as part of integrative teaching–reflections on the curriculum approach in Finland. *J. Curr. Stu.* 53, 546–562. doi: 10.1080/00220272.2020.1759145

Hang, R., Hu, H., and Cai, C. (2020). Reflections on the construction of Practice Base for undergraduate majors of applied psychology in medical colleges. *Sci. Technol. Vision*, 13–16. doi: 10.19694/j.cnki.issn2095-2457.2020.32.005

Hu, H., and Wang, X. (2022). Exploration and reflection on the new medical talents training in the post-epidemic era. *Educ. Teach. Forum*. 1–4.

Lamparyk, K., Williams, A. M., Robiner, W. N., Bruschwein, H. M., and Ward, W. L. (2021). Interprofessional education: current state in psychology training. *J. Clin. Psychol. Med. Settings* 29, 20–30. doi: 10.1007/s10880-021-09765-5

Leung, S. F., Mok, E., and Wong, D. J. N. E. T. (2008). The impact of assessment methods on the learning of nursing students. *Nurse Educ. Today* 28, 711–719. doi: 10.1016/j.nedt.2007.11.004

Lü, X., Tong, X., Wu, C., Zheng, W., and Wang, X. (2020). Development direction of master of applied psychology (MAP): reflections after COVID-19 pandemic. *Psychol. Tech. Appl.* 8, 331–341. doi: 10.16842/j.cnki.issn2095-5588.2020.06.002

MacFarland, T. W., Yates, J. M., MacFarland, T. W., and Yates, J. M. (2016). Mann–Whitney U test. *Intr. Nonparametric Statistics Biol. Sci.*, 103–132. doi: 10.1007/978-3-319-30634-6_4

Mayhew, M. J., Selznick, B., Zhang, L., Barnes, A., and Mangia, S. (2021). Teaching innovation capacities in undergraduate leadership courses: the influence of a short-term pedagogical intervention. *J. High. Educ.* 92, 877–896. doi: 10.1080/00221546.2021.1876480

McKnight, P. E., and Najab, J. J. (2010). Mann-Whitney U, Test. The Corsini encyclopedia of psychology, 1.

Ministry of Education of China (2020a). Notice of the Ministry of Education on announcing the record and approval results of undergraduate major in ordinary colleges and universities in 2019. Available at: http://www.moe.gov.cn/srcsite/A08/moe_1034/S4930/202003/T20200303_426853.html.

Ministry of Education of China. (2020b). Notice of the Ministry of Education on setting up the first-class disciplines of "interdisciplinary", "integrated circuit science and engineering" and "national security". Ministry of Education of the People's Republic of China (PRC). Available at: http://www.moe.gov.cn/srcsite/A22/yjss_xwgl/xwgl_xwsy/202101/t20210113_509633.html

Noll Gonçalves, J., Noll Gonçalves, R., Da Rosa, S. V., Schaia Rocha Orsi, J., Moysés, S. J., and Iani Werneck, R. (2021). Impact of interprofessional education on the teaching and learning of higher education students: a systematic review. *Nurse Educ. Pract.* 56:103212. doi: 10.1016/j.nepr.2021.103212

Noll Gonçalves, J., Noll Gonçalves, R., Da Rosa, S. V., Schaia Rocha Orsi, J., Santos De Paula, K. M., Moysés, S. J., et al. (2023). Potentialities and limitations of Interprofessional education during graduation: a systematic review and thematic synthesis of qualitative studies. *BMC Med. Educ.* 23:236. doi: 10.1186/s12909-023-04211-6

Oliver, R., Kersten, H., Vinkka-Puhakka, H., Alpasan, G., Bearn, D., Cema, I., et al. (2008). Curriculum structure: principles and strategy. *J. Dental Educ.* 12, 74–84. doi: 10.1111/j.1600-0579.2007.00482.x

Piaw, C. Y. (2008). Asas statistik penyelidikan. New York, NY: Mc-Graw Hill.

Qin, Y., Wu, H., Cheng, Q., Wang, H., and Zheng, J. (2022). Collides of physics with medicine: construction and practice of an interdisciplinary course. *Chin. J. Med. Educ.* 42, 309–333. doi: 10.3760/cma.j.cn115259-20210922-01194

Rabin, E., Kalman, Y. M., and Kalz, M. (2019). An empirical investigation of the antecedents of learner-centered outcome measures in MOOCs. *Int. J. Educ. Technol. High. Educ.* 16:14. doi: 10.1186/s41239-019-0144-3

Reis, S. (2018). Curriculum reform: why? What? How? And how will we know it works? *Isr. J. Health Policy Res.* 7:30. doi: 10.1186/s13584-018-0221-4

Shay, S., and Peseta, T. L. (2019). Curriculum as contestation. London: Routledge.

Soulie, P., and Cosson, P. (2021). Learning objectives: an epiphany. *FEBS Open Bio* 11, 3189–3192. doi: 10.1002/2211-5463.13328

Stabback, P. J. (2016). What makes a quality curriculum? In-progress reflection no. 2 on" current and critical issues in curriculum and learning". Geneva: UNESCO International Bureau of Education.

Sutter, J. M., and Kalivas, J. H. J. M. J. (1993). Comparison of forward selection, backward elimination, and generalized simulated annealing for variable selection 47, 60–66.

The Network Essential for College Students. (2024). A list of universities majoring in applied psychology. Available at: https://www.dxsbb.com/news/10254.html (Accessed August 25, 2024).

Vu, D. H., Muttaqi, K. M., and Agalgaonkar, A. P. J. A. E. (2015). A variance inflation factor and backward elimination based robust regression model for forecasting monthly electricity demand using climatic variables. *Appl. Energy* 140, 385–394. doi: 10.1016/j.apenergy.2014.12.011

Wang, R., Han, B., and Zhang, K. (2022a). A brief review of applied psychology in China. *Psych J* 11, 126–131. doi: 10.1002/pchj.519

Wang, C., and Ma, C. (2022). Taking the new medicine construction as an opportunity to promote the innovative development of medical education. *China Higher Educ.* 15–17.

Wang, C., Pang, N., and Yang, M. (2020). Exploration and practice of personnel training system of applied psychology under medical background. *J. China Univ. Sci. Technol.* 20, 88–91. doi: 10.3969/j.issn.2095-2708.2020.01.088

Wang, Z., Yang, Y., Niu, X., Shao, L., and Fan, X. (2022b). Thinking of medical major setting under the background of "new medicine". *Chinese J. Med. Educ. Res.* 21, 1601–1606. doi: 10.3760/cma.j.cn116021-20220830-01091

World Health Organization (2010). Framework for action on interprofessional education and collaborative practice. Geneva: World Health Organization.

Xinhuanet. (2016). The state council, the central Committee of the Communist Party of China issued the "outline of healthy China 2030" plan. Available at: http://www.xinhuanet.com/politics/2016-10/25/c_1119785867.htm (Accessed June 15, 2023).

Xu, L., Wu, X., Jia, S., and Zhou, L. (2015). The exploration of training pattern of multi-skill graduates of applied psychology in medical colleges. *Med. Teach. Univ.* 5, 14–17.

Yan, C., Liu, Y., Fang, A., Niu, Y., Su, Y., and Zhang, L. (2021). Cultivation of medical students' innovative ability based on blended teaching mode of "integration of medicine and science". *J. Gansu Univ. Chin. Med.* 38, 91–93. doi: 10.3969/j.issn.2095-1582.2015.03.004

Yang, C., and Wang, Z. (2023). Preliminary study and reform of the "medicine+X" compound talent training mode. *Med. Educ. Res. Prac.* 31, 11–15. doi: 10.3969/j.issn.2095-1582.2015.03.004

Yin, S. (2007). Thinking about specialty construction of applied psychology in medical colleges and universities. *Chin. J. Med. Educ. Res.* 6, 818–828. doi: 10.13555/j.cnki.c.m.e.2023.01.003

Zeff, R. (2007). Universal design across the curriculum. *N. Dir. High. Educ.* 2007, 27–44. doi: 10.1002/he.244

Zhang, S. (2022). Teaching reform of SPSS statistical software course for applied psychology major. *Surv. Educ.* 11, 95–98.

Zhang, J., Zhang, Y., and Liu, Y. (2022). Exploration on teaching reform of family therapy course for applied psychology majors. *Univ. Educ.* 11, 181–183. doi: 10.16070/j.cnki.cn45-1388/g4s.2022.25.010

Zhao, J. (2019). Difficulties and solutions of practical teaching of applied psychology specialty in colleges and universities. *Guide Sci. Educ.* 134–135. doi: 10.16400/j.cnki.kjdks.2019.11.063

Zhao, Y., Liu, W., Wang, Z., Chen, X., Zhao, J., and Zhou, X. (2022). The value of CBL-based teaching mode in training medical students' achievement rate, practical ability, and psychological quality. *Contrast Media Mol. Imaging* 2022:2121463. doi: 10.1155/2022/2121463

Zheng, B., Ganotice, F. A., Lin, C.-H., and Tipoe, G. L. (2023a). From self-regulation to co-regulation: refining learning presence in a community of inquiry in interprofessional education. *Med. Educ.* 28:2217549. doi: 10.1080/10872981.2023.2217549

Zheng, X., Li, C., Chen, Y., and Li, S. (2023b). Research on the influence of college students' participation and learning self-efficacy on curriculum satisfaction. *J. Hubei Normal Univ.* 43, 118–123.

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Toward a new model for the successful implementation of information and communication technologies in education

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The design of our Information and Communication Technologies for Education (ICT4E) implementation model highlights its adaptability to local realities, considering available resources, existing technological infrastructures, and the specific needs of learners. However, it is crucial to recognize that the inherent variability of educational contexts and resource constraints can present challenges to a generalized application of the model. In addition, the rapid pace of technological change can have an impact on the ongoing training of teachers, requiring constant vigilance to maintain the relevance of their pedagogical skills. Despite these challenges, our model stands out for its adaptable approach, encouraging ongoing adjustments to respond effectively to the diversity of educational environments. In addition, the prospect of research and innovation, the promotion of interdisciplinary collaboration and the adoption of holistic evaluation are essential strategies for strengthening the robustness of our model. However, it is imperative to remain attentive to ethical considerations, the issue of equity and inclusion, and the long-term impact of integrating ICT into education. Ultimately, our model aspires to be a balanced solution, aware of the challenges and open to the developments needed to ensure the harmonious and optimal integration of ICT into today's educational landscape.

KEYWORDS

ICT integration, ICT4E, pedagogical skills, teaching, technologies

1 Introduction

The integration of Information and Communication Technologies applied to Education (ICTE) has radically reshaped the educational landscape, opening new perspectives for rethinking, and enriching traditional teaching and learning methods (Zafar et al., 2022). Faced with this rapid evolution, the need for effective integration of ICTE into pedagogical practices is becoming a crucial concern for researchers and educators alike. With this in mind, our scientific research aims to explore and compare in depth the main existing models of ICTE integration. Our aim is to highlight the successes and challenges specific to each approach, while identifying emerging best practices from these established models. By examining models such as "ADDI," "4C/ID," "Bate's techno-pedagogical model," "SAMR," "TPACK," and the "Triple E FRAMEWORK," we seek to draw lessons on how these approaches have been applied in various educational contexts. This comparative analysis will enable us to better understand

the specific strengths of each model, as well as the limitations that may have been identified in their implementation. However, our research will not be limited to examining these models. It will also aim to propose a new conceptual model for the integration of ICTE. The aim of this holistic approach is to transcend simple comparative analysis by integrating the lessons learned from the models studied into an innovative proposal. By proposing a new conceptual model, this intervention is positioned as an innovative contribution to the field of ICTE integration, offering a perspective that aspires to fill the gaps and offer a more adaptive and effective approach in various educational contexts.

2 Context

Rapid advances in Information and Communication Technologies (ICT) in education have opened new perspectives (Beavis et al., 2014), prompting reflection on how these technologies can be effectively integrated to enhance learning processes. Many researchers have developed models to guide this integration, focusing on aspects such as teacher training, program design, and learner engagement. These existing models have played a crucial role in guiding this integration, but it is now essential to evaluate them in the light of technological developments and new educational needs (Anctil, 2023).

3 Methodology

Our study adopts a qualitative and quantitative methodology, distinguished by a careful analysis of context, processes and experiences. Through a literature review, we explore a diverse range of models of ICTE integration, making a careful selection of the main models (Haseeb and Dwivedi, 2021). The in-depth analysis focuses on the theoretical underpinnings, concrete applications, as well as highlighting the relevant research findings for each model examined (Lachner et al., 2024). These components form the basis of our proposal for an innovative model, which incorporates contemporary technological advances and responds to current educational needs.

3.1 Criteria for choosing the models

The criteria for selecting the models for this comparative study were determined according to several factors, all aimed at ensuring a complete and balanced representation of the various existing approaches to integrating ICT into contemporary education (Buabeng-Andoh, 2019). To define them, we carried out a literature review to find those already used in similar studies, and we also sought the opinions of experts in the field of ICT (teachers, trainers, researchers, and decision-makers) to help us refine them and shed light on the most relevant aspects to be evaluated, as defined below:

1. Complementarity of approaches: Each model studied offers a unique approach that complements the others, covering a wide range of considerations, from educational planning to solving complex problems (Dron and Anderson, 2023).
2. Recognition of popularity and relevance: The models examined are among the most widely used and recognized in the field of education, which testifies to their relevance and usefulness for practitioners and researchers (Andler and Guerry, 2008).
3. Diversity of perspectives: the selected models represent a diversity of perspectives on ICTE integration, enabling different dimensions of this integration to be explored (Tamer and Nejjari, 2022).
4. Consideration of contemporary educational needs: The selected models focus on connections and networks in a digital context, which is particularly relevant in today's educational environment characterized by rapidly evolving technologies and teaching methods (Gane et al., 2018).
5. Compatibility with educational reality: The models selected are recognized for their pragmatic nature and their applicability in real educational contexts, thus reinforcing their credibility and relevance (Joulia, 2005).

Applying these criteria to the various models of ICTE integration proposed by researchers and practitioners, we have selected the following models to delimit our comparative study: "ADDIE," "4C/ID," "Bates' techno-pedagogical model," "SAMR," "TPACK," and the "Triple E Framework."

3.2 Description of the ICTE integration model

We will therefore briefly outline the characteristics appropriate to each model examined.

1. Analysis, Design, Development, Implementation, Evaluation (ADDIE) model: Although initially designed for the development of educational programs, the ADDIE model (1970) offers a systematic approach that can be adapted to the integration of ICTE at every stage. Developed by the Center for Educational Technology at Florida State University, it is a classic framework for instructional design that guides the process of developing educational programs (Almelhi, 2021).
2. Four Component for Instructional Design (4C/ID) model: Developed by Van Merriënboer and his colleagues in the 1990s, the 4C/ID model is based on the theory of cognitive development. It proposes an approach to instructional design that integrates ICT to encourage the resolution of complex problems. This model focuses on building skills and solving authentic tasks (Instituto de Educação da Universidade de Lisboa, Portugal, mmlmelo@hotmail.com and Melo, 2018).
3. Bates' Techno-pedagogical model: Developed by Tony Bates (2005), this model explores the relationship between technology choice and pedagogical strategy. It highlights the need to align technology choices with pedagogical objectives and the learning context.
4. Substitution, Augmentation, Modification, Redefinition (SAMR) model: Developed by Ruben Puentedura (Blundell et al., 2022), this model proposes a hierarchy of four levels for evaluating the integration of ICTE. It ranges from the simple substitution of traditional tools to more complex tasks that redefine learning. It proposes a hierarchy of levels of integration of technology in teaching and learning. Each level represents a different way of using technology, ranging from simple

substitutions of traditional tools to more profound transformations of learning processes.

5. Technological Pedagogical Content Knowledge (TPACK) model: this model focuses on the intersection of three types of knowledge: technological, pedagogical, and disciplinary. It explores how this knowledge interacts to support effective teaching with ICT, linking technological knowledge (TK), pedagogical knowledge (PK), and disciplinary content knowledge (CK) (Bedin et al., 2023).
6. Triple E Framework Model (Engage, Enhance, Extend): Developed by Liz Kolb, this model provides an approach to evaluating the use of technology in the classroom, focusing on engaging learners, enhancing learning, and extending educational opportunities. It guides the integration of ICT into teaching by evaluating their use according to these three criteria (Ruzaman and Rosli, 2020).

3.3 Comparative study of the main models chosen

To carry out an effective comparison of these models of ICTE integration, we used a participatory methodology. We solicited the participation of 42 pedagogical actors with expertise in the field of education and technology, including 21 teachers of different subjects, seven educational inspectors, 11 school headmasters (primary and secondary), and three trainers from the Regional Center for Trades and Training (CRMEF). We began with a SWOT analysis of ICT integration models. The participants met in sub-groups of seven people, each focusing on a specific model to identify its strengths, weaknesses, opportunities, and threats. We then aggregated the results to obtain an overall view. Secondly, the educational inspectors and CRMEF trainers worked together to create a grid to measure the performance of each model. This grid assigns a score to each previously defined criterion, based on the results obtained during the SWOT analysis.

3.4 Diversification of data sources

To enrich our analysis and provide a more nuanced perspective on the integration of ICT in education, we included detailed case studies and recent empirical data. For example, a case study on a school using Puentedura's SAMR model revealed significant improvements in student engagement and the quality of work produced. Additionally, UNESCO's annual reports on education and technology provide recent statistics showing the increasing adoption of ICT in schools worldwide, with notable variations across geographical regions and educational levels.

3.4.1 Expansion of the sample

To generalize our findings to a broader range of educational contexts, we expanded our sample to include schools from different geographical regions, educational levels (primary, secondary, higher education), and types of schools (public, private, rural, urban). For instance, our sample includes well-funded urban schools as well as rural schools with limited resources, allowing us to compare challenges and successes across diverse contexts. This diversity helps us identify ICT integration strategies that are effective in various educational environments.

3.4.2 Integration of teacher's and students' perspectives

To gain a better understanding of ICT integration, we conducted in-depth interviews and focus groups with educational stakeholders: teachers, educational inspectors, school directors, and trainers at the regional center for trades and training. These interviews revealed valuable information about the daily challenges faced by teachers, such as the lack of adequate training and the need for ongoing technical support. Students, meanwhile, expressed their enthusiasm for interactive technology tools. Nonetheless, the stakeholders interviewed stressed the need for a balance between the use of ICT and traditional teaching methods.

4 Results

Each of these models is evaluated according to criteria predefined by the participants in this study, namely: Pedagogical Relevance, Adaptability, Ease of Use, Learner Engagement, Accessibility, Curricular Integration, Evaluation, Professional Support, Cost, and Innovation. Table 1 summarizes the results of this study by applying a score scale of 1–5 for each criterion, where 1 represents poor performance and 5 excellent performances. In this evaluation, the numbers 1–5 represent the relative performance of each model on each criterion.

We adopted Friedman's statistical test to analyze the data collected from the various participants in our focus groups, given that this test is the most suitable for comparing several models in relation to the same criteria on a performance scale ranging from 1 to 5 (from poor to excellent) (ordinal and non-parametric data). For statistical analysis, we used SPSS software.

The Friedman test carried out to compare the significant differences between the six selected models yielded the following results:

- Friedman statistic: 33.57.
- p value obtained: 2.90e−06 (0.0000029), this value is below the significance threshold of 0.05. This indicates statistically significant differences between at least two of the models evaluated.

5 Discussion of results

In terms of pedagogical relevance, the 4C/ID and TPACK models stand out with scores of 5 out of 5, underlining their ability to be aligned with pedagogical objectives. These models emphasize the creation of learning environments adapted to learners' needs (Herring et al., 2016). In contrast, the EEE model scores less than 3 out of 5, suggesting less relevance. In terms of adaptability, the TPACK model obtained the highest score of 5 out of 5, indicating its ability to be flexible and to adapt to different educational contexts. The 4C/ID and SAMR models also obtain solid scores of 4 out of 5,

TABLE 1 Comparison of ICTE integration models.

Criteria	ADDIE	4C/ID	Techno-pedagogical	SAMR	TPACK	Triple E
Educational relevance	4	5	4	4	5	3
Adaptability	3	4	3	4	5	3
Ease of use	3	4	4	3	4	3
Learner engagement	4	5	4	4	4	3
Accessibility	3	4	3	3	4	3
Curricular integration	4	4	4	3	4	3
Evaluation	4	4	3	4	4	3
Professional support	3	4	4	3	4	3
Cost	3	4	3	4	4	3
Innovation	3	4	4	3	4	3

while the ADDIE model, receives a lower score of 3 out of 5, revealing average adaptability. In terms of ease of use, the 4C/ID, techno-pedagogical and TPACK models stand out with scores of 4 out of 5, highlighting their user-friendliness for teachers. In contrast, the ADDIE, SAMR and Triple EEE models scored slightly lower, at 3 out of 5. For learner engagement, the 4C/ID model scores a perfect 5 out of 5, indicating its effectiveness in engaging learners in the learning process. The ADDIE, Techno-pedagogical, SAMR and TPACK models obtain solid scores of 4 out of 5, while the EEE model has a lower score of 3 out of 5. As far as accessibility is concerned, the 4C/ID, TPACK and Techno-pedagogical models obtain high scores of 4 out of 5, showing their attention to making resources and activities accessible to all learners. In contrast, the ADDIE, SAMR and Triple E models have slightly lower scores of 3 out of 5. In terms of curricular integration, the 4C/ID, Techno-pedagogical, and TPACK models stood out with scores of 4 out of 5, indicating their effective alignment with the program objectives. On the other hand, the ADDIE, SAMR and Triple E models obtained slightly lower scores of 3 out of 5, suggesting a need to improve their curricular integration. In terms of assessment, the 4C/ID, ADDIE, Techno-pedagogical, TPACK and SAMR models score high at 4 out of 5, highlighting their ability to effectively assess learners' learning, while the Triple E model scores slightly lower at 3 out of 5. From the point of view of professional support, the 4C/ID, Techno-pedagogical, and TPACK models obtain high scores of 4 out of 5, indicating that they offer adequate support to teachers. In contrast, the ADDIE, SAMR and Triple E models score slightly lower at 3 out of 5. In terms of costs, the 4C/ID and SAMR models stand out with scores of 4 out of 5, indicating that they are relatively profitable. The other ADDIE, Techno-pedagogical, TPACK and Triple E models have average scores of 3 out of 5. In terms of costs, the 4C/ID and SAMR models stand out with scores of 4 out of 5, indicating that they are relatively profitable. The other ADDIE, Techno-pedagogical, TPACK and Triple E models have average scores of 3 out of 5. Finally, in terms of innovation, the 4C/ID, Techno-pedagogical and TPACK models received high scores of 4 out of 5, underlining their ability to encourage educational innovation. The ADDIE, SAMR and Triple E models received slightly lower scores of 3 out of 5. We can deduce that the 4C/ID, Techno-pedagogical and TPACK models often stand out as solid choices in several categories, while the Triple E model shows lower scores suggesting a need for improvement to better meet current pedagogical needs. Indeed, these results reveal that each model has specific characteristics and performances that cannot be replaced, or used in the same way in all teaching acts. The low p value underlines the statistical robustness of this difference, suggesting that some models may be particularly effective for certain criteria, while being less effective for others. This heterogeneity calls for a strategic and differentiated approach to the choice and implementation of ICTE, depending on the objectives being pursued. Reflection on a new model for integrating ICTE is timely for improving teaching and learning in an education system that aims to change educational practices in close alignment with technologies and should therefore draw on these findings to fill the gaps identified and meet the emerging needs of contemporary education.

6 Proposal for a new model

With a view to designing a new Model for Pedagogical Integration of ICT Model (MIPTICE)' incorporating the performance of the above-mentioned ICTE integration models, the following approach is recommended. We began with an in-depth analysis of the existing models, identifying their strengths, weaknesses, and gaps. We then defined the objectives of the new model, establishing guiding principles such as alignment with pedagogical objectives, flexibility, and accessibility. The model was designed by incorporating best practice, then tested in real environments and improved based on feedback. It aims to provide a comprehensive framework for the effective and relevant use of technology in learning.

6.1 Fundamental principles

The MIPTICE model is based on five fundamental principles that guide its design and implementation in learning environments (see Figure 1).

1. Pedagogical Alignment: All activities and technological resources are aligned with specific pedagogical objectives, thus ensuring the relevance of teaching and learning.
2. Flexibility and Adaptability: The MIPTICE model is designed to be flexible and adaptable to different learning contexts,

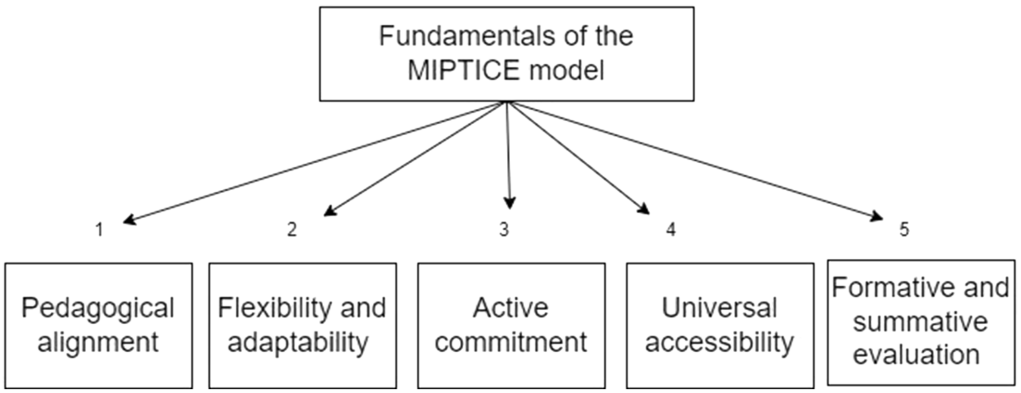

FIGURE 1
The five principals for implementing the MPTICE model in the Learning environment.

allowing teachers to customize learning experiences according to students' needs.

3. Active Engagement: The model encourages the active engagement of students in the learning process, promoting interaction, collaboration and critical thinking.
4. Universal Accessibility: The MIPTICE model ensures that all resources and activities are accessible to all learners, whatever their level of ability or specific needs.
5. Formative and Summative Assessment: The model incorporates formative and summative assessment mechanisms to regularly evaluate student progress and inform pedagogical adjustments.
5. Support: Professional support is available for teachers, including training, resources, and personalized advice. Technical support is also provided to ensure the smooth operation of the technologies used (Sommerhoff et al., 2023).
6. Evaluation and Continuous Improvement: The model encourages continuous evaluation of its effectiveness, collecting data on learning outcomes, feedback from students and teachers, and the performance of the technologies used. Adjustments are made based on the results of this evaluation to continuously improve the integration of ICT in teaching and learning (Mastafi, 2020).

6.2 Model components

By following the five principles of our approach, the MIPTICE model aims to provide a comprehensive and effective framework for the integration of ICTE into education, thereby promoting rich, relevant, and engaging learning experiences for all learners. Figure 2 shows the process we have proposed for integrating ICTE into education.

The MIPTICE model consists of:

1. Content: Content is chosen according to the learning objectives and needs of the learners. It is varied and adapted to suit different learning styles (Noureddine, 2006).
2. Pedagogy: Teaching methods are learner-centered, encouraging active involvement and the construction of knowledge. They incorporate collaborative approaches, problem solving and regular feedback (Leibold and Schwarz, 2015).
3. Technology: Technologies are selected based on their ability to support pedagogical objectives and enrich the learning experience. They are used in creative and innovative ways to stimulate student engagement (McCain and Jukes, 2001).
4. Assessment: Assessment is built into every stage of the learning process, enabling continuous monitoring of student progress. It includes formative assessments to guide learning and summative assessments to evaluate achievement (Nadeau-Tremblay et al., 2022).

6.3 Example of an application scenario

We propose this scenario based on the MIPTICE model for an introductory IT course for the core curriculum at secondary school: "Discovering the Fundamentals of IT" (see Table 2).

This scenario enables students to learn about computing in an interactive and practical way, with an emphasis on active learning and the use of technology. It incorporates the principles of the MIPTICE model by offering a diversified teaching approach, using technology in a relevant way and providing personalized support for students. By following this scenario, students will develop essential computer skills and be better prepared to use technological tools in their studies and everyday life.

7 Conclusion

In conclusion, our exploration of models for integrating Information and Communication Technologies for Education (ICT4E) has highlighted the diversity of approaches and perspectives in this constantly evolving field. Each model examined has specific strengths and limitations, underlining the importance of understanding local educational needs and choosing appropriate approaches for the successful integration of ICT into teaching and learning. Through our proposal for a new model of ICTE implementation, we have sought to fill the gaps identified in existing

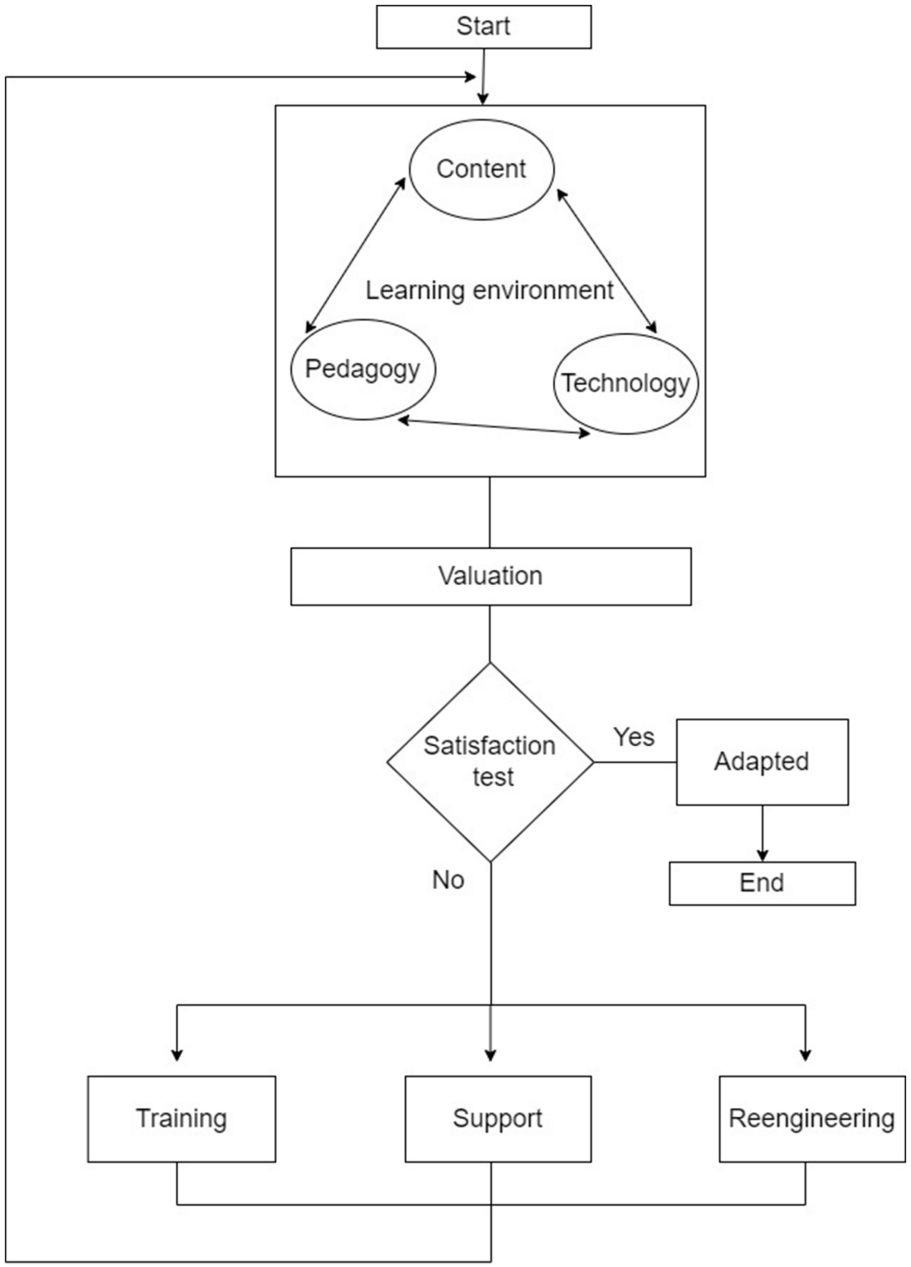

FIGURE 2
Presentation of the MPTICE model.

models by integrating best practice, with an emphasis on adaptability, contextualization, and continuous evaluation. This model, called MIPTICE (Successful ICTE implementation model), offers a methodical and participative approach to guide each stage of the ICTE integration process, while considering the specificities of local educational contexts. Although our model has significant advantages, it is essential to recognize its limitations, in particular the need for constant vigilance to maintain the relevance of teaching skills in a rapidly changing environment. To overcome these limitations, it is imperative to focus on three main areas: teacher training, student support, and the reengineering of educational practices. Teacher training requires ongoing training models that keep teachers up to date with technological developments, including online training, interactive workshops, and communities of practice. In addition, pre-service training programs need to incorporate specific models for the pedagogical use of ICT to effectively prepare future teachers. As far as student support is concerned, it is essential to develop technological solutions that are accessible to all, with ICT enabling learning to be personalized by adapting content and pedagogical approaches to students' needs. To re-engineer educational practices, it is necessary to examine hybrid teaching models combining face-to-face and online learning to determine best practices for implementing ICT. It is also essential to promote interdisciplinary collaboration between different academic and professional fields. Finally, developing assessment tools using ICT will provide real-time feedback and analysis of pedagogical data, continuously improving

TABLE 2 Teaching scenario based on the MIPTICE model for a computer science course.

Educational objectives	- Understand the fundamental concepts of computing. - Develop basic skills in the use of IT tools. - Stimulate interest in information and communication technologies.
Contents	- Introduction to the computer and its components. - How the operating system and software work. - Browsing the Internet and using search tools. - Notions of computer security and data protection.
Teaching	- Theoretical presentation of the basic concepts of computing, illustrated by computer demonstrations. - Practical classroom exercises to handle the various hardware and software components. - Interactive activities where students solve simple problems using appropriate software. - Class discussions on the ethical and social issues surrounding the use of technology.
Technology	- Use of computers in the classroom for demonstrations and practical exercises. - Use of interactive educational software to make learning fun and engaging. - Use of a web browser to explore online resources and carry out research exercises.
Evaluation	- Formative assessment during practical exercises in class, by observing students' ability to apply the concepts they have learned. - Summative assessment based on a project in which students have to create a digital document using the skills they have learned.
Support	- Individual support for students experiencing difficulties, with tutoring sessions and additional resources available online. - Awareness-raising sessions on computer security and online ethics, in partnership with experts in the field.

teaching/learning practices. The results of examining the three perspectives in practical experiments will be the subject of future publications.

8 Recommendations

The present study leads to several strategic recommendations. Firstly, researchers are advised to explore the integration and application of ICTE in recognized schools of educational psychology, particularly with regard to its impact on accepted learning styles. This approach could provide valuable insights for adapting ICTE to the needs of different apparent. It is also recommended to carry out post-hoc analyses to draw more precise and oriented conclusions about pedagogical choices or educational acts in a more targeted way.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

LL: Funding acquisition, Investigation, Methodology, Writing – original draft. MM: Conceptualization, Formal analysis, Writing – review & editing. SF: Supervision, Visualization, Writing – review & editing. KM: Supervision, Validation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Almelhi, A. M. (2021). Effectiveness of the ADDIE model within an E-learning environment in developing creative writing in EFL students. *Engl. Lang. Teach.* 14:20. doi: 10.5539/elt.v14n2p20

Anctil, D. (2023). L'éducation supérieure à l'ère de l'IA générative. 36.

Andler, D., and Guerry, B. (2008). Apprendre Demain: Sciences Cognitives et Éducation à l'ère Numérique: Hatier.

Beavis, C., Rowan, L., Dezuanni, M., McGillivray, C., O'Mara, J., Prestridge, S., et al. (2014). Teachers' beliefs about the possibilities and limitations of digital games in classrooms. *E-Learn. Digit. Media* 11, 569–581. doi: 10.2304/elea.2014.11.6.569

Bedin, E., Marques, S. M., and Das Graças Cleophas, M. (2023). Research on the content, technological, and pedagogical knowledge (TPACK) of chemistry teachers during remote teaching in the pandemic in the light of students' perceptions. *J. Info. Technol. Educ. Res.* 22, 001–024. doi: 10.28945/5063

Blundell, C. N., Mukherjee, M., and Nykvist, S. (2022). A scoping review of the application of the SAMR model in research. *Comput. Educ. Open* 3:100093. doi: 10.1016/j.caeo.2022.100093

Buabeng-Andoh, C. (2019). Factors that influence teachers' pedagogical use of ICT in secondary schools: a case of Ghana. *Contemp. Educ. Technol.* 10, 272–288. doi: 10.30935/cet.590099

Dron, J., and Anderson, T. (2023). "Pedagogical paradigms in open and distance education" in Handbook of Open, Distance and Digital Education. eds. O. Zawacki-Richter and I. Jung (Springer Nature Singapore), 147–163.

Gane, B. D., Zaidi, S. Z., and Pellegrino, J. W. (2018). Measuring what matters: using technology to assess multidimensional learning. *Eur. J. Educ.* 53, 176–187. doi: 10.1111/ejed.12269

Haseeb, M., and Dwivedi, S. K. (2021). School teachers' perspective on technology-pedagogy content knowledge. *J. Teach. Educ. Res.* 16, 19–21. doi: 10.36268/JTER/16104

Herring, M. C., Koehler, M. J., and Mishra, P. (2016). Handbook of Technological Pedagogical Content Knowledge (TPACK) for Educators. *0th* Edn: Routledge.

Joulia, D. (2005). Les nouvelles potentialités des TICE: Entre mythe et réalité. *Les Cahiers l'APLIUT* XXIV, 7–26. doi: 10.4000/apliut.2972

Lachner, A., Backfisch, I., and Franke, U. (2024). Towards an integrated perspective of teachers' technology integration: a preliminary model and future research directions. *Frontline Learn. Res.* 12, 1–15. doi: 10.14786/flr.v12i1.1179

Leibold, N., and Schwarz, L. M. (2015). The art of giving online feedback. *J. Effect. Teach.* 15, 34–46.

Mastafi, M. (2020). Rôles et impacts des TIC dans l'enseignement et l'apprentissage des mathématiques: Perceptions des enseignants du secondaire. *Format. Prof.* 28:60. doi: 10.18162/fp.2020.508

McCain, T. D. E., and Jukes, I. (2001). Windows on the Future: Education in the Age of Technology: Corwin Press.

Melo, M. (2018). The 4C/ID-model in physics education: instructional design of a digital learning environment to teach electrical circuits. *Int. J. Instr.* 11, 103–122. doi: 10.12973/iji.2018.1118a

Nadeau-Tremblay, S., Tremblay, M., Laferrière, T., and Allaire, S. (2022). Les enjeux et défis d'accompagnement d'enseignantes et d'enseignants dans l'évaluation des apprentissages à l'aide de technologies collaboratives au primaire et au secondaire. *Méd. Médiat.* 9, 7–27. doi: 10.52358/mm.vi9.249

Noureddine, T.-T. (2006). Réforme de l'éducation et innovation pédagogique en Algérie. UNESCO.

Ruzaman, N. K., and Rosli, D. I. (2020). Inquiry-based education: innovation in participatory inquiry paradigm. *Int. J. Emerg. Technol. Learn.* 15:4. doi: 10.3991/ijet.v15i10.11460

Sommerhoff, D., Codreanu, E., Nickl, M., Ufer, S., and Seidel, T. (2023). Pre-service teachers' learning of diagnostic skills in a video-based simulation: effects of conceptual vs. interconnecting prompts on judgment accuracy and the diagnostic process. *Learn. Instr.* 83:101689. doi: 10.1016/j.learninstruc.2022.101689

Tamer, H., and Nejjari, I. (2022). Les attitudes des enseignants et des étudiants vis-à-vis l'adoption et l'utilisation des TIC. *Rev. Littérat. Proposit. Mod.* doi: 10.5281/ZENODO.7395434

Zafar, M. W., Zaidi, S. A. H., Mansoor, S., Sinha, A., and Qin, Q. (2022). ICT and education as determinants of environmental quality: the role of financial development in selected Asian countries. *Technol. Forecast. Soc. Chang.* 177:121547. doi: 10.1016/j.techfore.2022.121547

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Unlocking innovation: how enjoyment drives GenAI use in higher education

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Introduction: Generative Artificial Intelligence (Gen AI) is rapidly transforming education holds immense potential for enhancing learning experiences and fostering innovation skills crucial for success in today's rapidly changing job market. However, successful integration depends on student adoption. This study investigates factors influencing business students' intention to use Gen AI in Innovation courses, focusing on the role of Perceived Enjoyment.

Method: A cross-sectional predictive analysis was conducted using data from 92 business undergraduate students in a Peruvian higher education institution. A survey questionnaire, adapted from Teo and Noyes, was used to measure perceived enjoyment, usefulness, ease of use, attitude toward, and intention to use Gen AI tools.

Results: The study found a strong positive relationship between Perceived Enjoyment and the intention to use Gen AI in Innovation courses. Furthermore, Perceived Enjoyment was positively associated with perceived ease of use. Interestingly, perceived usefulness did not show a significant effect on the intention to use Gen AI.

Conclusion: Our finding challenges the traditional emphasis on perceived usefulness as the primary driver of technology acceptance. Instead, our results suggest that prioritizing user enjoyment and ease of use in the design and implementation of Gen AI tools may be a more effective strategy for promoting their adoption in educational settings. This shift in focus from utility to experience could be crucial in unlocking the full potential of Gen AI to transform education.

KEYWORDS

generative artificial intelligence, higher education, technology adoption, perceived enjoyment, innovation education

1 Introduction

Rapid technological advancements are reshaping the educational landscape, challenging educators to prepare students for an increasingly innovative and adaptable job market (Ortíz and Fumás, 2020). Traditional teaching methods often struggle to cultivate the critical and soft skills demanded by modern employers (Prince and Felder, 2006; Succi and Canovi, 2019). In response, educators are turning to emerging technologies,

particularly Generative Artificial Intelligence (Gen AI), to enhance learning experiences and foster innovation skills (Børte et al., 2023).

Gen AI has demonstrated significant potential in education, improving learning outcomes, enhancing productivity, providing personalized instruction, and increasing student engagement (Gilson et al., 2023). It also supports collaborative learning and constructivist pedagogies (Prentzas, 2013). However, the successful integration of Gen AI in education depends on students' willingness to adopt and use these tools effectively.

The Technology Acceptance Model (TAM), proposed by Davis (1987), focuses on perceptions of usefulness and ease of use, as essential variables for understanding the adoption of new technologies in educational settings, particularly in the case of innovative tools such as Gen AI. Unlike Rogers' Diffusion of Innovations Theory (Rogers, 1962), which examines adoption at the macro level, TAM allows to get more detail about how individual factors, such as perceived enjoyment, influence students' intention to use these technologies. Although technology acceptance models like UTAUT and UTAUT2 incorporate additional constructs such as price value and habits (Venkatesh et al., 2012), they do not delve into perceived enjoyment as a key driver of innovative technology use. Given that Gen AI is characterized by its accessibility, where its price is not a determining factor, TAM emerges as a robust theoretical framework and as an effective methodology for understanding the technology adoption dynamics in academic settings, enabling to get more accurate assessments of the impact of perceived enjoyment on the use of these innovations, allowing to foster creativity skills and critical thinking among students.

ChatGPT represents a significant advance in artificial intelligence, where one of its main features is the ability to convincingly emulate human conversations. By learning from its past mistakes, ChatGPT can rapidly adapt to new interaction contexts and deliver more realistic and effective exchanges (Deng and Lin, 2023; Farrokhnia et al., 2023). In the field of education, AI has demonstrated its potential to improve educational quality, teaching-learning processes and career opportunities (Hamal et al., 2022). Generative AI tools such as ChatGPT-4, Gemini, and Copilot have become essential resources for educators in tasks like writing and learning, as well as academic assessment, lesson planning, personalized content creation or differentiation and adaptive instruction (Popenici and Kerr, 2017; Kasneci et al., 2023). Hence, these tools significantly reduce educators' workload, allowing them to focus more on interactive and adaptive pedagogy (Kiryakova and Angelova, 2023).

Similarly, students can benefit from Gen AI tools in several activities, including creative writing, essay writing, prompt generation, scheduling, and question answering (Taecharungroj, 2023). This interactions may significantly improve student engagement, by fostering peer-to-peer collaboration, and broadening access to educational resources, contributing to a more inclusive and dynamic educational experience (Strzelecki, 2023; Cotton et al., 2023).

Therefore, our study investigates the impact of Perceived Enjoyment on business undergraduate students' intention to use Gen AI in Innovation courses. By exploring this relationship, we aim to bridge the gap between technological advancements and effective pedagogical practices, contributing to the growing body of knowledge on technology adoption in higher education (Lai, 2017).

1.1 Artificial intelligence in higher education

Over the past decade, higher education has undergone significant transformations driven by technological advancements and digitalization (Fülöp et al., 2022). Artificial Intelligence (AI), augmented reality, and gamification have enhanced student-technology interactions (Fülöp et al., 2022; Prentzas, 2013), with educators playing a crucial role in facilitating this integration (Teo, 2011). Universities now offer a range of digital teaching tools to meet the demands of digitally proficient students (Fülöp et al., 2022; Lewis et al., 2024).

Generative AI (Gen AI), a recent advancement in this field, has shown promise in enhancing reading, writing, learning, and academic evaluation processes through its ability to emulate human conversations (Bozkurt, 2023). It has also improved student engagement, peer collaboration, and access to educational resources (Strzelecki, 2023; Cotton et al., 2023).

In recent years, Gen AI has gained significant popularity due to its remarkable advances in various fields. However, some readers may not be fully familiar with its underlying components. Gen AI encompasses several branches, including Large Language Models (LLMs), such as ChatGPT and Gemini, which are known for their unique capabilities to simplify many daily tasks for people of diverse backgrounds and social statuses (Agathokleous et al., 2023).

Another key branch is Generative Antagonistic Networks (GANs), mainly used in image generation, such as DALL-E. In addition, the transformer architecture, fundamental to many GenAI models, enables a wide range of applications beyond text generation.

However, Gen AI faces challenges such as limitations in deep understanding, quality evaluation of responses, and risks of biases and discrimination (Farrokhnia et al., 2023). These issues have prompted educators to adapt their teaching methods, fostering critical and creative approaches to integrate Gen AI in education in an effective and ethical way (Barros et al., 2023).

1.2 Technology adoption and innovation skills

Innovation encompasses three core aspects: creativity, knowledge, and operationalization capacity (Tura et al., 2008; Saunila and Ukko, 2012). These dimensions rely heavily on human capacity, which Lawson and Samson (2001) define as the ability to transform ideas into beneficial products, processes, and systems. Assink (2006) further emphasizes that disruptive innovation involves exploring radical ideas and leveraging resources to create marketable innovations.

In educational settings, (Gen AI) has emerged as a powerful tool to develop innovation skills. By supporting teaching activities, Gen AI stimulates student interest and enhances critical thinking and creativity (Kiryakova and Angelova, 2023), expands problem-solution spaces, facilitating greater knowledge generation and connections, ultimately leading to superior innovation performance (Bouschery et al., 2023).

The Technology Acceptance Model (TAM) (Davis et al., 1989) provides a framework for understanding the adoption of such

innovative tools. TAM posits that perceived usefulness (PU) and perceived ease of use (PEU) are key determinants of technology acceptance. Teo and Noyes (2011) extended TAM by incorporating perceived enjoyment (PE) as an external variable, finding that it significantly influences PU, PEU, and intention to use technology.

Recent studies suggest that PE may have an even more significant effect on intention to use than PU (Lee et al., 2019). This highlights the importance of considering enjoyment alongside traditional TAM variables when examining the adoption of innovative technologies in educational settings.

By fostering the adoption of tools like Gen AI through consideration of factors such as perceived enjoyment, educators can enhance students' innovation skills, aligning with the core dimensions of innovation and preparing students for the demands of an increasingly technology-driven workplace (Barros et al., 2023; Rogers et al., 2014).

1.3 Perceived enjoyment in educational technology adoption

Perceived enjoyment, defined as the extent to which using a technology is inherently pleasurable (Davis et al., 1992), has emerged as a crucial factor in educational technology adoption. This construct extends beyond traditional Technology Acceptance Model (TAM) variables, often rivaling or exceeding the impact of perceived usefulness and ease of use (Teo and Noyes, 2011; Venkatesh et al., 2012).

Across various educational technologies, including augmented reality (AR), virtual reality (VR), MOOCs, and mobile learning, perceived enjoyment consistently influences adoption intentions and usage behavior (Tao et al., 2019; Ghobadi et al., 2022). For instance, in AR and VR contexts, enjoyment not only predicts usage intentions but also positively affects academic performance (Lee et al., 2013; Ghobadi et al., 2022). Similarly, in mobile learning and Web 2.0 technologies, perceived enjoyment significantly impacts adoption intentions and future teaching practices (Mubuke et al., 2017; Teo et al., 2018).

Recent studies on AI-powered educational tools like ChatGPT further emphasize the role of perceived enjoyment. Xu and Thien (2024) found that enjoyment mediates various factors influencing ChatGPT adoption for language learning. However, Rahman et al. (2023) noted that trust moderates the relationship between perceived enjoyment and attitudes towards ChatGPT use, highlighting the complex interplay of factors in AI technology adoption.

The influence of perceived enjoyment extends to emerging educational technologies such as the metaverse (Al-Adwan et al., 2023) and broader applications like fintech and branded sports apps (Winarno et al., 2021; Won et al., 2023). This widespread impact underscores the need for developers and educators to prioritize enjoyable user experiences in their technological designs.

Importantly, the role of perceived enjoyment in technology adoption may vary across cultures and contexts (Sánchez-Prieto et al., 2017). For instance, in some collectivist cultures, social influence might moderate the effect of perceived enjoyment on adoption intentions (Tarhini et al., 2017). Additionally, the relationship between perceived enjoyment and other factors like self-efficacy and facilitating conditions can significantly impact the overall acceptance of educational technologies (Abdullah and Ward, 2016).

As educational technologies continue to evolve, understanding the nuanced role of perceived enjoyment becomes increasingly crucial. Future research should explore how perceived enjoyment interacts with other factors in emerging technologies, potentially leading to more comprehensive models of technology acceptance in educational settings (Scherer et al., 2019).

1.4 Challenges and opportunities in the adoption of GenAI

Generative Artificial Intelligence (GenAI) offers significant opportunities in education, although its adoption has several challenges, as its limited ability to assess the quality of responses, introducing biases that threaten the integrity of educational content (Farrokhnia et al., 2023). Also, the production of incorrect or fabricated responses affects their reliability (Baidoo-Anu and Ansah, 2023). Therefore, these issues require educators to adapt their methodologies to tackle these limitations (Barros et al., 2023).

Risks associated with privacy and ethical implications are another concern among students and teachers. The handling of sensitive data and automated profiling present ethical challenges that could affect trust and acceptance of these technologies in the educational setting (Chan and Hu, 2023).

Regarding academic integrity, the use of GenAI poses the risk of enabling plagiarism and diminishing the development of critical thinking (Michel-Villarreal et al., 2023). Although teachers acknowledge the benefits, their non-supervised and indiscriminate use will cultivate technological dependence, emphasizing the need of clear educational policies for their responsible use (Chan and Lee, 2023).

Rather than banning their use, various institutions suggest strengthening critical and ethical digital literacy to ensure appropriate and equitable use of technology (Chan and Lee, 2023; Saúde et al., 2024; Singh et al., 2024). This is relevant to avoid disparities in academic achievement, especially among students with less access to advanced technologies (Singh et al., 2024). The adoption of GenAI also requires that educational programs get aligned with technological trends like Industry 4.0 to develop critical digital skills necessary for an increasingly digitized labor market (Abulibdeh et al., 2024).

Perceived enjoyment acts as a catalyst in this process, enabling faster adoption of GenAI even among students with limited digital skills. A rapid adoption not only stimulates the development of professional skills, but also contributes to reduce the gap in learning outcomes. By integrating enjoyment as a key variable in pedagogical design, an effective redesign of teaching-learning strategies can be promoted, preparing students to face the challenges of the modern work environment.

Therefore, the integration of enjoyment as a central variable in pedagogical design is critical to preparing students for the challenges of the modern work environment. While addressing the risks and limitations of GenAI, a focus on perceived enjoyment may be key to successful and beneficial adoption in the educational setting.

1.5 Study hypotheses

The evidence presented suggests that there are operational relationships between perceived enjoyment, perceived usefulness, perceived ease of use, attitude toward use and intention to use. The hypotheses under consideration are illustrated in Figure 1.

> H1: Perceived Enjoyment (PE) has a direct and significant effect on Perceived Usefulness (PU) among the business students.

> H2: Perceived Enjoyment (PE) has a direct and significant effect on Perceived Ease of Use (PEU) among the business students.

> H3: Perceived Enjoyment (PE) has a direct and significant effect on Intention to Use (ITU) among the business students.

> H4: Perceived Ease of Use (PEU) has a direct and significant effect on Attitude Toward Use (ATU) among the business students.

> H5: Perceived Usefulness (PU) has a direct and significant effect on Attitude Toward Use (ATU) among the business students.

> H6: Attitude Toward Use (ATU) acts as a mediator between Perceived Ease of Use (PEU) and Perceived Usefulness (PU) and Intention to use (ITU) among the business students.

1.6 Study objective

Our study aims to explore the relationships between perceived enjoyment, perceived usefulness, perceived ease of use, attitude toward use and intention to use ChatGPT as a learning tool.

2 Materials and methods

2.1 Study design

This study utilizes a cross-sectional predictive analysis, where data were gathered at a specific point in time to measure key variables and explore potential correlations and trends. Participants were selected using convenience sampling (Etikan et al., 2016), a non-probabilistic sampling method. Given that this study was conducted as part of an educational intervention within an Innovation course, convenience sampling was deemed the most suitable methodological approach. The dependent variable used was intention to use, while the independent variables were perceived enjoyment, perceived ease of use, and perceived usefulness, following the model proposed by Teo and Noyes (2011). Accordingly, a structural equation modeling approach (PLS-SEM) was employed, where these variables represent constructs related to technology adoption.

The study was developed in 2023 within the framework of a course called "Business Innovation", where the use of Design Thinking was taught for 4 weeks, and ChatGPT was used as a support tool for the training of students. The work developed with Gen AI was carried out in groups, totaling 20 teams composed of 4 to 5 students per group.

The students were informed about the objectives of Challenge-Based Learning (CBL), focused on the Sustainable Development Goals (SDGs). The pedagogical process followed the five stages of Design Thinking: problem definition, insight discovery, ideation and solution generation, solution decision matrix, prototyping and testing, applying AI in each of these stages. After the end of the project, each student answered a survey, where the questions were based on the items raised by Teo and Noyes (2011).

2.2 Study participants

92 students from a Peruvian higher education college participated in the study: 39 were male (42%) and 53 were female (58%); their ages ranged from 18 to 52 years (mean = 29.18, *SD* = 6.54). The students were selected through non-probabilistic sampling. Ethical procedures were followed by the institution, then the participants were briefed on the study and informed of their rights of participation.

2.3 Data collection procedure

Data were obtained through an anonymous online survey using the Google Forms platform between July and September 2023. Participants completed the questionnaire during their free time, outside class hours. The institution followed the appropriate ethical procedures, and participants were informed about the study and their participation rights.

2.4 Pedagogical intervention and study context

The survey was administered to students from a higher education institution located in Lima, Peru. The students participated in the Business Innovation course, where an educational intervention was carried out using ChatGPT for the formulation of innovative business projects, framed in the 17 Sustainable Development Goals (SDGs), in groups of 4 to 5 students.

2.5 Instruments

A survey questionnaire was devised by comprising items that were adapted from a scale developed by Teo and Noyes (2011). This scale comprises 11 Likert-type items with five possible responses: 1 = extremely dissatisfied, 2 = generally dissatisfied, 3 = undecided, 4 = generally satisfied, and 5 = extremely satisfied. The instrument

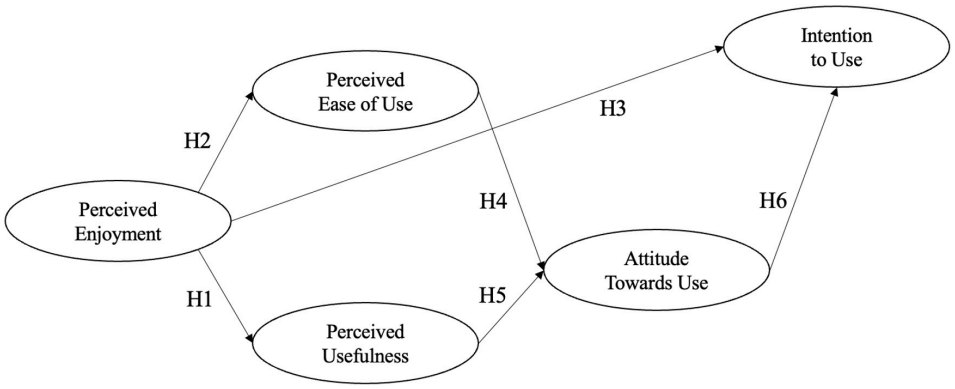

FIGURE 1
Theoretical model.

was translated into Spanish according to established guidelines for the translation and cross-cultural validation of instruments (Tsang et al., 2017). The scale showed good internal consistency in this study, ω = 0.92.

3 Results

3.1 Exploratory factor analysis

The psychometric properties of the latent constructs were evaluated using exploratory factor analysis (EFA) (Table 1). The results demonstrate satisfactory levels of reliability and validity for all latent variables, as evidenced by the Cronbach's α values exceeding 0.767 and composite reliability (CR) surpassing 0.732 (Hair et al., 2014). Furthermore, the convergent validity of the reflective models was assessed, revealing factor loadings greater than 0.700 and average variance extracted (AVE) values above 0.625, indicating an adequate fit (Hair et al., 2014). These findings support the suitability of the variables for subsequent analyses.

To test the proposed hypotheses, we used partial least squares structural equation modeling (PLS-SEM) as shown in Hair et al. (2014), Richter et al. (2016) and Shiau et al. (2019). PLS-SEM is a powerful approach that allows for the simultaneous modeling of the relationships between both measured variables (the measurement model) and latent variables (the structural model). This method was particularly appropriate for this study because it enables a comprehensive analysis of the intricate relationships between the variables of interest.

3.2 Structural model

To assess the structural model's relevance and predictive power, the multiple correlation coefficient ($R2 = 0.517$) and Stone-Geisser's predictive relevance test ($Q2 = 0.127$) were used and show good fit measures (Chin and Todd, 1995; Chin, 2009). Also, the standardized root mean square residual coefficient (SRMR = 0.052) has an appropriate adjustment level (Hu and Bentler, 1998). It is possible to confirm the significance of the model, since the measures of the model's fit show appropriate levels and predictive capacity ($R2 = 0.517$; $Q2 = 0.127$; SRMR = 0.052; Hair et al., 2017). Table 2 summarizes PLS-SEM results.

Our findings indicate that perceived enjoyment influences the perceived usefulness of Gen AI among the students, therefore H1 is supported. H2 is accepted as students' perceived enjoyment by using Gen AI on innovation has a direct effect on perceived ease of use. High levels of perceived enjoyment increase the intention to use Gen AI, supporting H3. Also, a higher level of perceived ease of use increases students' attitude to use, supporting H4. Regarding H5, students' perceived usefulness of Gen AI exhibits non-significant effects on attitude to use, hence H5 is rejected in the model. Students' attitude to use has positive effects on job satisfaction even though the direct effect is small. Therefore, results support H6. Table 3 summarizes the hypotheses testing results.

4 Discussion

This study was designed to explore the relationships between perceived enjoyment, perceived usefulness, perceived ease of use, attitude toward use, and intention to use ChatGPT as a learning tool among business students. Our findings elucidate the factors that influence the adoption of Gen AI in higher education.

Our results confirm that perceived enjoyment plays a crucial role in the adoption of technology (Yu et al., 2017; Song and Han, 2009), significantly affecting perceived usefulness, perceived ease of use, and the intention to use Gen AI among business students. This aligns with Teo and Noyes (2011), who highlighted the importance of perceived enjoyment in technology adoption. When students find the use of Gen AI tools enjoyable, they are more likely to perceive these tools as useful and easy to use, thereby enhancing their intention to adopt such technologies in their learning processes.

Interestingly, contrary to the traditional assumptions of the Technology Acceptance Model (TAM) as proposed by Davis et al. (1989), our study indicates that perceived usefulness does not significantly affect attitude toward use. This suggests that within the context of Gen AI adoption among business students, perceived usefulness may not be the primary driver of their attitudes toward its use (Lee et al., 2019). Instead, enjoyment and ease of use

TABLE 1 Exploratory factor analysis.

	α	Rho_A	CR	AVE	Factorial Loads
Perceived Enjoyment (PE)	0.865	0.872	0.881	0.877	> 0.700***
Perceived Usefulness (PU)	0.767	0.801	0.783	0.625	> 0.700***
Perceived Ease of Use (PEU)	0.887	0.892	0.911	0.728	> 0.700***
Attitude Toward Use (ATU)	0.901	0.909	0.914	0.781	> 0.700***
Intention to Use (ITU)	0.713	0.756	0.732	0.694	> 0.700***

Bootstrapping = 5,000. Significance level: $\rho < 0.10$; $\rho < 0.05$; ***$\rho < 0.01$.

experienced while interacting with Gen AI tools seem to play a more influential role. This finding prompts a reevaluation of the components of TAM, particularly in the educational technology context, and suggests that user enjoyment could be a more significant determinant of technology adoption than previously understood.

However, the use of Gen AI can have negative implications in terms of educational justice (Singh et al., 2024), particularly in environments where access to information technologies is limited. For example, in emerging countries like Peru, Internet access does not have the same speed in different regions, and there are cities where Internet coverage is limited. Therefore, it is possible to identify factors other than technology that can deepen knowledge gaps. Additionally, although most of the Gen IA tools offer free access, they also have premium (paid) versions with more advanced functionalities (number of queries, quality of responses, type of content generated, etc.), limiting this premium access to individuals or organizations that do not have the resources to pay for the access. It is therefore essential to study in subsequent studies whether the introduction of Gen IA could end up extending educational gaps.

The practical implications of our findings are two-fold. Educators should prioritize enhancing the perceived enjoyment of Gen AI tools to boost adoption rates. This can be achieved by integrating engaging and interactive elements into these technologies, such as gamification and interactive simulations, which can create a more enjoyable learning experience. Additionally, software and technology developers should focus on creating user-friendly interfaces and personalized learning experiences that meet individual preferences to further improve ease of use and enjoyment.

Our study has some limitations, where the cross-sectional design limits our ability to establish causality, and the sample from a single institution may affect the generalizability of the findings. Future research should employ longitudinal designs to understand the evolution of these relationships over time and include a more diverse demographic to enhance the external validity of the results. Moreover, exploring the moderating effects of individual differences and specific educational outcomes on the relationship between perceived usefulness and attitude toward use could provide deeper insights.

Despite these limitations, our study adds valuable insights to the TAM literature by challenging the conventional role of perceived usefulness and highlighting the importance of perceived enjoyment in the adoption of new technologies. Future studies should investigate the dimensionality of perceived enjoyment and its effects across different technologies, user populations, and cultural contexts to better understand its role in the broader framework of technology acceptance.

TABLE 2 PLS-SEM results.

	Path	f2	R2	Q2	SRMR
PE → PU	0.121***	0.109			
PE → PEU	0.872***	0.591			
PE → ITU	0.578***	0.273			
PEU → ATU	0.714***	0.543			
PU → ATU	−0.066***	0.000			
ATU → ITU	0.060***	0.021			
PEU			0.126	0.101	
PU			0.157	0.143	
ATU			0.045	0.039	
ITU			0.517	0.127	
Common Factor Model					0.052

Bootstrapping = 5,000. Significance level: $\rho < 0.10$; $\rho < 0.05$; ***$\rho < 0.01$.

TABLE 3 Hypothesis results.

Hypothesis	Description	Result
H1	Perceived enjoyment influences the perceived usefulness of Gen AI among students.	Supported
H2	Perceived enjoyment from using Gen AI in innovation has a direct effect on perceived ease of use.	Supported
H3	High levels of perceived enjoyment increase the intention to use Gen AI.	Supported
H4	A higher level of perceived ease of use increases students' attitude towards using Gen AI.	Supported
H5	Perceived usefulness of Gen AI has no significant effect on attitude towards use.	Rejected
H6	Students' attitude towards use has positive effects on job satisfaction, though the direct effect is small.	Supported

By highlighting the importance of perceived enjoyment, our study offers a novel perspective on Gen AI adoption among business students. As educators and developers work together to integrate Gen AI into higher education, prioritizing enjoyment and ease of use will be crucial for the future of teaching. This will not only foster widespread acceptance but also maximize the educational benefits of these innovative technologies.

In summary, our findings highlight that perceived enjoyment is a key factor in the adoption of Gen AI tools, while perceived usefulness does not directly influence the attitude towards their use. Ease of use, mediated by enjoyment, plays a fundamental role in adoption. This suggests that, for the successful integration of Gen AI in the classroom, educational experiences centered on enjoyment should be prioritized. The main findings are summarized below:

1. Perceived Enjoyment (PE) significantly influences students' intention to use Gen AI tools in Innovation.
2. Perceived Usefulness (PU) did not show a significant effect on the attitude towards using Gen AI, challenging traditional technology acceptance models.
3. Perceived Ease of Use (PEU), mediated by perceived enjoyment, positively influences students' attitude towards using these tools.
4. A pedagogical approach that prioritizes user experience and enjoyment may be key to promoting the effective adoption of Gen AI in educational settings and reducing gaps in academic performance.
5. The practical implications for educators and developers are to create intuitive, enjoyment-centered technological tools to maximize their adoption in teaching, ensuring an equitable and sustainable educational impact.

Data availability statement

The datasets presented in this article are not readily available because they are proprietary data. Requests to access the datasets should be directed to nnunezm@pucp.edu.pe.

Ethics statement

The studies involving humans were approved by the Direccion de Investigacion ISIL. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

JRC: Conceptualization, Investigation, Project administration, Resources, Visualization, Writing – original draft, Writing – review and editing. NN: Data curation, Formal analysis, Funding acquisition, Methodology, Resources, Software, Supervision, Validation, Writing – original draft, Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Abdullah, F., and Ward, R. (2016). Developing a general extended technology acceptance model for E-learning (GETAMEL) by analysing commonly used external factors. *Comput. Hum. Behav.* 56, 238–256.

Abulibdeh, A., Zaidan, E., and Abulibdeh, R. (2024). Navigating the confluence of artificial intelligence and education for sustainable development in the era of industry 4.0: Challenges, opportunities, and ethical dimensions. *J. Clean. Prod.* 437, 140527–140527.

Agathokleous, E., Saitanis, C. J., Fang, C., and Yu, Z. (2023). Use of ChatGPT: What does it mean for biology and environmental science? *Sci. Total Environ.* 888, 164154–164154. doi: 10.1016/j.scitotenv.2023.164154

Al-Adwan, A., Li, N., Al-Adwan, A., Abbasi, G., Albelbisi, N., and Habibi, A. (2023). "Extending the technology acceptance model (TAM) to predict university students' intentions to use metaverse-based learning platforms. *Educ. Inform. Technol.* 28, 15381–15413. doi: 10.1007/s10639-023-11816-3

Assink, M. (2006). Inhibitors of disruptive innovation capability: A conceptual model. *Eur. J. Innov. Manag.* 9, 215–233.

Baidoo-Anu, D., and Ansah, O. (2023). Education in the era of generative artificial intelligence (AI): Understanding the potential benefits of ChatGPT in promoting teaching and learning. *J. AI*, 7, 52–62.

Barros, A., Prasad, A., and Martyna, Ś. (2023). Generative artificial intelligence and academia: Implication for research, teaching and service. *Manag. Learn.* 54:1445. doi: 10.1080/15548627.2020.1797280

Børte, K., Nesje, K., and Lillejord, S. (2023). Barriers to student active learning in higher education. *Teach. High. Educ.* 28, 597–615.

Bouschery, S. G., Blazevic, V., and Piller, F. T. (2023). Augmenting human innovation teams with artificial intelligence: Exploring transformer-based language models. *J. Prod. Innov. Manag.* 40, 139–153.

Bozkurt, A. (2023). Generative artificial intelligence (AI) powered conversational educational agents: The inevitable paradigm shift. *Asian J. Distance Educ.* 18, 198–204.

Chan, C. K. Y., and Hu, W. (2023). Students' voices on generative AI: Perceptions, benefits, and challenges in higher education. *Int. J. Educ. Technol. High. Educ.* 20:43.

Chan, C. K. Y., and Lee, K. K. W. (2023). The AI generation gap: Are Gen Z students more interested in adopting generative AI such as ChatGPT in teaching and learning than their Gen X and millennial generation teachers? *Smart Learn. Environ.* 10:60.

Chin, W. W. (2009). "Bootstrap cross-validation indices for PLS path model assessment," in *Handbook of partial least squares: Concepts, methods and applications*. Berlin: Springer Berlin Heidelberg, 83–97.

Chin, W. W., and Todd, P. A. (1995). On the use, usefulness, and ease of use of structural equation modeling in MIS research: A note of caution. *MIS Q.* 19, 237–246.

Cotton, D. R. E., Cotton, P. A., and Shipway, J. R. (2023). Chatting and cheating: Ensuring academic integrity in the era of ChatGPT. *Innov. Educ. Teach. Int.* 61, 228–239.

Davis, F. D. (1987). *User acceptance of information systems: The technology acceptance model (TAM)*. Available online at: https://umich.edu/

Davis, F. D., Bagozzi, R. P., and Warshaw, P. R. (1989). Technology acceptance model. *J. Manag. Sci.* 35, 982–1003.

Davis, F. D., Bagozzi, R. P., and Warshaw, P. R. (1992). Extrinsic and intrinsic motivation to use computers in the workplace1. *J. Appl. Soc. Psychol.* 22, 1111–1132.

Deng, J., and Lin, Y. (2023). The benefits and challenges of ChatGPT: An overview. *Front. Comput. Intell. Syst.* 2:81–83. doi: 10.54097/fcis.v2i2.4465

Etikan, I., Musa, S. A., and Alkassim, R. S. (2016). Comparison of convenience sampling and purposive sampling. *Am. J. Theoretical Appl. Stat.* 5, 1–4.

Farrokhnia, M., Banihashem, S. K., Noroozi, O., and Wals, A. (2023). A SWOT analysis of ChatGPT: Implications for educational practice and research. *Innov. Educ. Teach. Int.* 61, 460–474.

Fülöp, M., Breaz, T., He, X., Ionescu, C., Cordoș, G., and Stanescu, S. (2022). The role of universities' sustainability, teachers' wellbeing, and attitudes toward e-learning during COVID-19. *Front. Public Health* 10:981593. doi: 10.3389/fpubh.2022.981593

Ghobadi, M., Shirowzhan, S., Ghiai, M. M., Mohammad Ebrahimzadeh, F., and Tahmasebinia, F. (2022). Augmented reality applications in education and examining key factors affecting the users' behaviors. *Educ. Sci.* 13:10.

Gilson, A., Safranek, C. W., Huang, T., Socrates, V., Chi, L., Taylor, A., et al. (2023). How does ChatGPT perform on the United States medical licensing examination? The implications of large language models for medical education and knowledge assessment. *JMIR Med. Educ.* 9:e45312.

Hair, J. F., Babin, B. J., and Krey, N. (2017). Covariance-based structural equation modeling in the journal of advertising: Review and recommendations. *J. Adv.* 46:454.

Hair, J. F., Sarstedt, M., Ringle, C. M., Smith, D., and Reams, R. (2014). Partial least squares structural equation modeling (PLS-SEM): A useful tool for family business researchers. *J. Fam. Bus. Strategy* 5, 105–115. doi: 10.1016/j.jfbs.2014.01.002

Hamal, O., El Faddouli, N.-E., Harouni, M. H. A., and Lu, J. (2022). Artificial Intelligent in Education. *Sustainability* 14:2862.

Hu, L. T., and Bentler, P. M. (1998). Fit indices in covariance structure modeling: Sensitivity to underparameterized model misspecification. *Psychol. Methods* 3:424.

Kasneci, E., Seßler, K., Küchemann, S., Bannert, M., Dementieva, D., Fischer, F., et al. (2023). ChatGPT for good? On opportunities and challenges of large language models for education. *Learn. Individ. Differ.* 103:102274. doi: 10.1097/ACM.0000000000005636

Kiryakova, G., and Angelova, N. (2023). ChatGPT–A challenging tool for the university professors in their teaching practice. *Educ. Sci.* 13, 1056–1056.

Lai, P. C. (2017). The literature review of technology adoption models and theories for the novelty technology. *J. Inform. Syst. Technol. Manag.* 14, 21–38.

Lawson, B., and Samson, D. (2001). DEVELOPING INNOVATION CAPABILITY IN ORGANISATIONS: A DYNAMIC CAPABILITIES APPROACH. *Int. J. Innov. Manag.* 05, 377–400.

Lee, H.-G., Chung, S., and Lee, W.-H. (2013). Presence in virtual golf simulators: The effects of presence on perceived enjoyment, perceived value, and behavioral intention. *New Media Soc.* 15, 930–946.

Lee, J., Kim, J., and Choi, J. Y. (2019). The adoption of virtual reality devices: The technology acceptance model integrating enjoyment, social interaction, and strength of the social ties. *Telemat. Inform.* 39, 37–48.

Lewis, C. C., Fretwell, C. E., Ryan, J., and Parham, J. B. (2024). Faculty use of established and emerging technologies in higher education: A unified theory of acceptance and use of technology perspective. *Int. J. High. Educ.* 2, 22–34.

Michel-Villarreal, R., Vilalta-Perdomo, E., Salinas-Navarro, D., Thierry-Aguilera, R., and Gerardou, F. (2023). Challenges and opportunities of generative ai for higher education as explained by ChatGPT. *Educ. Sci.* 13:856.

Mubuke, F., Ogenmungu, C., Masaba, A. K., and Andrew, W. (2017). The predictability of perceived enjoyment and its impact on the intention to use mobile learning systems. *Asian J. Comput. Sci. Inform. Technol.* 7, 1–5.

Ortíz, J., and Fumás, V. (2020). Technological innovation and the demand for labor by firms in expansion and recession. *Econ. Innov. New Technol.* 29, 417–440.

Popenici, S. A. D., and Kerr, S. (2017). Exploring the impact of artificial intelligence on teaching and learning in higher education. *RPTEL* 12:22.

Prentzas, J. (2013). "Artificial intelligence methods in early childhood education," in *Artificial intelligence, evolutionary computing and metaheuristics. studies in computational intelligence*, Vol. 427, ed. X. S. Yang (Berlin: Springer).

Prince, M. J., and Felder, R. M. (2006). Inductive teaching and learning methods: Definitions, comparisons, and research bases. *J. Eng. Educ.* 95, 123–138.

Rahman, M. S., Sabbir, M. M., Zhang, D. J., Moral, I. H., and Hossain, G. M. S. (2023). Examining students' intention to use ChatGPT: Does trust matter? *Australas. J. Educ. Technol.* 39, 51–71. doi: 10.14742/ajet.8956

Richter, N. F., Cepeda-Carrión, G., Roldán Salgueiro, J. L., and Ringle, C. M. (2016). European management research using partial least squares structural equation modeling (PLS-SEM). *Eur. Manag. J.* 34, 589–597.

Rogers, E. M. (1962). *Diffusion of innovations*. New York, NY: The Free Press of Glencoe.

Rogers, E. M., Singhal, A., and Quinlan, M. M. (2014). *Diffusion of innovations: An integrated approach to communication theory and research*. Milton Park: Routledge, 432–448.

Sánchez-Prieto, J. C., Olmos-Migueláñez, S., and García-Peñalvo, F. J. (2017). MLearning and pre-service teachers: An assessment of the behavioral intention using an expanded TAM model. *Comput. Hum. Behav.* 72, 644–654.

Saúde, S., Barros, J., and Almeida, I. (2024). Impacts of generative artificial intelligence in higher education: Research trends and students' perceptions. *Soc. Sci.* 13:410.

Saunila, M., and Ukko, J. (2012). A conceptual framework for the measurement of innovation capability and its effects. *Baltic J. Manag.* 7, 355–375.

Scherer, R., Siddiq, F., and Tondeur, J. (2019). The technology acceptance model (TAM): A meta-analytic structural equation modeling approach to explaining teachers' adoption of digital technology in education. *Comput. Educ.* 128, 13–35.

Shiau, W. L., Sarstedt, M., and Hair, J. F. (2019). Internet research using partial least squares structural equation modeling (PLS-SEM). *Internet Res.* 29, 398–406.

Singh, E., Vasishta, P., and Singla, A. (2024). AI-enhanced education: Exploring the impact of AI literacy on generation Z's academic performance in Northern India. *Q. Assur. Educ.* [Epub ahead of print].

Song, Y., and Han, J. (2009). "Is enjoyment important? An empirical research on the impact of perceive enjoyment on adoption of new technology," in *Proceedings of the 2009 international conference on information management, innovation management and industrial engineering*, Vol. 4, (Xi'an: IEEE), 511–514.

Strzelecki, A. (2023). Students' acceptance of ChatGPT in higher education: An extended unified theory of acceptance and use of technology. *Innov. High. Educ.* 49, 223–245.

Succi, C., and Canovi, M. (2019). Soft skills to enhance graduate employability: Comparing students and employers' perceptions. *Stud. High. Educ.* 45, 1834–1847.

Taecharungroj, V. (2023). What can ChatGPT Do?" Analyzing early reactions to the innovative AI chatbot on twitter. *Big Data Cogn. Comput.* 7:35.

Tao, D., Fu, P., Wang, Y., Zhang, T., and Qu, X. (2019). Key characteristics in designing massive open online courses (MOOCs) for user acceptance: An application of the extended technology acceptance model. *Interact. Learn. Environ.* 30, 882–895.

Tarhini, A., Hone, K., Liu, X., and Tarhini, T. (2017). Examining the moderating effect of individual-level cultural values on users' acceptance of E-learning in developing countries: A structural equation modeling of an extended technology acceptance model. *Interact. Learn. Environ.* 25, 306–328.

Teo, T. (2011). Factors influencing teachers' intention to use technology: Model development and test. *Comput. Educ. Comput. Educ.* 57, 2432–2440.

Teo, T., and Noyes, J. (2011). An assessment of the influence of perceived enjoyment and attitude on the intention to use technology among pre-service teachers: A structural equation modeling approach. *Comput. Educ.* 57, 1645–1653.

Teo, T., Sang, G., Mei, B., and Hoi, C. K. W. (2018). Investigating pre-service teachers' acceptance of Web 2.0 technologies in their future teaching: A Chinese perspective. *Interact. Learn. Environ.* 27, 530–546.

Tsang, S., Royse, C. F., and Terkawi, A. S. (2017). Guidelines for developing, translating, and validating a questionnaire in perioperative and pain medicine. *Saudi J. Anaesthes.* 11(Suppl. 1), S80–9.

Tura, T., Vesa Harmaakorpi, and Sanna Pekkola. (2008). Breaking inside the black box: Towards a dynamic evaluation framework for regional innovative capability. *Sci. Public Policy Sci. Public Policy* 35, 733–744.

Venkatesh, V., Thong, J. Y., and Xu, X. (2012). Consumer acceptance and use of information technology: Extending the unified theory of acceptance and use of technology. *MIS Q.* 36, 157–178.

Winarno, W. A., Mas'ud, I., and Palupi, T. W. (2021). Perceived enjoyment, application self-efficacy, and subjective norms as determinants of behavior intention in Using OVO applications. *J. Asian Finance Econ. Bus.* 8, 1189–1200.

Won, D., Chiu, W., and Byun, H. (2023). Factors influencing consumer use of a sport-branded app: The technology acceptance model integrating app quality and perceived enjoyment. *Asia Pac. J. Market. Logist.* 35, 1112–1133.

Xu, X., and Thien, L. M. (2024). Unleashing the power of perceived enjoyment: Exploring Chinese undergraduate EFL learners' intention to use ChatGPT for English learning. *J. Appl. Res. High. Educ.* [Epub ahead of print].

Yu, J., Lee, H., Ha, I., and Zo, H. (2017). User acceptance of media tablets: An empirical examination of perceived value. *Telemat. Inform.* 34, 206–223.

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The effect of augmented reality storybooks on the story comprehension and retelling of preschool children

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This study aimed to compare the retelling and story comprehension performance of two groups of preschool children—an experimental and a control group—who experienced printed and augmented reality storybooks. The participant group consisted of 90 participants, with 45 in the experimental group (22 girls, 23 boys) and 45 in the control group (21 girls, 24 boys). The average age of the children was 54.2 months. In the study, the researcher evaluated children's story-retelling performance using the rubric and used a Story Comprehension Test to measure their story comprehension performance. The researchers utilized the ROAR application to incorporate augmented reality content into the books. In the pre-test phase, the teachers read the designated texts to the children in the experimental and control groups. After the eight-week break, the control group experienced the same texts with printed books, while the experimental group experienced them with augmented reality support. Each child participated individually in the reading process with the teacher. In the study, teachers asked the children to retell the story and asked the questions from the Story Comprehension Test at the end of each book reading section for pre-test and post-test measurements. The pre-test results revealed no significant difference in the two groups' story-retelling and Story Comprehension Test scores. The post-test results indicated a significant difference in the story-retelling performance and Story Comprehension Test scores between the experimental and control groups, favoring the experimental group. Based on these findings, the augmented reality content can potentially enhance children's retelling and story comprehension performances.

KEYWORDS

augmented reality, story-retelling, story comprehension, preschool children, retelling

1 Introduction

The preschool period is a critical phase during which the foundations of children's cognitive, emotional, social, and language development are established. The educational materials and activities provided to children during this period significantly influenced their future learning and life skills. Among these materials, picture storybooks hold a special place. Reading picture storybooks can contribute to children's acquisition of knowledge, learning to communicate, forming their cultural identities, enhancing their imagination, and fulfilling their desire for discovery (Carrión Candel et al., 2020; Takacs and Bus, 2018; Yamaji et al., 2020). Additionally, it is known that picture storybooks are beneficial for developing children's current literacy skills (Fears and Lockman, 2020; Hu and Commeyras, 2008; Wang, 2022) and language skills (Grolig et al., 2019). Story reading provides a meaningful context for children

to acquire skills such as listening comprehension, retelling, following plot structures, and inferential thinking (Collins, 2016; Florit et al., 2011; Morrow, 1985; Strasser and Río, 2014). By contributing to language development, reading stories enables children to learn new words and grasp story elements (Breit-Smith et al., 2017; Han and Neuharth-Pritchett, 2015). Furthermore, it has been determined that reading storybooks contributes to language skills and academic achievement from the preschool period to university (Mol and Bus, 2011). Therefore, it is worth considering how children's interaction with picture storybooks can be supported.

With technological advancements, storybooks have started to be presented in different formats. As technology-enhanced books become prevalent, they have gained increased attention from researchers. Indeed, numerous studies have been conducted on topics such as electronic books (Lauricella et al., 2014), interactive books (Lim et al., 2021; Zipke, 2017), and multimedia book applications (Zhou and Yadav, 2017; Tsou et al., 2006). These books, used today, have also transformed children's early literacy experiences compared to previous generations. Children nowadays have the opportunity to experience both printed and digital books (Kucirkova, 2016). Each type of book has its distinctive features. Printed storybooks typically consist of static illustrations alongside the text, whereas digital storybooks offer multimedia features that enhance the story's content and allow children to listen to the narrative (Merjovaara et al., 2020; O'Byrne et al., 2018). Augmented reality technology, which has become increasingly prevalent in recent years, combines printed and digital books' features, enabling innovative storybooks to be created (Danaei et al., 2020; Şimşek and Direkci, 2023).

According to Azuma (1997), augmented reality is the innovative integration of real-world and virtual elements, enabling seamless interaction between the two realms. This technology presents a format where natural environment images are used as a background, and digital content (such as animation, 3D content, etc.) is overlaid on top, enabling user interaction (Billinghurst et al., 2001). In this regard, it bridges the real and virtual worlds through computer screens or mobile applications. The relevant literature has listed numerous benefits of augmented reality applications. These studies have shown that augmented reality applications reduce cognitive load (Alvarez-Marin and Velazquez-Iturbide, 2021; Cheng, 2015; Keller et al., 2021; Ibili and Billinghurst, 2019; Wilson, 2015; Wen, 2021), facilitates comprehension of abstract concepts (Yoon et al., 2017), enhance learning performance (Chang et al., 2015; Chen, 2019; Chin et al., 2021; Ferrer-Torregrosa et al., 2015), increase learning motivation (Amores-Valencia et al., 2022; Chiang et al., 2014; Di Serio et al., 2013; Ferrer-Torregrosa et al., 2015; Khan et al., 2019), and support academic achievement (Barreira et al., 2012; Duenser, 2008; Ibáñez et al., 2020; Ömurtak and Zeybek, 2022). Furthermore, augmented reality applications are enjoyable (Wojciechowski and Cellary, 2013) and engaging (Delello, 2014; Fidan and Tuncel, 2019; Perez-Lopez and Contero, 2013; Tomi and Rambli, 2013), as well as contributing to the development of positive attitudes toward the subject among students (Şahin and Yılmaz, 2020; Akçayır et al., 2016).

One of the applications of augmented reality technology is in storybooks. Augmented reality is often used in storybooks to enhance immersion through animations and virtual pop-ups (Kljun et al., 2019). Augmented reality storybooks incorporate characters and objects in 2D or 3D animations, accompanied by diverse technical effects such as videos, sounds, and interactive functions like touch, zoom, and rotate (Alhumaidan et al., 2018). This gives readers a reading experience that dynamically interacts with virtual content in a real-world setting (Cheng and Tsai, 2014; Green et al., 2019). According to Santos et al. (2016), when children engage with augmented reality storybooks, they can visualize information within a context-rich environment. This immersive experience enables them to forge genuine connections between educational content and the real world. Previous research has reported a range of advantages of augmented reality storybooks, including their ability to be engaging (Soon et al., 2022), enhance attention (Aydoğdu, 2022), contribute to learning (Duenser et al., 2012), improve empathy skills (Gil et al., 2014), enable interactive storytelling (Zhou et al., 2004), increase reading motivation (Roumba and Nicolaidou, 2022), and foster reading habits (Anuardi et al., 2022). One of the benefits mentioned in the literature is that the multisensory stimuli provided by augmented reality contribute to understanding the story (Ertem, 2009; Kao et al., 2016; Pan et al., 2021).

When reviewing the relevant literature, studies have been conducted on the effects of augmented reality storybooks on comprehension at different educational levels. Duenser (2008) has found through these studies that augmented reality storybooks offer a favorable learning environment that effectively supports readers with lower abilities. Moreover, in many studies, it has been found that students who read augmented reality storybooks have higher comprehension performance compared to groups reading printed books (Çetinkaya Özdemir and Akyol, 2021; Ebadi and Ashrafabadi, 2022; Şimşek and Direkci, 2023). Additionally, students who experienced augmented reality storybooks demonstrated better performance in retelling (Danaei et al., 2020), answering inferential questions (Liu et al., 2024), and learning retention (Bursalı and Yılmaz, 2019). However, Şimşek and Direkci's (2023) study found no significant difference in basic comprehension levels between augmented reality intervention and traditional reading. Similarly, Tobar-Munoz et al. (2017) did not detect a significant difference in total scores between groups in their study. Overall, when examining the studies in the relevant literature, it can be said that augmented reality storybooks have the potential to support comprehension.

In the conducted studies, comprehension processes have generally been evaluated through tests (Bursalı and Yılmaz, 2019; Çetinkaya Özdemir and Akyol, 2021; Ebadi and Ashrafabadi, 2022; Şimşek and Direkci, 2023; Tobar-Munoz et al., 2017) and retelling (Çetin and Ulusoy, 2023). Limited studies combine retelling and testing (Danaei et al., 2020; Liu et al., 2024). Therefore, this study used both assessment methods to yield more in-depth results. Furthermore, when examining studies conducted on augmented reality and language instruction in the literature, it can be observed that there is a scarcity of augmented reality studies with preschool children (Cai et al., 2022; Parmaxi and Demetriou, 2020). There is evidence of a connection between preschool children's listening comprehension skills and elementary school children's reading comprehension skills (Kendeou et al., 2007; Kendeou et al., 2009). Indeed, several studies have found that understanding narratives in preschool years predicts later reading comprehension (Kim, 2016; Language and Reading Research Consortium and Chiu, 2018). Therefore, the impact of augmented reality storybooks, which have clear findings supporting reading comprehension in elementary and later grades, on preschool children is an essential research topic.

1.1 Current study

This study examined and compared the retelling and story comprehension performance of preschool children who engage with printed and augmented reality storybooks. The following research questions were addressed in the study:

RQ1: What was the difference in retelling performance between children participating in the traditional storybook narration activity and those participating in the augmented reality storybook narration activity?

RQ2: What was the difference in story comprehension performance between children participating in the traditional storybook narration activity and those participating in the augmented reality storybook narration activity?

2 Methodology

2.1 Participants

This study was conducted in preschools located in Antalya, Türkiye. The participant group consisted of 90 participants, with 45 in the experimental group (22 girls, 23 boys) and 45 in the control group (21 girls, 24 boys). The average age of the children was 54.2 months. The children were randomly assigned to either the experimental group, where they experienced augmented reality storybooks under the teacher's guidance, or the control group, where the teacher individually read to each participant. The participants were enrolled in four classrooms, and the teachers were included in the research process to facilitate the children's comfortable expression. This choice was made to ensure that the children could express themselves freely. Moreover, preliminary interviews indicated that teachers and children were accustomed to using technological applications in the classroom.

2.2 The augmented reality storybook and application

This research aimed to provide children with an engaging reading experience by transforming three selected picture books into an augmented reality-supported storybook format. In line with this objective, the opinions of the teachers in the classrooms where the application was implemented were obtained to determine the suitability of the books titled "Aç Tırtıl (The Very Hungry Caterpillar)," "Kafası Karışık Bukalemun (The Mixed-Up Chameleon)" and "Huysuz Uğurböceği (The Grouchy Ladybug)" for children and the research. After identifying the books, a digital content scan was conducted to convert the books into an augmented reality-supported storybook format. Various video contents were identified, and necessary permissions were obtained to adjust the videos. The augmented reality content to be integrated into the reading text should contribute to understanding and consistency with the text. Thus, both the texts and visuals had been prepared in a manner consistent with the narrative flow. Consequently, each page in the printed book aligned with the pages of the augmented reality storybook. The differences were achieved by adding animations and voiceovers on certain pages. To highlight these pages, a small tablet icon had been placed on them. As a result, when teachers read the book with children, the children also heard the same sentences that were voiced using the augmented reality content. In this study, the ROAR application had been selected as the augmented reality tool. The ROAR application allows for content creation via the website "https://theroar.io/." Through this website, the visuals in the book had been matched with the digital content developed by the researcher. The ROAR application was chosen due to its utility for integrating digital content into printed text and its ability to facilitate the process for teachers during implementation. After the content matching was completed, the associated digital content was triggered when the ROAR application was opened on a tablet and pointed at the visual in the printed book. Consequently, the augmented reality content was activated solely on the designated visual. Data Collection Tools.

In the study, the researcher evaluated children's story-retelling performance using the rubric suggested by Cruz de Quiros et al. (2012). This rubric included indicators such as "Setting When and Where, Characters, Event/Plot, Problem, and Solution." Each indicator was assessed on a scale of 3 points, resulting in a score range of 0–15 for each story. This rubric was selected to evaluate children's storytelling performance more systematically in this study. In addition to assessing children's retelling performance, a Story Comprehension Test was used to measure their story comprehension performance. This test consists of nine open-ended questions prepared based on the three picture books. The researcher developed the questions. A draft scoring rubric was prepared to ensure a reliable evaluation of the open-ended questions. The draft rubric scoring key was presented for evaluation by the four teachers participating in the study. As a result of the assessment, the questions prepared by the researcher, specifically the 3rd question ("What happened after the caterpillar became enormous?") and the 4th question ("What would happen when the chameleon got cold?"), were revised as follows. Thus, a consensus was reached, and the final version of the rubric scoring key was established. According to the final scoring rubric, incorrect answers in the open-ended questions were evaluated as 0 points, partially correct answers as 1 point, and correct answers as 2 points. Additionally, two teachers participated in the evaluation process alongside the researcher, and the agreement between the results was assessed. Here are some sample questions from the Story Comprehension Test:

1. *Name four fruits that the caterpillar ate.*
2. *How did the caterpillar's stomachache go away?*
3. *What happened after the caterpillar became enormous and fat?*
4. *What would happen when the chameleon got cold and hungry?*
5. *What would the chameleon do when it was hungry?*
6. *Name four animals that the chameleon wanted to resemble.*
7. *Name four animals that the grumpy ladybug encountered.*
8. *What did the wet, hungry, and tiredladybug eat for dinner? Who did it eat with?*
9. *What were the fireflies doing when the ladybugs fell asleep?*

2.3 Procedures

This study is a pre-test, post-test, and control group design conducted as a quasi-experimental study. Before the implementation, ethical approval was obtained from the Ethics Committee of Akdeniz University, and permission to conduct the study was obtained from the Antalya Provincial Directorate of National Education.

Subsequently, meetings were held with the teachers working in the implementation schools to provide information about the study. The implementation phase began once the teachers fully understood the principles of the augmented reality storybook. The researcher presented in the classroom to provide technical support and oversee the implementation process. In the initial phase of the study, teachers read three printed texts to children in both the experimental and control groups. After each book was read, the children were asked to retell the story. Subsequently, questions from the Story Comprehension Test were posed to the children. The teacher recorded the children's storytelling performances and their responses to the comprehension test during both the pre-test and post-test. These processes were conducted in the classroom environment where the books were read. The pre-test phase was concluded after the children answered the questions, and the teacher recorded responses. An eight-week break was provided with the assumption that the content of the books could be remembered. During this period, the teachers did not intervene in the classrooms regarding this research. However, 1 week before the post-test phase with the experimental group, the teachers read the "Minik Tohum (The Tiny Seed)" book, which was not included in the assessment process, together with the children as an augmented reality-enriched reading experience. This practice was conducted to familiarize the children with augmented reality storybooks and make them feel more comfortable during the reading process in the post-test application. Tablet computers were used during the implementation process, and the researcher brought these devices to the classroom with the necessary applications installed. After an 8-week interval, the teacher read the same printed books to the control group. Meanwhile, the experimental group experienced the augmented reality storybooks. During this process, the teacher read the printed book to the children and used the tablet on the visuals that required activation of the augmented reality content. The augmented reality application activated an animation on the visual, which was accompanied by a narration of the story. As a result, the teacher remained more passive in situations where the augmented reality application was used. Visuals related to this application are presented in Figure 1. Each child participated individually in the reading process with the teacher. After the reading process, each child retold the story and answered the questions from the Story Comprehension Test. The children were informed that there were no right or wrong answers to the questions and that it was not an exam to encourage them to think freely. After collecting the post-test data, the analysis phase was initiated.

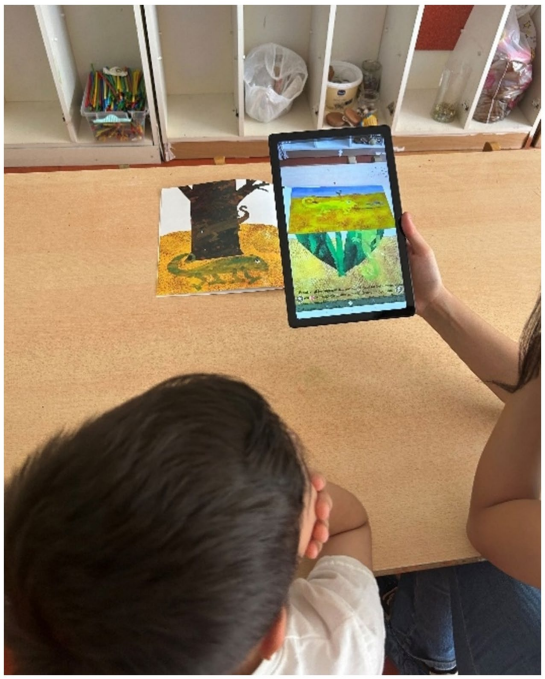

FIGURE 1
Augmented reality storybook application view.

2.4 Data analysis

Normality tests were initially performed to determine the analysis to be conducted in the study. Due to the normal distribution of the data, an independent samples *t*-test was used to examine possible differences between the experimental and control groups in the analysis of pre-test results. Similarly, a paired samples *t*-test was conducted to determine within-group differences in the analysis of post-test results, considering the normal distribution of the data. Furthermore, independent samples *t*-tests were utilized to examine potential variances between the experimental and control groups. Cohen's *d* was employed to determine the effect size when a statistically significant difference was found. Kendall's W Concordance coefficient was calculated to evaluate the agreement between the two teachers and the researcher involved in the Story Comprehension Test evaluation process. The results indicated a concordance coefficient of 0.964 for the pre-test and 0.973 for the post-test.

3 Results

The study's data analysis commenced with a normality test. It was determined that the retelling and Story Comprehension Test scores for both the experimental and control groups followed a normal distribution. Subsequently, the analysis of the data obtained from the pre-tests revealed no significant difference in the retelling and Story Comprehension Test scores between the children in the two groups within a 95% confidence interval. The means, standard deviations, and results of the independent samples *t*-test for the pre-test processes are presented in Table 1.

Upon reviewing Table 1, it is evident that there was no notable difference in the story-retelling performance in the experimental and control groups ($t = 1.340$, $p > 0.05$). Similar results were obtained for the Story Comprehension Test scores between the groups ($t = 1.392$, $p > 0.05$). Therefore, it can be concluded that there is no significant difference in the comprehension and retelling performance of the children who participated in the study without any intervention. No intervention was conducted for the control group during the post-test phase of the study. However, it was found that the retelling score of the control group increased from 22.115 to 23.622. Nevertheless, no significant distinction was observed between the pre-test and post-test scores of the control group ($t = -1.843$, $p > 0.05$). Similarly, the Story Comprehension Test scores of the control group increased from 11.177 to 11.888. However, there was no significant difference between the

TABLE 1 Mean, standard deviation and results of the independent samples *t*-test for the pre-test.

	Group	*N*	Mean	SD	*t*	*p*
Retelling	Experimental group	45	23.533	5.020	1.340	0.184
	Control group	45	22.155	4.728		
Story comprehension test	Experimental group	45	11.755	2.101	1.392	0.167
	Control group	45	11.177	1.825		

TABLE 2 Mean, standard deviation and results of the independent samples *t*-test for the post-test.

	Group	*N*	Mean	SD	*t*	Cohen *d*
Retelling	Experimental group	45	28.822	3.978	5.701*	1.202
	Control group	45	23.622	4.648		
Story comprehension test	Experimental group	45	14.555	2.388	6.075*	1.281
	Control group	45	11.888	1.721		

*$p < 0.05$.

scores ($t = -1.907$, $p > 0.05$). In contrast, significant differences were discovered in the pre-test and post-test scores of the experimental group, indicating notable variations in retelling performance ($t = -13.984$, $p < 0.05$) and Story Comprehension Test ($t = -10.715$, $p < 0.05$). Furthermore, the disparity between the post-test scores of the experimental and control groups was assessed. The means, standard deviations, and results of the independent samples *t*-test for the post-test are presented in Table 2.

Based on the findings in Table 2, a significant difference was evident between the retelling performance of the story in the experimental and control groups ($t = 5.701$, $p < 0.05$). Similar results were found for the Story Comprehension Test scores indicating a significant difference between the two groups ($t = 6.075$, $p < 0.05$). The findings demonstrated that the augmented reality intervention better supported the understanding of the story compared to traditional narration. Additionally, the retelling performance of the children also improved with the augmented reality intervention. The effect size analyses indicated a substantial effect size for both the retelling and Story Comprehension Test scores, highlighting the substantial difference between the two groups (Cohen, 1988).

Given the information provided, the research questions can be addressed and answered in the following manner:

RQ1: The retelling performance of children who participated in the augmented reality storybook narration activity is better than that of children who participated in the traditional story narration activity.

RQ2: The story comprehension performance of children who participated in the augmented reality storybook narration activity is better than that of children who participated in the traditional story narration activity.

4 Discussion

This study delved into the differences in comprehension levels between the control group, which was exposed to printed books with traditional storytelling, and the experimental group, which engaged in augmented reality storybook narration. The children were tasked with retelling the stories they heard and answering the questions in the Story Comprehension Test to gauge this difference. In the pre-test phase, there was no discernible difference between the two groups regarding retelling and Story Comprehension Test scores. However, the final test results unveiled a compelling revelation-augmented reality storybook narration that significantly bolstered comprehension and retelling, surpassing the effectiveness of traditional storytelling using printed books.

According to the research findings, children who participated in augmented reality storybook narration performed better in retelling the story than in traditional storytelling activities. Augmented reality studies conducted with preschool children demonstrate that this technology is well-liked by children (Rambli et al., 2013), provides an enjoyable learning environment for children (Albayrak and Yılmaz, 2022), enhances children's motivation (Aydoğdu, 2022), and captures children's interest (Bülbül and Özdinç, 2022). Therefore, augmented reality storybooks may have also captured children's interest and contributed to their comprehension. It can be argued that this situation supports children's performance in retelling the story. Another factor that may support children's performance is the multimedia features within the augmented reality storybooks. Elements such as the tone of voice of narrators that can convey emotions and moods, music, and sound effects may capture the readers' attention and immerse them in the story, potentially enhancing their imagination as if they were the narrative's main characters. Additionally, animations can better depict characters' facial expressions and gestures than static images (Danaei et al., 2020). These features provide augmented reality with a rich and vibrant reading experience (ChanLin, 2018). Furthermore, augmented reality support enhances students' learning experiences by providing interactivity and visual representation (Bujak et al., 2013; Teng et al., 2018). Consequently, with their existing features, augmented reality storybooks can support children's storytelling performance. Indeed, previous studies in the literature also support these results. In their study, Liu et al. (2024) compared comprehension levels between two groups. One group read an augmented reality storybook, while the other read a printed picture book. The results showed that participants were particularly successful in the narrative structures related to the setting and plot during the retelling process.

Furthermore, using augmented reality, storybooks helped participants better understand the characters and their emotional

changes (Liu et al., 2024). In contrast to this study, Danaei et al. (2020) found no difference in the setting between groups in their research. However, when looking at the total scores, it was determined that augmented reality storybooks improved retelling performance (Danaei et al., 2020). Another research conducted by Çetin and Ulusoy (2023) with third-grade students also supports these results. Upon reviewing the literature, it can be observed that the participants in the relevant studies were elementary and post-elementary school students. Therefore, the results regarding how augmented reality storybooks affect the retelling performance of preschool children are essential for the relevant literature.

According to the research results, children who participated in augmented reality storybook narration activities exhibited better performance in story comprehension than in traditional storytelling activities. According to the study by Takacs and Bus (2016), children exposed to an animated book understand the story better than those who view static images. In this regard, the ability of augmented reality to integrate verbal and non-verbal information and provide dynamic interaction may assist children in comprehending the text (Alsowat, 2016; Dunleavy et al., 2009). Additionally, augmented reality storybooks can offer children a sense of presence and an immersive environment through audiovisual content (Ebadi and Ashrafabadi, 2022). Consequently, it can be concluded that augmented reality storybooks support children's story comprehension performance. Studies in the literature indicate that augmented reality storybooks enhance users' comprehension performance. Yılmaz et al. (2017) determined that children who interacted with these books displayed strong story comprehension in their study with five- and six-year-olds. The majority of other studies conducted on this topic involve students in elementary and higher grades, and these studies also provide evidence that augmented reality storybooks support comprehension (Bursalı and Yılmaz, 2019; Çetinkaya Özdemir and Akyol, 2021; Ebadi and Ashrafabadi, 2022). Some of these studies show that augmented reality interventions do not create a significant difference compared to printed books in simple comprehension-based questions (Danaei et al., 2020; Şimşek and Direkci, 2023). However, users perform better in answering implicit questions (Danaei et al., 2020; Liu et al., 2024; Şimşek and Direkci, 2023) and higher-level questions related to reorganization, evaluation, and appreciation compared to printed books (Şimşek and Direkci, 2023). Augmented reality storybooks can support users' comprehension performance with their ability to appeal to different senses and make the story more tangible. For example, children who interacted with an augmented reality storybook were more likely to provide correct answers to the question, "What were the fireflies doing when the ladybugs fell asleep?" The reason behind this could be that the visuals supported by sound and video make it easier to follow the flow of the story.

This study, along with various studies in the literature, provides evidence that augmented reality storybooks support users' comprehension performance. Enriching the learning experience using multimedia content, such as text-to-speech, video, and interactive elements, can be a reason for this observed difference (Billinghurst and Duenser, 2012; Yuen et al., 2011). Indeed, incorporating information through multiple channels, encompassing both auditory and visual modalities, has contributed to more effective learning and better retention than processing information through a single channel (Bus et al., 2015). Thus, multimedia content can reduce cognitive load and enhance the story's comprehensibility (Kao et al., 2016). The relevant literature also supports the idea that multimedia content can enhance preschool children's comprehension (Altun, 2024) and retelling performance (Crawshaw et al., 2020; Diehm et al., 2020). However, the integrated multimedia content must be consistent with the text. Multimedia content that is not aligned with the story may distract children's attention from the narrative and increase cognitive load, thereby reducing children's comprehension performance (Chang et al., 2011; Takacs and Bus, 2016; Takacs et al., 2015).

5 Conclusion, limitations and recommendations

This study compared the comprehension levels of preschool children who experienced printed and augmented reality storybooks. In this context, children's books titled "Aç Tırtıl (The Very Hungry Caterpillar)," "Kafası Karışık Bukalemun (The Mixed-Up Chameleon)" and "Huysuz Uğurböceği (The Grouchy Ladybug)" were enriched with augmented reality content. Subsequently, teachers read the books in printed and augmented reality-supported formats and engage in activities. In order to compare the groups, children retold the stories and answered the questions from the Story Comprehension Test. The results indicated that children who listened to augmented reality storybooks demonstrated higher comprehension and retelling performance than children who listened to printed storybooks. The consistently high scores in both the test and retelling provide in-depth evidence supporting the effectiveness of augmented reality storybooks in enhancing comprehension. Additionally, the limited data available in the literature regarding preschool children makes the findings of this study noteworthy.

This study has several limitations. Firstly, the participants were children between the ages of four and five. Thus, the results are limited to this age range. However, future studies could involve children in different age groups within the preschool period, enabling broader interpretations regarding the impact of augmented reality storybooks on preschool children's comprehension and retelling performance.

Additionally, the data in this study is limited to 90 children. While studies testing new technological devices and applications generally have smaller sample sizes, a more significant number of studies are needed for the generalizability of the data. The current study's lack of a follow-up assessment limits the research. Therefore, there is an urgent need for future studies should include follow-up assessments that could provide insights into the lasting effects of augmented reality interventions. The researcher did not use multimedia content on every page in the augmented reality storybooks created in this study. This decision was made to maintain the narrative of a storybook and avoid creating an environment solely focused on watching videos. The integration of multimedia content into the books was done in consultation with teachers and placed in locations deemed appropriate by the researcher. As there are currently no established design principles for augmented reality storybooks regarding factors such as appropriate duration and frequency of multimedia experiences in the literature, future studies should focus on developing design principles that cater to different age groups and align with the characteristics of different texts. Furthermore, this study used videos as the augmented reality content. Subsequent studies could explore the role of interactive options or 3D visuals in children's comprehension and retelling performance.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the author, without undue reservation.

Ethics statement

The studies involving humans were approved by Akdeniz University Rectorate Social and Human Sciences Scientific Research and Publication Ethics Committee. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

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References

Akçayır, M., Akçayır, G., Pektaş, H. M., and Ocak, M. A. (2016). Augmented reality in science laboratories: the effects of augmented reality on university students' laboratory skills and attitudes toward science laboratories. *Comput. Hum. Behav.* 57, 334–342. doi: 10.1016/j.chb.2015.12.054

Albayrak, S., and Yılmaz, R. M. (2022). An investigation of pre-school children's interactions with augmented reality applications. *Int. J. Hum. Comput. Interact.* 38, 165–184. doi: 10.1080/10447318.2021.1926761

Alhumaidan, H., Lo, K., and Selby, A. (2018). Co-designing with children a collaborative augmented reality book based on a primary school textbook. *Int. J. Child Comput. Interact.* 15, 24–36. doi: 10.1016/j.ijcci.2017.11.005

Alsowat, H. H. (2016). Breaking down the classroom walls: augmented reality effect on EFL reading comprehension, self-efficacy, autonomy and attitudes. *Stud. English Lang. Teach.* 5, 1–23. doi: 10.22158/selt.v5n1p1

Altun, D. (2024). The effects of e-stories on preschoolers' narrative comprehension, retelling and reading attitudes among poor and good comprehenders. *J. Early Child. Lit.* 24, 471–504. doi: 10.1177/14687984221079010

Alvarez-Marin, A., and Velazquez-Iturbide, J. (2021). Augmented reality and engineering education: a systematic review. *Trans. Learn. Technol.* 14, 817–831. doi: 10.1109/TLT.2022.3144356

Amores-Valencia, A., Burgos, D., and Branch-Bedoya, J. W. (2022). Influence of motivation and academic performance in the use of augmented reality in education. A systematic review. *Front. Psychol.* 13:1011409. doi: 10.3389/fpsyg.2022.1011409

Anuardi, M. A. K., Mustapha, S., and Mohammed, M. N. (2022). Towards increase reading habit for preschool children through interactive augmented reality storybook. 2022 IEEE 12th symposium on computer applications & industrial electronics (ISCAIE) (pp. 252–257). IEEE.

Aydoğdu, F. (2022). Augmented reality for preschool children: an experience with educational contents. *Br. J. Educ. Technol.* 53, 326–348. doi: 10.1111/bjet.13168

Azuma, R. (1997). A survey of augmented reality. *Presence Teleop. Virt.* 6, 355–385. doi: 10.1162/pres.1997.6.4.355

Barreira, J., Bessa, M., Pereira, L. C., Adão, T., Peres, E., and Magalhães, L. (2012). MOW: augmented reality game to learn words in different languages: case study: learning English names of animals in elementary school. In 7th Iberian conference on information systems and technologies (CISTI 2012) (pp. 1–6). IEEE.

Billinghurst, M., and Duenser, A. (2012). Augmented reality in the classroom. *Computer* 45, 56–63. doi: 10.1109/MC.2012.111

Billinghurst, M., Kato, H., and Poupyrev, I. (2001). Collaboration with tangible augmented reality interfaces. In Proceedings of the HCI 2001, 797–803.

Breit-Smith, A., van Kleeck, A., Prendeville, J. A., and Pan, W. (2017). Preschool children's exposure to story grammar elements during parent-child book reading. *J. Res. Read.* 40, 345–364. doi: 10.1111/1467-9817.12071

Bujak, K. R., Radu, I., Catrambone, R., MacIntyre, B., Zheng, R., and Golubski, G. (2013). A psychological perspective on augmented reality in the mathematics classroom. *Comput. Educ.* 68, 536–544. doi: 10.1016/j.compedu.2013.02.017

Bülbül, H., and Özdinç, F. (2022). How real is augmented reality in preschool? Examination of young children's AR experiences. *Kuramsal Eğitimbilim* 15, 884–906. doi: 10.30831/akukeg.1098113

Bursalı, H., and Yılmaz, R. M. (2019). Effect of augmented reality applications on secondary school students' reading comprehension and learning permanency. *Comput. Hum. Behav.* 95, 126–135. doi: 10.1016/j.chb.2019.01.035

Bus, A. G., Takacs, Z. K., and Kegel, C. A. T. (2015). Affordances and limitations of electronic storybooks for young children's emergent literacy. *Dev. Rev.* 35, 79–97. doi: 10.1016/j.dr.2014.12.004

Cai, Y., Pan, Z., and Liu, M. (2022). Augmented reality technology in language learning: a meta-analysis. *J. Comput. Assist. Learn.* 38, 929–945. doi: 10.1111/jcal.12661

Carrión Candel, E., Pérez Agustín, M., Matilde Barrios Vicente, I., and Aparicio Molina, Y. (2020). Benefits of introducing picture books through ICTs in bilingual settings: an example with cuadernia and press here by herve tullet. *ARTSEDUCA* 27, 144–158. doi: 10.6035/Artseduca.2020.27.11

Çetin, H., and Ulusoy, M. (2023). The effect of augmented reality-based reading environments on retelling skills: formative experiment. *Educ. Inf. Technol.* 28, 5849–5873. doi: 10.1007/s10639-022-11415-8

Çetinkaya Özdemir, E., and Akyol, H. (2021). Effect of augmented reality-based reading activities on some reading variables and participation in class. *Int. J. Progress. Educ.* 17, 135–154. doi: 10.29329/ijpe.2021.366.9

Chang, Y. L., Hou, H. T., Pan, C. Y., Sung, Y. T., and Chang, K. E. (2015). Apply an augmented reality in a mobile guidance to increase sense of place for heritage places. *J. Educ. Technol. Soc.* 18, 166–178. doi: 10.2307/jeductechsoci.18.2.166

Chang, C. C., Lei, H., and Tseng, J. S. (2011). Media presentation mode, English listening comprehension and cognitive load in ubiquitous learning environments: modality effect or redundancy effect? *Australas. J. Educ. Technol.* 27, 633–654. doi: 10.14742/ajet.942

ChanLin, L. J. (2018). Bridging children's reading with an augmented reality story library. *Libri* 68, 219–229. doi: 10.1515/libri-2018-0017

Chen, Y. C. (2019). Effect of mobile augmented reality on learning performance, motivation, and math anxiety in a math course. *J. Educ. Comput. Res.* 57, 1695–1722. doi: 10.1177/0735633119854036

Cheng, K. H. (2015). Reading an augmented reality book: an exploration of learners' cognitive load, motivation, and attitudes. *Australas. J. Educ. Technol.* 33, 53–69. doi: 10.14742/ajet.2820

Cheng, K. H., and Tsai, C. C. (2014). Children and parents' reading of an augmented reality picture book: analyses of behavioral patterns and cognitive attainment. *Comput. Educ.* 72, 302–312. doi: 10.1016/j.compedu.2013.12.003

Chiang, T. H., Yang, S. J., and Hwang, G. J. (2014). An augmented reality-based mobile learning system to improve students' learning achievements and motivations in natural science inquiry activities. *J. Educ. Technol. Soc.* 17, 352–365. doi: 10.2307/jeductechsoci.17.4.352

Chin, K. Y., Kao, Y. C., and Wang, C. S. (2021). Effects of augmented reality technology in a mobile touring system on university students' learning performance and interest. *Australas. J. Educ. Technol.* 37, 27–42. doi: 10.14742/ajet.5841

Cohen, J. (1988). Statistical power analysis for the behavioral sciences. *2nd* Edn: United States: Routledge.

Collins, M. F. (2016). Supporting inferential thinking in preschoolers: effects of discussion on children's story comprehension. *Early Educ. Dev.* 27, 932–956. doi: 10.1080/10409289.2016.1170523

Crawshaw, C. E., Kern, F., Mertens, U., and Rohlfing, K. J. (2020). Children's narrative elaboration after reading a storybook versus viewing a video. *Front. Psychol.* 11:569891. doi: 10.3389/fpsyg.2020.569891

Cruz de Quiros, A. M., Lara-Alecio, R., Tong, F., and Irby, B. J. (2012). The effect of a structured story reading intervention, story retelling and higher order thinking for English language and literacy acquisition. *Journal of Research in Reading*, 35, 87–113. doi: 10.1111/j.1467-9817.2010.01472.x

Danaei, D., Jamali, H. R., Mansourian, Y., and Rastegarpour, H. (2020). Comparing reading comprehension between children reading augmented reality and print storybooks. *Comput. Educ.* 153:103900. doi: 10.1016/j.compedu.2020.103900

Delello, J. A. (2014). Insights from pre-service teachers using science-based augmented reality. *J. Comput. Educ.* 1, 295–311. doi: 10.1007/s40692-014-0021-y

Di Serio, Á., Ibáñez, M. B., and Kloos, C. D. (2013). Impact of an augmented reality system on students' motivation for a visual art course. *Comput. Educ.* 68, 586–596. doi: 10.1016/j.compedu.2012.03.002

Diehm, E. A., Wood, C., Puhlman, J., and Callendar, M. (2020). Young children's narrative retell in response to static and animated stories. *Eur. J. Disord. Commun.* 55, 359–372. doi: 10.1111/1460-6984.12523

Duenser, A. (2008). Supporting low ability readers with interactive augmented reality. *Annu. Rev. Cyberther. Telemed.* 6, 39–46.

Duenser, A., Walker, L., Horner, H., and Bentall, D. (2012). Creating interactive physics education books with augmented reality. In Proceedings of the 24th Australian computer-human interaction conference, 107–114.

Dunleavy, M., Dede, C., and Mitchell, R. (2009). Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning. *J. Sci. Educ. Technol.* 18, 7–22. doi: 10.1007/s10956-008-9119-1

Ebadi, S., and Ashrafabadi, F. (2022). An exploration into the impact of augmented reality on EFL learners' reading comprehension. *Educ. Inf. Technol.* 27, 9745–9765. doi: 10.1007/s10639-022-11021-8

Ertem, I. S. (2009). Investigating the effects of electronic CD-ROM storybooks and traditional print storybooks on reading comprehension of fourth grade struggling readers [Unpublished Doctoral Dissertation]: University of Florida.

Fears, N. E., and Lockman, J. J. (2020). Case- and form-sensitive letter frequencies in children's picture books. *Early Child. Res. Q.* 53, 370–378. doi: 10.1016/j.ecresq.2020.05.004

Ferrer-Torregrosa, J., Torralba, J., Jimenez, M. A., Garcia, S., and Barcia, J. M. (2015). ARBOOK: development and assessment of a tool based on augmented reality for anatomy. *J. Sci. Educ. Technol.* 24, 119–124. doi: 10.1007/s10956-014-9526-4

Fidan, M., and Tuncel, M. (2019). Integrating augmented reality into problem based learning: the effects on learning achievement and attitude in physics education. *Comput. Educ.* 142:103635. doi: 10.1016/j.compedu.2019.103635

Florit, E., Roch, M., and Levorato, M. C. (2011). Listening text comprehension of explicit and implicit information in preschoolers: the role of verbal and inferential skills. *Discourse Process.* 48, 119–138. doi: 10.1080/0163853X.2010.494244

Gil, K., Rhim, J., Ha, T., Doh, Y. Y., and Woo, W. (2014). AR petite theater: augmented reality storybook for supporting children's empathy behavior. In 2014 IEEE international symposium on mixed and augmented reality-media, art, social science, humanities and design (ISMAR-MASH'D) (pp. 13–20). IEEE.

Green, M., McNair, L., Pierce, C., and Harvey, C. (2019). An investigation of augmented reality picture books: meaningful experiences or missed opportunities? *J. Educ. Multimedia Hypermedia* 28, 357–380.

Grolig, L., Cohrdes, C., Tiffin-Richards, S. P., and Schroeder, S. (2019). Effects of preschoolers' storybook exposure and literacy environments on lower level and higher level language skills. *Read. Writ.* 32, 1061–1084. doi: 10.1007/s11145-018-9901-2

Han, J., and Neuharth-Pritchett, S. (2015). Meaning-related and print-related interactions between preschoolers and parents during shared book reading and their associations with emergent literacy skills. *J. Res. Child. Educ.* 29, 528–550. doi: 10.1080/02568543.2015.1073819

Hu, R., and Commeyras, M. (2008). A case study: Emergent biliteracy in English and Chinese of a 5-year-old Chinese child with wordless picture books. *Read. Psychol.* 29:1–30. doi: 10.1080/02702710701260581

Ibáñez, M. B., Uriarte Portillo, A., Zatarain Cabada, R., and Barrón, M. L. (2020). Impact of augmented reality technology on academic achievement and motivation of students from public and private Mexican schools. A case study in a middle-school geometry course. *Comput. Educ.* 145:103734. doi: 10.1016/j.compedu.2019.103734

Ibili, E., and Billinghurst, M. (2019). Assessing the relationship between cognitive load and the usability of a mobile augmented reality tutorial system: a study of gender effects. *Int. J. Assess. Tools Educ.* 6, 378–395. doi: 10.21449/ijate.594749

Kao, G. Y. M., Tsai, C. C., Liu, C. Y., and Yang, C. H. (2016). The effects of high/low interactive electronic storybooks on elementary school students' reading motivation, story comprehension and chromatics concepts. *Comput. Educ.* 100, 56–70. doi: 10.1016/j.compedu.2016.04.013

Keller, S., Rumann, S., and Habig, S. (2021). Cognitive load implications for augmented reality supported chemistry learning. *Information* 12, 96–115. doi: 10.3390/info12030096

Kendeou, P., Van Den Broek, P., White, M. J., and Lynch, J. (2007). "Comprehension in preschool and early elementary children: skill development and strategy interventions" in Reading comprehension strategies: Theories, interventions, and technologies. ed. D. S. McNamara (United States: Lawrence Erlbaum Associates), 27–45.

Kendeou, P., Van den Broek, P., White, M. J., and Lynch, J. S. (2009). Predicting reading comprehension in early elementary school: the independent contributions of oral language and decoding skills. *J. Educ. Psychol.* 101, 765–778. doi: 10.1037/a0015956

Khan, T., Johnston, K., and Ophoff, J. (2019). The impact of an augmented reality application on learning motivation of students. *Adv. Hum. Comput. Interact.* 2019, 1–14. doi: 10.1155/2019/7208494

Kim, Y. S. G. (2016). Direct and mediated effects of language and cognitive skills on comprehension of oral narrative texts (listening comprehension) for children. *J. Exp. Child Psychol.* 141, 101–120. doi: 10.1016/j.jecp.2015.08.003

Kljun, M., Pucihar, K. Č., Alexander, J., Weerasinghe, M., Campos, C., Ducasse, J., et al. (2019). Augmentation not duplication: considerations for the design of digitally-augmented comic books. In Proceedings of the 2019 CHI conference on human factors in computing systems (pp. 1–12).

Kucirkova, N. (2016). Personalisation: a theoretical possibility to reinvigorate children's interest in storybook reading and facilitate greater book diversity. *Contemp. Issues Early Child.* 17, 304–316. doi: 10.1177/1463949116660950

Language and Reading Research ConsortiumChiu, Y. D. (2018). The simple view of reading across development: prediction of grade 3 reading comprehension from prekindergarten skills. *Remedial Spec. Educ.* 39, 289–303. doi: 10.1177/0741932518762055

Lauricella, A. R., Barr, R., and Calvert, S. L. (2014). Parent–child interactions during traditional and computer storybook reading for children's comprehension: implications for electronic storybook design. *Int. J. Child Comput. Interact.* 2, 17–25. doi: 10.1016/j.ijcci.2014.07.001

Lim, J., Whitehead, G. E., and Choi, Y. (2021). Interactive e-book reading vs. paper-based reading: comparing the effects of different mediums on middle school students' reading comprehension. *System* 97:102434. doi: 10.1016/j.system.2020.102434

Liu, S., Sui, Y., You, Z., Shi, J., Wang, Z., and Zhong, C. (2024). Reading better with AR or print picture books? A quasi-experiment on primary school students' reading comprehension, story retelling and reading motivation. *Educ. Inf. Technol.* 29, 11625–11644. doi: 10.1007/s10639-023-12231-4

Merjovaara, O., Nousiainen, T., Turja, L., and Isotalo, S. (2020). Digital stories with children: examining digital storytelling as a pedagogical process in ECEC. *J. Early Childhood Educ. Res.* 9, 99–123.

Mol, S. E., and Bus, A. G. (2011). To read or not to read: a meta-analysis of print exposure from infancy to early adulthood. *Psychol. Bull.* 137, 267–296. doi: 10.1037/a0021890

Morrow, L. M. (1985). Retelling stories: a strategy for improving young children's comprehension, concept of story structure, and oral language complexity. *Elem. Sch. J.* 85, 647–661. doi: 10.1086/461427

O'Byrne, W. I., Stone, R., White, M., and White, M. (2018). Digital storytelling in early childhood: student illustrations shaping social interactions. *Front. Psychol.* 9:1800. doi: 10.3389/fpsyg.2018.01800

Ömurtak, E., and Zeybek, G. (2022). The effect of augmented reality applications in biology lesson on academic achievement and motivation. *J. Educ. Environ. Sci. Health* 8, 55–74. doi: 10.21891/jeseh.1059283

Pan, Z., López, M., Li, C., and Liu, M. (2021). Introducing augmented reality in early childhood literacy learning. *Res. Learn. Technol.* 29, 1–21. doi: 10.25304/rlt.v29.2539

Parmaxi, A., and Demetriou, A. A. (2020). Augmented reality in language learning: a state-of-the-art review of 2014–2019. *J. Comput. Assist. Learn.* 36, 861–875. doi: 10.1111/jcal.12486

Perez-Lopez, D., and Contero, M. (2013). Delivering educational multimedia contents through an augmented reality application: a case study on its impact on knowledge acquisition and retention. *Turkish Online J. Educ. Technol.* 12, 19–28.

Rambli, D. R. A., Matcha, W., and Sulaiman, S. (2013). Fun learning with AR alphabet book for preschool children. *Proc. Comput. Sci.* 25, 211–219. doi: 10.1016/j.procs.2013.11.026

Roumba, E., and Nicolaidou, I. (2022). Augmented reality books: motivation, attitudes, and behaviors of young readers. *Int. J. Interact. Mob. Technol.* 16, 59–73. doi: 10.3991/ijim.v16i16.31741

Şahin, D., and Yılmaz, R. M. (2020). The effect of augmented reality technology on middle school students' achievements and attitudes towards science education. *Comput. Educ.* 144:103710. doi: 10.1016/j.compedu.2019.103710

Santos, M. E. C., Lübke, A. I. W., Taketomi, T., Yamamoto, G., Rodrigo, M. M. T., Sandor, C., et al. (2016). Augmented reality as multimedia: the case for situated vocabulary learning. *Res. Pract. Technol. Enhanc. Learn.* 11:4. doi: 10.1186/s41039-016-0028-2

Şimşek, B., and Direkci, B. (2023). The effects of augmented reality storybooks on student's reading comprehension. *Br. J. Educ. Technol.* 54, 754–772. doi: 10.1111/bjet.13293

Soon, C. T., Neo, H. F., and Teo, C. C. (2022). Reading augmented reality story book in enhancing learning perceptions. *J. Logist. Inf. Serv. Sci.* 9, 105–118. doi: 10.33168/LISS.2022.0408

Strasser, K., and Río, F. D. (2014). The role of comprehension monitoring, theory of mind, and vocabulary depth in predicting story comprehension and recall of kindergarten children. *Read. Res. Q.* 49, 169–187. doi: 10.1002/rrq.68

Takacs, Z. K., and Bus, A. G. (2016). Benefits of motion in animated storybooks for Children's visual attention and story comprehension. An eye-tracking study. *Front. Psychol.* 7:1591. doi: 10.3389/fpsyg.2016.01591

Takacs, Z. K., and Bus, A. G. (2018). How pictures in picture storybooks support young children's story comprehension: an eye-tracking experiment. *J. Exp. Child Psychol.* 174, 1–12. doi: 10.1016/j.jecp.2018.04.013

Takacs, Z. K., Swart, E. K., and Bus, A. G. (2015). Benefits and pitfalls of multimedia and interactive features in technology-enhanced storybooks: a meta-analysis. *Rev. Educ. Res.* 85, 698–739. doi: 10.3102/0034654314566989

Teng, C. H., Chen, J. Y., and Chen, Z. H. (2018). Impact of augmented reality on programming language learning: efficiency and perception. *J. Educ. Comput. Res.* 56, 254–271. doi: 10.1177/0735633117706109

Tobar-Munoz, H., Baldiris, S., and Fabregat, R. (2017). Augmented reality game-based learning: enriching students' experience during reading comprehension activities. *J. Educ. Comput. Res.* 55, 901–936. doi: 10.1177/0735633116689789

Tomi, A. B., and Rambli, D. R. A. (2013). An interactive mobile augmented reality magical playbook: learning number with the thirsty crow. *Proc. Comput. Sci.* 25, 123–130. doi: 10.1016/j.procs.2013.11.015

Tsou, W., Wang, W., and Tzeng, Y. (2006). Applying a multimedia storytelling website in foreign language learning. *Comput. Educ.* 47, 17–28. doi: 10.1016/j.compedu.2004.08.013

Wang, R. (2022). Application of augmented reality technology in children's picture books based on educational psychology. *Front. Psychol.* 13:782958. doi: 10.3389/fpsyg.2022.782958

Wen, Y. (2021). Augmented reality enhanced cognitive engagement: designing classroom-based collaborative learning activities for young language learners. *Educ. Technol. Res. Dev.* 69, 843–860. doi: 10.1007/s11423-020-09893-z

Wilson, L. E. (2015). The utilization of technology-mediated evaluation tools to analyze learning efficiency through cognitive load and performance. [dissertation/doctorate]. Pennsylvania: Indiana University of Pennsylvania.

Wojciechowski, R., and Cellary, W. (2013). Evaluation of learners' attitude toward learning in ARIES augmented reality environments. *Comput. Educ.* 68, 570–585. doi: 10.1016/j.compedu.2013.02.014

Yamaji, N., Sawaguchi, M., and Ota, E. (2020). Talking with children about cancer: a content analysis of text in children's picture books. *Health* 12, 750–763. doi: 10.4236/health.2020.127055

Yılmaz, R. M., Küçük, S., and Göktaş, Y. (2017). Are augmented reality picture books magic or real for preschool children aged five to six? *Br. J. Educ. Technol.* 48, 824–841. doi: 10.1111/bjet.12452

Yoon, S., Anderson, E., Lin, J., and Elinich, K. (2017). How augmented reality enables conceptual understanding of challenging science content. *J. Educ. Technol. Soc.* 20:156. doi: 10.2307/jeductechsoci.20.1.156

Yuen, S., Yaoyuneyong, G., and Johnson, E. (2011). Augmented reality: an overview and five directions for AR in education. *J. Educ. Technol. Dev. Exchange* 4, 119–140. doi: 10.18785/jetde.0401.10

Zhou, Z., Cheok, A. D., Pan, J., and Li, Y. (2004). An interactive 3D exploration narrative interface for storytelling. In Proceedings of the 2004 conference on interaction design and children: building a community (pp. 155–156).

Zhou, N., and Yadav, A. (2017). Effects of multimedia story reading and questioning on preschoolers' vocabulary learning, story comprehension and reading engagement. *Educ. Technol. Res. Dev.* 65, 1523–1545. doi: 10.1007/s11423-017-9533-2

Zipke, M. (2017). Preschoolers explore interactive storybook apps: the effect on word recognition and story comprehension. *Educ. Inf. Technol.* 22, 1695–1712. doi: 10.1007/s10639-016-9513-x

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Parents' rearing styles and adolescents' math achievement: the multiple mediating effect of self-control and math anxiety

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Introduction: This cross-sectional study examined the mechanisms underlying adolescent math achievement by investigating the relationship between parents' rearing styles (including different dimensions of rearing style) and adolescent self-control, math anxiety, and math achievement based on the ecological systems theory.

Method: A total of 584 junior high school students (*M* age = 12.52) completed the Parenting Style Questionnaire, Self-control Scale, and Math Anxiety Rating Scale and provided their math test scores.

Results: The rearing styles of both fathers and mothers directly predicted adolescents' math achievement. Maternal rearing style indirectly predicted adolescents' math achievement through their self-control and math anxiety; however, the indirect effect of paternal rearing style on adolescents' math achievement was not significant. After distinguishing the three dimensions of rearing styles, we found that paternal emotional warmth can increase adolescents' self-control, while maternal emotional warmth can reduce adolescents' self-control. Further, paternal overprotectiveness can directly and positively predict adolescents' math achievement, while maternal rejection and overprotectiveness can positively predict adolescents' math achievement. None of the three dimensions of rearing styles can predict math achievement through adolescents' self-control; however, they can predict math achievement indirectly through adolescents' math anxiety and the chain-mediation of adolescents' self-control and math anxiety.

Discussion: Our results suggest both commonalities and differences in how paternal and maternal rearing styles, along with their three dimensions (emotional warmth, rejection, overprotection), predict adolescent math achievement. These findings highlight the importance of paternal and maternal rearing styles on adolescents' math achievement and underscore the need to examine them separately to better understand their impact.

KEYWORDS

parents' rearing styles, self-control, math anxiety, math achievement, adolescent

1 Introduction

Math is a fundamental discipline in the fields of science, technology, and engineering (STEM) and one of the best predictors of success therein (Fong et al., 2021; Le and Robbins, 2016). Math achievement, typically measured by students' scores in standardized math tests, is a crucial metric for assessing learning outcomes, comprehension, and mastery. It also serves as a significant reference factor for students' academic advancement and career development (Fong et al., 2021; St Omer and Chen, 2023). Adolescence is a critical period in children's development, during which math achievement is closely linked to negative emotions such as academic boredom (Borgonovi et al., 2023), which further influence children's future career choices and developmental trajectories (Toh and Watt, 2022). There are at least two theories that can explain the factors that influence adolescents' math achievement—ecological systems and social cognitive theories. Ecological systems theory suggests that children's math achievement is affected by both individual and environmental factors (Bronfenbrenner, 1979). Similarly, social cognitive theory holds that environmental and children's individual factors will have a decisive impact on their math achievement and other accomplishments (Bandura, 1997; Zimmerman, 1989). Based on this, previous studies have found that parents' rearing styles, as an important environmental factor, and adolescents' self-control and math anxiety, as important individual factors, all play an important role in adolescents' math achievement (Bardach et al., 2023; Barroso et al., 2021; Pinquart, 2015). However, previous studies have not revealed the complex nature of this relationship. Thus, this study aimed to extensively investigate the relationship between parents' rearing styles and adolescents' self-control, math anxiety, and math achievement from the perspective of both environmental and individual factors. This could help enhance the understanding of the underlying mechanisms affecting adolescents' math achievement and provide guidance for improvement.

1.1 Parents' rearing styles and adolescents' math achievement

As the primary context in which children first interact with the outside world, the family is the most direct micro-environment affecting children's development (Underdown, 2007). Within this micro-environment, parents' rearing styles are closely related to adolescents' math achievement (Ogg and Anthony, 2020). Parents' rearing styles encompass both the attitudes conveyed by parents and the emotional atmosphere created by their behavior and can be categorized as positive or negative. Positive rearing styles are characterized by emotional warmth and care, an emphasis on communication and understanding, and the encouragement of autonomy and independence. Conversely, negative rearing styles are marked by a lack of emotional communication, excessive severity, control, and rejection (Li et al., 2019; Ogg and Anthony, 2020). According to the autonomy-supportive parenting and distance-conflicted family theories (Guo et al., 2021), affective, encouraging, and related parenting styles are characterized by support and autonomy, whereas rejection- and control-based parenting styles are characterized by distance and conflict. The parenting style based on supporting autonomy is more inclusive and creates a more relaxed and pleasant atmosphere at home, making it easier to cultivate children to produce positive results in school and other aspects. Contrastingly, the parenting style based on distance and conflict may cause tension and exert pressure on children, which may hinder their academic development (Guo et al., 2021). Regarding children's math achievement, empirical studies have found that parenting styles based on autonomy and support features, such as the emotional warmth style, are conducive to the improvement of adolescents' math performance, while those based on rejection are linked to a reduction in adolescents' math achievement (Retanal et al., 2021). This reveals that different parenting styles have varying effects on adolescents' math achievement. To elucidate these varying effects and comprehensively explore the relationship between parents' rearing styles and adolescents' math achievement, we subdivided the specific dimensions of different rearing styles.

Most studies have only focused on the combined influence of parents (i.e., fathers and mothers) (Wang and Fletcher, 2015). Recent research, including the male breadwinner-female housewife model, has suggested significant differences in paternal and maternal rearing styles owing to gender, roles, and division of labor between parents (Du et al., 2021; Waismel-Manor and Levanon, 2024). Moreover, this difference leads to variations in the effects of paternal and maternal rearing styles on adolescents' cognition and behavior (Moilanen et al., 2014). Therefore, by considering paternal and maternal rearing styles separately, we can have a clear understanding of the specific effect of parents' rearing styles on adolescents' math achievement, which would enable more targeted prevention and intervention efforts. Thus, by distinguishing the rearing styles of fathers and mothers, this study examines the relationship between the sub-dimensions of parental rearing and adolescents' math achievement.

1.2 Relationship between parents' rearing styles and adolescents' self-control and math achievement

Self-control is a crucial psychological function that allows individuals to voluntarily regulate unwarranted thoughts, emotions, and behaviors in alignment with societal norms to support the achievement of long-term goals (Li et al., 2019; Muraven and Baumeister, 2000). Previous studies have found that effective self-control can improve adolescents' social adaptability and reduce their risk of substance use, emotional problems, and aggressive behavior (Li et al., 2019; Li et al., 2023a; Rodríguez-Ruiz et al., 2023; Tangney et al., 2004), as well as alleviate family conflict and academic burnout in adolescents (Luo et al., 2020). Additionally, self-control can improve academic performance, specifically in math (Duckworth et al., 2019). Empirical studies have shown that self-control is positively correlated with math achievement (Cleary and Chen, 2009; Cleary and Kitsantas, 2017; Dent and Koenka, 2015). The self-control strength model (Muraven, 2010; Muraven and Baumeister, 2000), self-determination theory (Husain, 2023; Peterson et al., 2020; Wang et al., 2022), social cognitive theory (Martin, 2004; Zimmerman, 1989), and other theories support the view that self-control is closely related to academic achievement in subjects such as math. For example, social cognitive theory suggests that students with strong self-control often exhibit higher self-efficacy, which boosts their confidence in completing tasks, increases their willingness to put effort into and

persist in mathematical learning, and ultimately enhances their chances of achieving good results in math (Martin, 2004; Zimmerman, 1989).

The ecological systems theory posits that parents' rearing styles constitute a crucial component of the family environment. Parents' rearing styles significantly guide and shape the development of adolescents' self-control (Li et al., 2019; Pallini et al., 2018; Yang et al., 2023) and can indirectly do so through factors such as family atmosphere and parent–child relationships (Moilanen et al., 2014; Mun et al., 2018). For example, emotional warmth and other positive rearing styles, provide adolescents with appropriate care and support and reasonably limit and guide their behavior, enabling them to achieve balanced development in self-cognition, emotional regulation, and behavior control. In contrast, rejection-based and other negative rearing styles, are more likely to cause parents to ignore the needs of adolescents, provide insufficient guidance and education, and lack necessary care and support. As a result, adolescents may struggle to develop effective self-control (Abedini et al., 2012; Li et al., 2014; Moilanen et al., 2014). Similar findings have been observed across different cultural backgrounds and age groups (Finkenauer et al., 2005; Li et al., 2023b; Yang et al., 2023), suggesting that parents' rearing styles may affect adolescents' self-control, with parents and their specific parenting styles potentially having varying effects on self-control. In addition, considering the relationship between parents' rearing styles (and their differences) and adolescents' math achievement, as well as adolescents' self-control and math achievement, this study proposes the following hypotheses:

> *H1:* Adolescents' self-control mediates the relationship between parents' rearing styles and adolescents' math achievement. However, this mediating role differs between parents (i.e., paternal or maternal rearing styles).
>
> *H2:* The above mediating effect is also related to the specific rearing style adopted by fathers or mothers (for example, whether it is emotional warmth or rejection).

1.3 Relationship between parents' rearing styles and adolescents' self-control, math anxiety, and math achievement

How does self-control impact adolescents' math achievement? First, multiple theories have explained the relationship between self-control and emotions (Burt, 2020; King and Gaerlan, 2014). For instance, according to the cognitive theory of emotion, individual cognition can affect emotion and is the key factor determining the nature of emotion (Brewin, 1996; Oatley and Johnson-Laird, 2014). Compared to adolescents with effective self-control, those with poor self-control are more likely to experience negative emotions such as math anxiety, which can be exacerbated by reduced self-efficacy (Jain and Dowson, 2009). In addition, according to the motivational theory of emotion, children's math anxiety can reduce their interest and motivation in learning math by negatively impacting their enthusiasm and initiative. This lack of emotion and motivation may result in insufficient investment in math learning, ultimately leading to reduced math achievement (John et al., 2020; Wang et al., 2015). Research based on behavioral tests has confirmed that individuals with increased math anxiety tend to avoid math problems (Choe et al., 2019); this, in turn, hinders math achievement (Wang et al., 2021). Therefore, we formulate the following hypothesis:

> *H3:* Adolescents' math anxiety plays a mediating role in the relationship between self-control and math achievement.

In addition, previous research has indicated that parents' rearing styles may affect adolescents' math anxiety. For example, Macmull and Ashkenazi (2019) have found that controlling and punishing rearing styles are associated with adolescents' high math anxiety, and the more supportive and encouraging rearing styles lower adolescents' math anxiety. Based on the relationship between parents' rearing styles and adolescents' math achievement, and the relationship between adolescents' math anxiety and math achievement, we posit the following hypotheses:

> *H4:* Adolescents' math anxiety mediates the relationship between the specific rearing style adopted by parents (e.g., emotional warmth) and adolescents' math achievement. Moreover, the mediating effect of math anxiety between paternal rearing style and adolescents' math achievement is different from that between maternal rearing style and adolescents' math achievement because of the possible differences between paternal and maternal parenting styles.
>
> *H5:* Adolescents' self-control and math anxiety play a chain mediating role between parents' rearing styles and adolescents' math achievement. This chain mediation may be related to each parent (e.g., the paternal versus maternal rearing styles).
>
> *H6:* The chain mediating role of adolescents' self-control and math anxiety in the relationship between different dimensions of parents' rearing styles and adolescents' math achievement varies.

This study draws on ecological systems theory and considers both environmental and individual factors affecting adolescents. From the perspectives of both fathers and mothers, this study explores the relationships between paternal and maternal rearing styles (including the emotional warmth, rejection, and overprotection dimensions) and adolescents' self-control, math anxiety, and math achievement.

2 Materials and methods

2.1 Participants

This study employed a convenience sampling method to conduct a collective questionnaire survey in December 2023 with students from two full-time middle schools in Lanzhou, China. A total of 600 questionnaires were distributed. Sixteen participants were excluded due to incomplete or unserious responses, resulting in 584 valid questionnaires with an effective response rate of 97.33%. The sample consisted of 278 male (47.60%) and 306 female (52.40%) students, ranging in age from 12 to 15 years, with an average age of 12 years (M = 12.52, SD = 1.04). The studies involving human participants were

reviewed and approved by the Scientific Research Ethics Committee of the School of Psychology of Northwest Normal University (Approval No. 2023101). The study was conducted in the schools after verbal informed consent had been provided by the heads of middle schools and the children's parents.

2.2 Measures

2.2.1 Parents' rearing styles

This study used the Chinese version of the parental bonding instrument (PBI), which was translated and revised by Jiang et al. (2010). The original scale is divided into two parts for paternal and maternal rearing styles, with a total of 42 items. The scale comprises three dimensions: rejection, emotional warmth, and overprotection, which include six, seven, and eight items, respectively. All the items are scored on a five-point Likert scale, with higher subscale scores indicating a stronger tendency toward a particular rearing style. The average scores for the three dimensions of emotional warmth, rejection, and overprotection were calculated separately for fathers and mothers. The emotional warmth dimension was used to assess positive rearing styles, whereas the rejection and overprotection dimensions were used to assess negative rearing styles (Li, 2018). The Cronbach's alpha coefficients for the three dimensions for the fathers and mothers ranged from 0.72 to 0.85, indicating good reliability.

2.2.2 Self-control scale

The study employed the Chinese version of the self-control dual-system scale (Xie et al., 2014). This scale comprises 21 items and is divided into two subscales: impulsive system and control system. The impulsive system includes three dimensions: impulsivity, distractibility, and low delay of gratification. The control system encompasses two dimensions: problem-solving and future time perspective. The scale uses a five-point Likert scale (1 = "strongly disagree"; 5 = "strongly agree"). In this study, Cronbach's alpha for the overall scale was 0.71.

2.2.3 Math anxiety scale

The study employed the Chinese version of the Mathematics Anxiety Rating Scale for children, which was originally developed by Suinn and Winston (2003). The Chinese version is considered an effective tool for assessing math anxiety among Chinese adolescents (Wu, 2014). The scale comprises 27 items and uses a five-point Likert scale (1 = "not anxious at all"; 5 = "extremely anxious"). The adolescents reported their anxiety levels, with higher scores indicating higher levels of anxiety. In this study, Cronbach's alpha for the overall scale is 0.87.

2.2.4 Math achievement

Data on participants' math achievement were obtained from school records, specifically the average scores of their two most recent major math examinations. Previous studies have found that performance in math courses effectively reflects academic achievement in Chinese children (Chen et al., 1997; Ding et al., 2012). During data analysis, we converted the math scores of all participants in this study. The resulting Z-scores were used as the final metric for analyzing math achievement.

2.3 Procedure

This study targeted first- and second-year junior high school students and conducted assessments in stages. Before administering the tests, math or homeroom teachers were requested to exclude children with sensory deficits or intellectual disabilities. Subsequently, the tests were conducted in classrooms, with each class assigned two rigorously trained psychology professionals with extensive experience in administering psychological tests as the primary testers. The testers collected data on the adolescent parents' parenting styles, the adolescents' self-control, math anxiety, and math scores on the last two major examinations. Prior to answering the questionnaires, the primary testers provided detailed instructions to the participants and answered their questions. The instructions emphasized the significance of the survey and the confidentiality of the results and required participants to respond independently based on their actual situations. After the administration, the questionnaires were collected by the primary testers. Questionnaire administration and score collection were conducted with the consent of both the students and the schools. The participants were given 25 min to complete the questionnaires and received a small gift upon completion.

2.4 Analysis

SPSS 26.0 was used for the three-stage statistical analysis. First, we tested the skewness of each variable and performed a correlation analysis. Second, after standardizing all variables and evaluating multicollinearity by testing the variance inflation factor (VIF), a mediating analysis was performed to test: (1) Whether paternal and maternal rearing styles have the same predictive effect on adolescents' math achievement and if there are any differences of the predictive effect of the three different rearing styles on adolescents' math achievement; (2) Whether adolescents' self-control plays a mediating role in the relationship between paternal and maternal rearing styles and adolescents' math achievement, and whether it plays the same role between the three different rearing styles and adolescents' math achievement; (3) Whether adolescents' math anxiety plays a mediating role in the relationship between their self-control and math achievement; and (4) Whether adolescents' self-control and math anxiety play a chain-mediating role in the relationship between paternal and maternal rearing styles and math achievement, and whether the three different rearing styles play the same role in the chain-mediating relationship.

For the above analyses, we established two models with adolescents' math achievement as the dependent variable. In the first model, paternal (maternal) rearing style was the independent variable, and self-control and math anxiety were the mediating variables. In the second model, the three dimensions of rearing style (emotional warmth, rejection, overprotection) were the independent variables, and self-control and math anxiety were mediating variables.

Finally, we further verified the mediation effect of the above model. The PROCESS macro in SPSS (Hayes, 2013) was used to calculate the predictive effects of independent variables on dependent variables in each model. This included both the direct effects of independent variables on mediating variables and the direct effects of mediating variables on dependent variables, as well as the indirect effects of independent variables on dependent variables through

mediating variables. The indirect effects of the size of the bias-corrected bootstrapped confidence interval (95% CI) (10,000 samples) without zero indicated that the mediation effect was significant; otherwise, it was deemed not significant. The results of the mediation analysis were reported after standardization.

3 Results

3.1 Descriptive statistics

The mean, standard deviation, and correlation matrix of paternal and maternal rearing styles and adolescents' self-control, math anxiety, and math achievement are shown in Table 1. After distinguishing the three dimensions of rearing styles, the mean, standard deviation, and correlation matrix of variables are shown in Table 2. The skewness analysis shows that the skewness values of each variable were between −1 and 1, indicating that there was no serious skewness distribution. Moreover, after normalizing all variables, the variance inflation factor was less than 10, indicating no multicollinearity issues.

3.2 Mediating analysis of rearing styles, self-control, math anxiety, and math achievement

The mediation analysis revealed that paternal rearing style positively predicted adolescents' self-control ($\beta = 0.083$, $p = 0.044$) (Figure 1). Adolescents' self-control positively predicted their math anxiety ($\beta = 0.229$, $p < 0.001$). Paternal rearing style positively predicted adolescents' math achievement ($\beta = 0.114$, $p = 0.003$). Adolescents' math anxiety negatively predicted their math achievement ($\beta = -0.419$, $p < 0.001$). Paternal rearing style did not significantly predict adolescents' math anxiety ($\beta = 0.041$, $p = 0.310$), and adolescents' self-control did not significantly predict their math achievement ($\beta = 0.027$, $p = 0.488$). Moreover, maternal rearing style positively predicted adolescents' self-control ($\beta = 0.128$, $p = 0.002$). Both maternal rearing style ($\beta = 0.083$, $p = 0.041$) and adolescents' self-control ($\beta = 0.222$, $p < 0.001$) positively predicted adolescents' math anxiety. Maternal rearing style positively predicted adolescents' math achievement ($\beta = 0.158$, $p < 0.000$). Adolescents' math anxiety negatively predicted their math achievement ($\beta = -0.428$, $p < 0.001$), while self-control had no significant predictive effect on math achievement ($\beta = 0.018$, $p = 0.637$). In addition, the mediation effect analysis found that the mediation effect of paternal rearing style on the three paths of math achievement was not significant (Table 3). There was a significant chain-mediated effect of adolescents' self-control and math anxiety on the relationship between maternal rearing style and adolescents' math achievement [95CI (−0.028, 0.001), without passing 0].

To investigate the relationship between the three dimensions of rearing style and adolescents' self-control, math anxiety, and math achievement, we explored these connections from both the perspective of fathers and mothers. The results show that there are both similarities and differences between the three dimensions of paternal and maternal rearing styles and adolescents' self-control, math anxiety, and math achievement (Table 4). Specifically, paternal emotional warmth positively predicted adolescents' self-control, while maternal emotional warmth negatively predicted adolescents' self-control. Only paternal overprotection positively predicted adolescents' math achievement, while both maternal rejection and overprotection positively predicted adolescents' math achievement. The similarity is that both paternal and maternal rejection and overprotection positively predicted adolescents' self-control. Both paternal and maternal emotional warmth negatively predicted adolescents' math

TABLE 1 Correlation analysis of the relationship between parents' rearing styles and adolescent' self-control, math anxiety and math achievement.

Variable	$M \pm SD$	1	2	3	4
1 Parents' rearing styles	57.22 ± 8.95	-	0.08*	0.06	0.09*
2 Self-control	57.53 ± 9.81	0.13**	-	0.23**	−0.06
3 Math anxiety	75.93 ± 20.09	0.11**	0.23**	-	−0.41**
4 Math achievement	71.13 ± 28.99	0.11**	−0.06	−0.41**	-
$M \pm SD$		58.48 ± 9.21	Same above	Same above	Same above

Data of father on the diagonal line, data of mother on the diagonal line, *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

TABLE 2 Correlation analysis of the three dimensions of rearing style and adolescent' self-control, math anxiety and math achievement.

Variable	$M \pm SD$	1	2	3	4	5	6
1. Emotional warmth	24.98 ± 6.81	-	−0.41**	−0.35**	−0.11**	−0.30**	0.18**
2. Rejection	13.66 ± 5.03	−0.40**	–	0.68**	0.18**	0.28**	−0.06
3. Overprotection	18.59 ± 5.14	−0.34**	0.72**	–	0.12**	0.24**	−0.02
4. Self-control	57.53 ± 9.81	−0.09*	0.19**	0.16**	–	0.23**	−0.06
5. Math anxiety	75.93 ± 20.09	−0.23**	0.27**	0.22**	0.23**	–	−0.41**
6. Math achievement	71.13 ± 28.99	0.15**	−0.03	0.04	−0.06	−0.41**	-
$M \pm SD$		25.81 ± 6.51	13.60 ± 5.02	19.07 ± 5.33	57.53 ± 9.81	75.93 ± 20.09	71.13 ± 28.99

Data of father on the diagonal line, data of mother below the diagonal line. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

anxiety, but they had no significant predictive effect on adolescents' math achievement. Rejection and overprotection by both fathers and mothers were positive predictors of adolescents' math anxiety. In addition, adolescents' self-control consistently positively predicted their math anxiety, and adolescents' math anxiety consistently negatively predicted their math achievement.

The results of the mediation effect test show that the mediating effects of adolescents' self-control between paternal (maternal) emotional warmth and math achievement, paternal (maternal) rejection and math achievement, and paternal (maternal) overprotection and math achievement were not significant (Table 5). However, adolescents' math anxiety had a significant mediating effect between paternal (maternal) emotional warmth and adolescents' math achievement, paternal (maternal) rejection and math achievement, and paternal (maternal) overprotection and math achievement. Moreover, adolescents' self-control and math anxiety had significant chain-mediated effects in the chain between paternal (maternal) emotional warmth and math achievement, paternal (maternal) rejection and math achievement, as well as paternal (maternal) overprotection and math achievement.

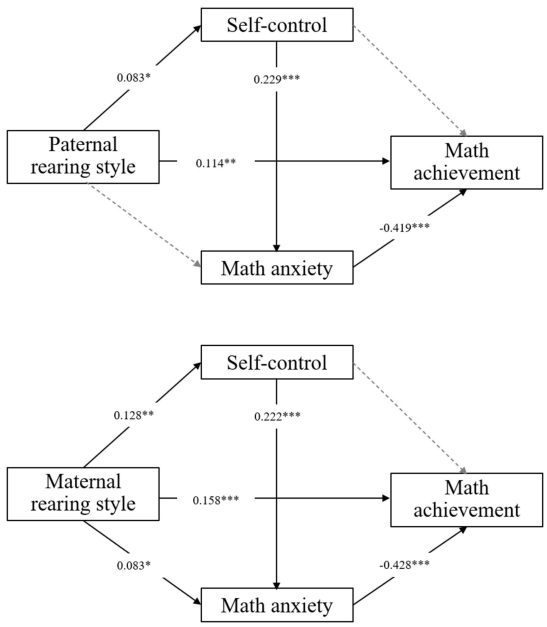

FIGURE 1
Relationship between paternal and maternal rearing styles and adolescents' self-control, math anxiety, and math achievement.

4 Discussion

Based on the ecosystem theory, this study examined the relationship between parents' rearing style and adolescents' self-control, math anxiety, and math achievement from the perspective of both environmental and individual factors influencing adolescents' math achievement. To our knowledge, this is the first study to examine separately the relationship between paternal and maternal rearing styles (including the three dimensions of rearing styles) and adolescent self-control, math anxiety, and math achievement. We found that both paternal and maternal rearing styles were positive predictors of adolescents' math achievement. In addition to the significant chain-mediated effect of adolescents' self-control and math anxiety between maternal rearing style and adolescents' math achievement, the (chain-mediated) effect of adolescents' self-control and math anxiety between paternal rearing style and math achievement, and the mediating effect of adolescents' self-control (math anxiety) between maternal rearing style and adolescents' math achievement were not significant. After distinguishing the rearing styles' three dimensions, this study further found that adolescents' math anxiety always plays a mediating role between the three dimensions of paternal and maternal rearing styles and math achievement, adolescents' self-control and math anxiety play a chain mediating role between the three dimensions of paternal and maternal rearing styles and math achievement. The mediating effect of adolescents' self-control on the three dimensions of paternal and maternal rearing styles and math achievement was not significant. However, the specific parenting styles adopted by fathers and mothers differ in their predictive effects on adolescents' math achievement. The above results are not entirely consistent with our expectations. The results suggest that although paternal and maternal rearing styles both directly predict adolescents' math achievement, their indirect prediction effects on adolescents' math achievement vary. Moreover, there are similarities and differences between the three dimensions of the paternal and maternal rearing styles in predicting adolescents' math achievement through math anxiety and the mediating role of self-control and math anxiety.

In this study, we found that both paternal and maternal rearing styles positively predicted adolescents' math achievement, which is consistent with ecological theory (Bronfenbrenner, 1979). This study further found that paternal and maternal emotional warmth, rejection, and overprotection predict adolescent math achievement through math anxiety and the chain mediation of self-control and math anxiety, enriching the ecosystem and social cognition theories. These results are also consistent with those of research based on the relationship between parents' (paternal and maternal) rearing styles and adolescents' math anxiety (Jin et al., 2024; Wang et al., 2023), as

TABLE 3 The mediating effect of self-control and math anxiety on the relationship between parents' rearing styles and adolescents' math achievement.

Pathways	Paternal			Maternal		
	Indirect effects	*SE*	95%CI	Indirect effects	*SE*	95%CI
RS → SC → MAc	0.002	0.005	−0.006, 0.016	0.002	0.007	−0.009, 0.018
RS → MAn → MAc	−0.017	0.020	−0.056, 0.023	−0.036	0.021	−0.078, 0.006
RS → SC → MAn → MAc	−0.008	0.007	−0.023, 0.004	−0.012	0.007	−0.028, −0.001
Total indirect effect of RS → MAc	−0.023	0.020	−0.061, 0.016	−0.045	0.021	−0.088, −0.005

RS, rearing styles; SC, self-control; MAc, math achievement; MAn, math anxiety.

TABLE 4 Standard coefficients between the three dimensions of paternal and maternal rearing styles and self-control, math anxiety, and math achievement.

Pathways	Paternal	Maternal
Emotional warmth → Self-control	0.112**	−0.093*
Rejection → Self-control	0.183***	0.186***
Overprotection → Self-control	0.115**	0.159**
Emotional warmth → Math anxiety	−0.281***	−0.210***
Rejection → Math anxiety	0.240***	0.231***
Overprotection → Math anxiety	0.215***	0.191***
Emotional warmth → Math achievement	0.060	0.060
Rejection → Math achievement	0.025	0.079*
Overprotection → Math achievement	0.083*	0.138**
Self-control→ Math achievement	0.201***/0.188***/0.207***	0.213***/0.189***/0.202***
Math anxiety → Math achievement	−0.396***/−0.427***/−0.433***	−0.401***/−0.433***/−0.441***

RS, rearing styles; SC, self-control; MAc, math achievement; MAn, math anxiety.
The three data points between self-control and math anxiety, and math anxiety and math achievement are standardized regression coefficients under three different parenting styles.

TABLE 5 The mediating effect of self-control and math anxiety on the three dimensions of parents' rearing styles and adolescents' math achievement.

Paths	Paternal			Maternal		
	Indirect effects	*SE*	95%CI	Indirect effects	*SE*	95%CI
EW → SC → MAc	−0.004	0.006	−0.018, 0.005	−0.004	0.005	−0.016, 0.005
EW → MAn → MAc	0.111	0.021	0.073, 0.154	0.084	0.020	0.048, 0.125
EW → SC → MAn → MAc	0.009	0.005	0.002, 0.019	0.008	0.005	0.001, 0.018
Total indirect effect of EW → MAc	0.116	0.021	0.077, 0.159	0.089	0.020	0.052, 0.131
RE → SC → MAc	0.005	0.009	−0.010, 0.026	0.005	0.009	−0.011, 0.025
RE → MAn → MAc	−0.102	0.021	−0.145, −0.062	−0.099	0.021	−0.142, −0.060
RE → SC → MAn → MA	−0.015	0.006	−0.029, −0.005	−0.015	0.007	−0.030, −0.005
Total indirect effect of RE → MAc	−0.112	0.022	−0.155, −0.070	−0.110	0.021	−0.153, −0.070
OV → SC → MAc	0.003	0.006	−0.006, 0.019	0.003	0.008	−0.010, 0.021
OV → MAn → MAc	−0.093	0.020	−0.134, −0.054	−0.084	0.021	−0.126, −0.044
OV → SC → MAn → MA	−0.010	0.006	−0.024, −0.001	−0.014	0.006	−0.029, −0.004
Total indirect effect of OV → MAc	−0.100	0.021	−0.143, −0.060	−0.095	0.022	−0.138, −0.053

EW, emotional warmth; RE, rejection; OV, overprotection; SE, standard error of the coefficient.

well as previous meta-analysis and recent follow-up studies that found a close relationship between adolescent math anxiety and math achievement (Barroso et al., 2021; St Omer and Chen, 2023). Some studies have found that both parental emotional warmth and rejection can predict adolescent depression and other emotions (Li et al., 2024; Wang et al., 2023). Moreover, parental emotional warmth and rejection are associated with adolescent personality development and creativity (Guo et al., 2021). These results indicate that less emotional warmth of both fathers and mothers will increase adolescents' math anxiety, which is not conducive to the improvement of math achievement. Further, the higher the level of overprotection and rejection, the higher the adolescents' math anxiety, which is also not conducive to the improvement of adolescents' math achievement. However, both fathers and mothers should pay attention to their rearing styles as they are important for adolescents' math achievement and healthy growth.

While both paternal and maternal rearing styles positively predict math achievement, the predictive effects of paternal and maternal rearing styles on adolescent math achievement vary. This variation is mainly reflected in the following three aspects. First, the indirect predictors of math achievement differ between paternal and maternal rearing styles. The paternal rearing style does not predict adolescent math achievement through self-control, math anxiety, or the chain mediation between self-control and math anxiety; however, the maternal rearing style does predict math achievement through the chain mediation between self-control and math anxiety. This may be related to the different roles and division of labor between fathers and mothers in housework. For example, according to the male breadwinner-female housewife model, in most Chinese families, fathers are more focused on working or earning a living, while mothers are more focused on family and childcare (Waismel-Manor and Levanon, 2024). Therefore, maternal rearing styles predict

adolescent math achievement through the indirect effect of adolescent self-control and math anxiety, indicating that the indirect prediction effects of paternal and maternal rearing styles differ. More obvious maternal rearing styles lead to increased adolescent self-control. However, this may increase adolescent math anxiety, which, in turn, can negatively affect adolescent math achievement. Therefore, this result highlights how maternal rearing styles play a role in adolescents' math achievement.

Second, we found that different dimensions of paternal and maternal rearing styles variably directly predicted adolescent math achievement. Only the overprotection of fathers can directly and positively predict adolescents' math achievement, while maternal rejection and overprotection can positively predict adolescents' math achievement. This is inconsistent with the autonomy-supportive and distance-conflict theory (Guo et al., 2021). Such differences may be related to factors such as family education and children's cognition caused by cultural differences between China and the West (Li et al., 2019). In addition, the differences between paternal and maternal rearing styles and the three dimensions of rearing styles are considered (Li et al., 2024). Our results suggest that, on the one hand, fathers should devote more time to adolescents' daily education and care to balance with mothers. On the other hand, mothers, who often accompany and care for adolescents at home, should appropriately let go and let adolescents make their own decisions to cultivate their sense of responsibility, making adolescents more active and tenacious in facing problems, such as those in math. Furthermore, if necessary, educational supervision can be strengthened to help adolescents improve their math and other achievements.

Third, the three dimensions of paternal and maternal rearing styles vary in predicting adolescents' self-control. Maternal emotional warmth reduces adolescent self-control, while paternal emotional warmth increases adolescent self-control. This is consistent with previous studies and corresponding theoretical views (Cullen et al., 2008). According to the ecological theory, environmental factors (such as parents' rearing style) play crucial roles in the self-control of individuals (Bronfenbrenner, 1979; Li et al., 2019). In addition, according to autonomy-supportive parenting theory (Guo et al., 2021), too much or too little parental warmth and support may be detrimental to the development of various abilities of children, such as self-control (Retanal et al., 2021). Therefore, the findings of this study indicate that mothers should be cautious when adopting emotional warmth rearing style, as excessive levels of emotional warmth may not be conducive to adolescents' self-control.

In addition, this study found that self-control consistently positively predicts math anxiety in adolescents. This contradicts previous research findings based on adolescent participants. For instance, Tevfik (2015) has found a significant negative relationship between adolescents' self-control and math anxiety. Our results may align with Kremen and Block's (1998) explanation, which suggests that the benefits of self-control follow a curved pattern. Insufficient control (defined as low self-control) predisposes individuals to undesirable outcomes such as anxiety and antisocial behavior. However, excessive control (defined as high self-control) may suppress spontaneity, creativity, and joy in learning and other areas of life. They further propose that insufficient control may be associated with behavioral issues such as criminality and aggression, while excessive control may be linked to emotional problems such as anxiety and depression (Finkenauer et al., 2005). Our findings suggest that excessive self-control among adolescents may increase math anxiety.

We further found a significant negative correlation between math anxiety and adolescents' math achievement. This differs from a recent study conducted in a Chinese cultural context (St Omer and Chen, 2023). In their one-year longitudinal study involving Taiwanese adolescents, St Omer and Chen (2023) found a significant positive relationship between math anxiety and math achievement. This discrepant result could stem from differences in the participant setting, sample sizes, and measurement tools for math anxiety between the two studies (Namkung et al., 2019). Specifically, we selected 584 children from economically and relatively underdeveloped northwestern regions of mainland China, while St Omer and Chen (2023) included 335 children from economically developed Taiwan. Additionally, our study employed a math anxiety scale revised by Chinese scholars that has been considered appropriate for measuring math anxiety among Chinese children, whereas St Omer and Chen (2023) used a more widely applicable math anxiety scale. Our findings indicate that within the same cultural background, the relationship between adolescents' math anxiety and math achievement can vary. In mainland China, adolescents' math anxiety is detrimental to improving their math achievement.

5 Limitations and implications

This study has several limitations. First, it is a cross-sectional study, which precludes the investigation of causal relationships between variables. Future research could employ longitudinal studies to examine bidirectional and causal relationships between variables. Second, the methodology of this study relies on self-reports from adolescents to measure perceived parenting styles, rather than actual parenting practices. Future studies could utilize multi-informant assessments to gain a more comprehensive understanding of the role of parenting styles. Last, the study employed a convenience sampling method, recruiting first- and second-year junior high school students as participants, which may limit the sample's representativeness. Future research should employ more systematic sampling methods to include adolescents and children of various age groups, enhancing the representativeness of the sample.

However, this study holds significant theoretical and practical implications. Our findings reveal that parenting styles, especially maternal rearing styles, have a direct or indirect predictive effect on adolescents' math achievement. Further, we distinguished the three dimensions of rearing style and found both similarities and differences in the influence thereof on adolescents' math achievement. This has enriched the ecosystem theory research on the relationship between parents' parenting style and adolescents' math achievement. Second, to comprehensively analyze the formation mechanism of adolescents' math achievement, our study focused on environmental factors (rearing style) and individual adolescent factors (self-control and math anxiety). This perspective and the corresponding results expand the application of social cognitive, emotional motivation and other related theories in the field of education and provide a reference for follow-up research regarding adolescent math achievement. Finally, this study found that math anxiety is a stable mediating variable between the three dimensions of parents' rearing styles and adolescents' math achievement, which provides an important basis for understanding the role of math anxiety in the formation of academic achievement.

This study has practical implications for alleviating adolescents' math anxiety and improving their math achievement. We found that

paternal and maternal emotional warmth negatively predicts adolescents' math anxiety, parental rejection and overprotection positively predict adolescents' math anxiety, the three dimensions of paternal and maternal rearing styles predict adolescents' self-control and math anxiety, and the chain mediators of math anxiety and self-control predict math achievement. These findings provide guidance for family education as follows: First, adolescence is a critical period for the development of math anxiety (Wang et al., 2020). When educating children, both parents should pay attention to positive rearing styles such as warmth and support, and avoid negative rearing styles such as rejection and punishment to reduce adolescents' math anxiety and improve their math performance. Second, the emotional communication between father/mother and adolescents should be controlled so that adolescents can feel paternal and maternal warmth. At the same time, parents should appropriately 'let go' to exercise adolescents' sense of autonomy and responsibility, promote the balanced development of adolescents' mental health, and help adolescents improve their math performance.

6 Conclusion

Both paternal and maternal rearing styles can significantly predict adolescents' math achievement. Moreover, maternal rearing styles can indirectly predict adolescents' math achievement through self-control and math anxiety. Furthermore, paternal and maternal emotional warmth can reduce adolescents' math anxiety, and thus improve adolescents' math achievement. While parental rejection and over-protection may appear to enhance adolescents' self-control, they actually hinder the improvement of adolescents' math achievement by increasing math anxiety. Our results suggest the importance of parental, especially maternal, rearing styles to adolescent math achievement and the difference between paternal and maternal rearing styles in predicting adolescent math achievement. Parents should adopt more warm, positive, and supportive rearing styles and less rejection, punishment, and other negative rearing styles; furthermore, parents should grasp a certain degree of such styles to increase adolescents' self-control, reduce their math anxiety, and help them improve their math performance.

Data availability statement

The datasets presented in this article are not readily available due to the sensitivity of the data: adolescent math achievement. Requests to access the datasets should be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by the Scientific Research Ethics Committee on School of Psychology of Northwest Normal University (Approval No. 2023101). The study was carried out in the schools after verbal informed consent had been given by the head of middle schools and the children's parents.

Author contributions

YW: Writing – original draft, Formal analysis, Conceptualization. LH: Writing – original draft, Methodology, Conceptualization. YT: Writing – review & editing, Methodology, Investigation, Conceptualization. YM: Writing – review & editing, Supervision, Project administration, Investigation.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Abedini, Y., Zamani, B. E., Kheradmand, A., and Rajabizadeh, G. (2012). Impacts of mothers' occupation status and parenting styles on levels of self-control, addiction to computer games, and educational progress of adolescents. *Addict. Health.* 4, 102–110

Bandura, A. (1997). Self-efficacy: The exercise of control. New York: Freeman.

Bardach, L., Yanagida, T., Goetz, T., Jach, H., and Pekrun, R. (2023). Self-regulated and externally regulated learning in adolescence: developmental trajectories and relations with teacher behavior, parent behavior, and academic achievement. *Dev. Psychol.* 59, 1327–1345. doi: 10.1037/dev0001537

Barroso, C., Ganley, C. M., McGraw, A. L., Geer, E. A., Hart, S. A., and Daucourt, M. C. (2021). A meta-analysis of the relation between math anxiety an math achievement. *Psychol. Bull.* 147, 134–168. doi: 10.1037/bul0000307

Borgonovi, F., Pokropek, M., and Pokropek, A. (2023). Relations between academic boredom, academic achievement, ICT use, and teacher enthusiasm among adolescents. *Comput. Educ.* 200:104807. doi: 10.1016/j.compedu.2023.104807

Brewin, C. R. (1996). Theoretical foundations of cognitive-behavior therapy for anxiety and depression. *Annu. Rev. Psychol.* 47, 33–57. doi: 10.1146/annurev.psych.47.1.33

Bronfenbrenner, U. (1979). The ecology of human development. Cambridge, MA: Harvard University Press.

Burt, C. H. (2020). Self-control and crime: beyond Gottfredson and Hirschi's theory. *Annu. Rev. Criminol.* 3, 43–73. doi: 10.1146/annurev-criminol-011419-041344

Chen, X., Rubin, K. H., and Li, D. (1997). Relation between academic achievement and social adjustment: evidence from chinese children. *Dev. Psychol.* 33, 518–525. doi: 10.1037/0012-1649.33.3.518

Choe, K. W., Jenifer, J. B., Rozek, C. S., Berman, M. G., and Beilock, S. L. (2019). Calculated avoidance: math anxiety predicts math avoidance in effort-based decision-making. *Sci. Adv.* 5:1062. doi: 10.1126/sciadv.aay1062

Cleary, T. J., and Chen, P. P. (2009). Self-regulation, motivation, and math achievement in middle school: variations across grade level and math context. *J. Sch. Psychol.* 47, 291–314. doi: 10.1016/j.jsp.2009.04.002

Cleary, T. J., and Kitsantas, A. (2017). Motivation and self-regulated learning influences on middle school mathematics achievement. *Sch. Psychol. Rev.* 46, 88–107. doi: 10.1080/02796015.2017.12087607

Cullen, F. T., Unnever, J. D., Wright, J. P., and Beaver, K. M. (2008). "Parenting and self- control" in Out of control: Assessing the general theory of crime. ed. E. Goode (Stanford University, United States: Stanford University Press), 61–74.

Dent, A. L., and Koenka, A. C. (2015). The relation between self-regulated learning and academic achievement across childhood and adolescence: a meta-analysis. *Educ. Psychol. Rev.* 28, 425–474. doi: 10.1007/s10648-015-9320-8

Ding, X. C., Shi, X. X., and Liu, J. S. (2012). The predictive relationship between academic achievement and internalized behavior problems: a one-year follow-up study. *Chin. J. Clin. Psychol.* 20, 697–701. doi: 10.16128/j.cnki.1005-3611.2012.05.020

Du, Y., Dang, Q., Zhang, B., Wu, R., and Rasool, A. (2021). The effects of parenting differences on psychological resilience in adolescent students: the role of gratitude. *Child Youth Serv. Rev.* 130:106224. doi: 10.1016/j.childyouth.2021.106224

Duckworth, A. L., Taxer, J. L., Eskreis-Winkler, L., Galla, B. M., and Gross, J. J. (2019). Self-control and academic achievement. *Annu. Rev. Psychol.* 70, 373–399. doi: 10.1146/annurev-psych-010418-103230

Finkenauer, C., Engels, R., and Baumeister, R. (2005). Parenting behaviour and adolescent behavioural and emotional problems: the role of self-control. *Int. J. Behav. Dev.* 29, 58–69. doi: 10.1080/01650250444000333

Fong, C. J., Kremer, K. P., Hill-Troglin Cox, C., and Lawson, C. A. (2021). Expectancy-value profiles in math and science: a person-centered approach to cross-domain motivation with academic and STEM-related outcomes. *Contemp. Educ. Psychol.* 65:101962. doi: 10.1016/j.cedpsych.2021.101962

Guo, J., Zhang, J., and Pang, W. (2021). Parental warmth, rejection, and creativity: the mediating roles of openness and dark personality traits. *Per.s Indiv. Differ.* 168:110369. doi: 10.1016/j.paid.2020.110369

Hayes, A. F. (2013). I*ntroduction to mediation, moderation, and conditional Process analysis*. New York: Guilford.

Husain, F. (2023). The impact of physical training on academic progress: a perspective through self-determination theory and maslow's hierarchy of needs. *Brit. J. Educ.* 11, 82–92. doi: 10.37745/bje.2013/vol11n118292

Jain, S., and Dowson, M. (2009). Mathematics anxiety as a function of multidimensional self-regulation and self-efficacy. *Contemp. Educ. Psychol.* 34, 240–249. doi: 10.1016/j.cedpsych.2009.05.004

Jiang, S., Lu, Z. R., Jiang, B. J., and Xu, Y. (2010). Preliminary revision of the Chinese version of the simplified parenting style questionnaire. *Psychol. Dev. Edu.* 1, 94–99. doi: 10.16187/j.carolcarrollnkiissn1001-4918.2010.01.017

Jin, X., Li, X., Li, J., Kou, G., and Zhang, X. (2024). The relationship between parental autonomy support and adolescents' academic achievement in mathematics—the mediating role of the need for cognition and mathematics metacognition. *Curr. Psychol.* 43, 29189–29198. doi: 10.1007/s12144-024-06435-1

John, J. E., Nelson, P. A., Klenczar, B., and Robnett, R. D. (2020). Memories of math: narrative predictors of math affect, math motivation, and future math plans. *Contemp. Educ. Psychol.* 60:101838. doi: 10.1016/j.cedpsych.2020.101838

King, R. B., and Gaerlan, M. J. M. (2014). High self-control predicts more positive emotions, better engagement, and higher achievement in school. *Eur. J. Psychol. Educ.* 29, 81–100. doi: 10.1007/s10212-013-0188-z

Kremen, A. M., and Block, J. (1998). The roots of ego-control in young adulthood: links with parenting in early childhood. *J. Pers. Soc. Psychol.* 75, 1062–1075. doi: 10.1037//0022-3514.75.4.1062

Le, H., and Robbins, S. B. (2016). Building the STEM pipeline: findings of a 9-year longitudinal research project. *J. Vocat. Behav.* 95, 21–30. doi: 10.1016/j.jvb.2016.07.002

Li, Y. Z. (2018). A study on the influence mechanism of parental rearing style on high school students' learning engagement. *Chin. J. Clin. Psychol.* 26, 997–1001. doi: 10.16128/j.cnki.1005-3611.2018.05.034

Li, C., Dang, J., Zhang, X., Zhang, Q., and Guo, J. (2014). Internet addiction among Chinese adolescents: the effect of parental behavior and self-control. *Comput. Hum. Behav.* 41, 1–7. doi: 10.1016/j.chb.2014.09.001

Li, D., Li, W., and Zhu, X. (2023a). Parenting style and children emotion management skills among Chinese children aged 3–6: the chain mediation effect of self-control and peer interactions. *Front. Psychol.* 14:1231920. doi: 10.3389/fpsyg.2023.1231920

Li, Y., Scott Huebner, E., and Tian, L. (2023b). Deviant peer affiliation, self-control, and aggression during early adolescence: within-person effects and between-person differences. *Eur. Child Adolesc. Psychiatry* 33, 2343–2352. doi: 10.1007/s00787-023-02336-z

Li, J. B., Willems, Y. E., Stok, F. M., Deković, M., Bartels, M., and Finkenauer, C. (2019). Parenting and self-control across early to late adolescence: a three-level meta-analysis. *Perspect. Psychol. Sci.* 14, 967–1005. doi: 10.1177/1745691619863046

Li, Y., Ye, Y., and Zhou, X. (2024). Parent–child relationship, parenting behaviors, and adolescents' depressive symptoms after an earthquake: unraveling within-adolescent associations from between-adolescent differences. *Eur. Child. Adoles. Psy.* 33, 2301–2318. doi: 10.1007/s00787-023-02319-0

Luo, Y., Zhang, H., and Chen, G. (2020). The impact of family environment on academic burnout of middle school students: the moderating role of self-control. *Child Youth Serv. Rev.* 119:105482. doi: 10.1016/j.childyouth.2020.105482

Macmull, M. S., and Ashkenazi, S. (2019). Math anxiety: the relationship between parenting style and math self-efficacy. *Front. Psychol.* 10:1721. doi: 10.3389/fpsyg.2019.01721

Martin, J. (2004). Self-regulated learning, social cognitive theory, and agency. *Edu. Psychol.* 39, 135–145. doi: 10.1207/s15326985ep3902_4

Moilanen, K. L., Rasmussen, K. E., and Padilla-Walker, L. M. (2014). Bidirectional associations between self-regulation and parenting styles in early adolescence. *J. Res. Adolesc.* 25, 246–262. doi: 10.1111/jora.12125

Mun, C. J., Dishion, T. J., Tein, J. Y., and Otten, R. (2018). Adolescence effortful control as a mediator between family ecology and problematic substance use in early adulthood: a 16-year prospective study. *Dev. Psychopathol.* 30, 1355–1369. doi: 10.1017/s0954579417001742

Muraven, M. (2010). Building self-control strength: practicing self-control leads to improved self-control performance. *J. Ex. Soci Psychol.* 46, 465–468. doi: 10.1016/j.jesp.2009.12.011

Muraven, M., and Baumeister, R. F. (2000). Self-regulation and depletion of limited resources: does self-control resemble a muscle? *Psychol. Bull.* 126, 247–259. doi: 10.1037/0033-2909.126.2.247

Namkung, J. M., Peng, P., and Lin, X. (2019). The relation between mathematics anxiety and mathematics performance among school-aged students: a meta-analysis. *Rev. Educ. Res.* 89, 459–496. doi: 10.3102/0034654319843494

Oatley, K., and Johnson-Laird, P. N. (2014). Cognitive approaches to emotions. *Trends Cogn. Sci.* 18, 134–140. doi: 10.1016/j.tics.2013.12.004

Ogg, J., and Anthony, C. J. (2020). Process and context: longitudinal effects of the interactions between parental involvement, parental warmth, and SES on academic achievement. *J. School. Psychol.* 78, 96–114. doi: 10.1016/j.jsp.2019.11.004

Pallini, S., Chirumbolo, A., Morelli, M., Baiocco, R., Laghi, F., and Eisenberg, N. (2018). The relation of attachment security status to effortful self-regulation: a meta-analysis. *Psychol. Bull.* 144, 501–531. doi: 10.1037/bul0000134

Peterson, S. M., Aljadeff-Abergel, E., Eldridge, R. R., VanderWeele, N. J., and Acker, N. S. (2020). Conceptualizing self-determination from a behavioral perspective: the role of choice, self-control, and self-management. *J. Behav. Educ.* 30, 299–318. doi: 10.1007/s10864-020-09368-4

Pinquart, M. (2015). Associations of parenting styles and dimensions with academic achievement in children and adolescents: a meta-analysis. *Educ. Psychol. Rev.* 28, 475–493. doi: 10.1007/s10648-015-9338-y

Retanal, F., Johnston, N. B., Di Lonardo Burr, S. M., Storozuk, A., DiStefano, M., and Maloney, E. A. (2021). Controlling-supportive homework help partially explains the relation between parents' math anxiety and Children's math achievement. *Educ. Sci.* 11:620. doi: 10.3390/educsci11100620

Rodríguez-Ruiz, J., Zych, I., Ribeaud, D., Steinhoff, A., Eisner, M., Quednow, B. B., et al. (2023). The influence of different dimensions of the parent–child relationship in childhood as longitudinal predictors of substance use in late adolescence. The mediating role of self-control. *Int. J. Ment Health. Ad.* 3, 1–18. doi: 10.1007/s11469-023-01036-8

St Omer, S. M., and Chen, S. (2023). Examining the dynamics of mathematics anxiety, perceived cost, and achievement: a control-value theory approach. *Contemp. Educ. Psychol.* 73:102169. doi: 10.1016/j.cedpsych.2023.102169

Suinn, R. M., and Winston, E. H. (2003). The mathematics anxiety rating scale, a brief version: psychometric data. *Psychol. Rep.* 92, 167–173. doi: 10.2466/pr0.2003.92.1.167

Tangney, J. P., Baumeister, R. F., and Boone, A. L. (2004). High self-control predicts good adjustment, less pathology, better grades, and interpersonal success. *J. Pers.* 72, 271–324. doi: 10.1111/j.0022-3506.2004.00263.x

Tevfik, I. (2015). The relationship between secondary school students mathematics anxiety and self-regulation. *Educ. Res. Rev.* 10, 684–690. doi: 10.5897/err2014.1896

Toh, L., and Watt, H. M. G. (2022). How do adolescent mathematical self-concept and values explain attainment of different kinds of STEM degrees in adulthood? *Contemp. Educ. Psychol.* 69:102057. doi: 10.1016/j.cedpsych.2022.102057

Underdown, A. (2007). Children and families in communities: theory, research, policy and practice. *Child. Soc.* 21, 399–400. doi: 10.1111/j.1099-0860.2007.00103.x

Waismel-Manor, R., and Levanon, A. (2024). Inequality within the family: a comparative analysis of gendered working time preferences among dual-earner couples. *Sex Roles* 90, 832–847. doi: 10.1007/s11199-024-01481-2

Wang, Z., Borriello, G. A., Oh, W., Lukowski, S., and Malanchini, M. (2021). Co-development of math anxiety, math self-concept, and math value in adolescence: the roles of parents and math teachers. *Contemp. Educ. Psychol.* 67:102016. doi: 10.1016/j.cedpsych.2021.102016

Wang, C., Cho, H. J., Wiles, B., Moss, J. D., Bonem, E. M., Li, Q., et al. (2022). Competence and autonomous motivation as motivational predictors of college students' mathematics achievement: from the perspective of self-determination theory. *Int. J. Stem. Edu.* 9:41. doi: 10.1186/s40594-022-00359-7

Wang, D., and Fletcher, A. C. (2015). Parenting style and peer trust in relation to school adjustment in middle childhood. *J.Child Fam. Stud.* 25, 988–998. doi: 10.1007/s10826-015-0264-x

Wang, C., Li, X., and Wang, H. J. (2023). The mediating effect of math self-efficacy on the relationship between parenting style and math anxiety. *Front. Psychol.* 14:1197170. doi: 10.3389/fpsyg.2023.1197170

Wang, Z., Lukowski, S. L., Hart, S. A., Lyons, I. M., Thompson, L. A., Kovas, Y., et al. (2015). Is math anxiety always bad for math learning? The role of math motivation. *Psychol. Sci.* 26, 1863–1876. doi: 10.1177/0956797615602471

Wang, Z., Oh, W., Malanchini, M., and Borriello, G. A. (2020). The developmental trajectories of mathematics anxiety: cognitive, personality, and environmental correlates. *Contemp. Educ. Psychol.* 61:101876. doi: 10.1016/j.cedpsych.2020.101876

Wu, J. (2014). A study on the relationship between math anxiety, math self-efficacy and math academic achievement of junior high school students. China: Nanjing Normal University.

Xie, D. J., Wang, L. G., Tao, T., Fan, C., and Gao, W. B. (2014). Validity and reliability of the Chinese version of the two-system scale of adolescent self-control. *Chin. J. Mental Health.* 28, 386–391. doi: 10.3969/j.issn.1000-6729.2014.05.012

Yang, P., Li, X., Li, X., Li, D., Xu, X., and Zhao, C. (2023). Parent-grandparent co-parenting and preschoolers' self-control in China: the roles of maternal and grandparental parenting styles. *Early Educ. Dev.* 35, 572–587. doi: 10.1080/10409289.2023.2186087

Zimmerman, B. J. (1989). A social cognitive view of self-regulated academic learning. *J. Educ. Psychol.* 81:329. doi: 10.1037/0022-0663.81.3.329

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The influence of mind mapping on computational thinking skills and self-efficacy in students' learning of graphical programming

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Computational thinking is regarded as an essential skill for students in the 21st century, and programming is one of the means to cultivate it. This study introduces mind mapping into graphical programming to visualize the cognitive process of computational thinking, aiming to enhance students' computational thinking skills. After a semester of teaching experiments, independent-sample *t*-tests and paired-sample *t*-tests were conducted on the data, revealing significant improvements in both computational thinking skills and self-efficacy among the students in the experimental group. Further analysis of the data showed significant enhancements in their algorithmic thinking and modeling, as well as pattern recognition and evaluation sub-skills, while abstraction and decomposition sub-skills did not show significant improvement. Additionally, the experimental group demonstrated significant improvements to varying degrees in five dimensions of computational thinking self-efficacy: creativity, algorithmic thinking, collaboration skills, critical thinking, and problem-solving abilities.

KEYWORDS

mind mapping, computational thinking skills, self-efficacy, computational thinking, *t*-test

1 Introduction

The development of digital technology has created many new job opportunities while also posing a certain impact on the traditional employment structure, requiring enterprises to have more talents with digital technology and knowledge. As the digital society transforms the way people work and live, it also sets new requirements for citizens' digital literacy (Silva et al., 2021). Consequently, in today's era of rapid information technology development, understanding the fundamental principles of computer science is no longer solely the domain of programmers and computer scientists. Applying computer science to solve problems has become an essential skill for everyone, which also embodies the essence of computational thinking (Yang and Lin, 2024). Computational thinking is defined as a way of thinking that utilizes computer science concepts to solve problems, design systems, and understand human behavior (Wing, 2006). It is a fundamental skill essential for successful learners in the 21st century.

Against this backdrop, countries worldwide have recognized the importance of fostering computational thinking and have introduced policies to advance its education. Scholars are actively exploring strategies to enhance students' computational thinking skills and have proposed that programming is an ideal tool for nurturing computational thinking (Hsu et al., 2018). This is because programming provides avenues for applying computational

concepts and practices while also supporting the development of cognitive abilities related to computational thinking (Basogain Olabe et al., 2017). Research has found that visual programming can significantly boost students' computational thinking skills (Aksit and Wiebe, 2020). However, for younger students, programming poses certain challenges due to difficulties in comprehending abstract and generalizing concepts, as well as the prerequisite knowledge of basic concepts, syntax, and commands (Mladenović et al., 2021).

In response, scholars point out that learners' prior knowledge is a crucial factor influencing programming learning, as students often lack a programming background and related knowledge, leading to difficulties in grasping programming concepts and practical operations (Demir, 2022). Establishing a systematic mindset to comprehend programming concepts and principles is key to learning programming (Cui and Ng, 2021). In programming, the process of using computational thinking to solve problems is a systematic thought process involving a series of cognitive steps such as analyzing problems, decomposing them, extracting essences, selecting algorithms, and implementing programming. Therefore, through systematic thinking training, students' computational thinking and programming abilities can be effectively enhanced.

However, in current programming education, the teaching organization often proceeds directly from problem identification and understanding to code implementation, with the research focus on the realization of projects/works/functions (e.g., Atmatzidou and Demetriadis, 2016; Sullivan et al., 2017). There is a lack of developing students' process-oriented thinking in problem-solving, i.e., a lack of a thinking training process. The existing teaching places emphasis on the debugging phase of programming, with less emphasis on the most essential thinking processes in computational thinking, such as abstraction and decomposition. Furthermore, students' thinking is implicit in their programming works, making it difficult for teachers to identify issues. As a result, some scholars suggest that when teaching programming, in addition to using block-based programming with graphical interfaces, it is also crucial to help students articulate their programming logic to arrange appropriate programming blocks (Barr and Stephenson, 2011). We need tools to assist students in training their thinking, expressing their ideas, and visualizing their implicit thinking.

Research has shown that visual representations of thinking can help students express the relationships between complex ideas, showcasing internal cognitive structures in a visual form, which aids in recalling key components (Davies, 2011). Thus, organizing thoughts and supplementing ideas through relevant graphics (e.g., flowcharts, mind maps, graphic organizers) can significantly enhance students' learning outcomes (Batdi, 2015; Shi et al., 2023; Stokhof et al., 2020; Zhao et al., 2022). Scholars have empirically confirmed that using mind maps in teaching can positively impact students' academic performance, attitudes, conceptual learning, and critical thinking. Similarly, in research related to computational thinking, the use of mind maps has been proven to significantly improve primary school students' computational thinking skills. However, there is a lack of empirical research on the impact of mind maps on middle school students' computational thinking skills and self-efficacy in graphical programming. Therefore, this study aims to explore the effects of mind maps on middle school students' computational thinking skills and self-efficacy in graphical programming.

2 Literature review

2.1 Definition of computational thinking

Different scholars have defined computational thinking from various perspectives. Papert was the first to propose the concept of computational thinking, which he saw as a process of using computational representations to articulate important ideas, making them clearer and more explicit (Atmatzidou and Demetriadis, 2016). Wing defined computational thinking as "a process of solving problems, designing systems, and understanding human behavior by drawing on the concepts fundamental to computer science" (Wing, 2006). Brennan et al. believed that computational thinking encompasses three dimensions: computational concepts, computational practices, and computational perspectives (Brennan and Resnick, 2012). Many other scholars have understood computational thinking as a cognitive process that integrates multiple thinking processes (Israel-Fishelson and Hershkovitz, 2022; Selby, 2013), including decomposition (breaking down problems into smaller, manageable parts), abstraction (identifying and extracting key information from real-world situations), algorithmic thinking (solving problems through a series of steps and instructions), pattern recognition (the ability to identify similarities in problems and situations), and programming debugging (converting instructions into computer programs, identifying errors, and debugging for corrections). In this study, computational thinking is viewed as a cognitive process, and thus, enhancing computational thinking can be seen as training and nurturing this series of thinking processes.

Enhancing students' computational thinking is not about turning them into programmers, but empowering them to apply the thought processes of computer science to solve problems. As such, in nurturing computational thinking, it is crucial to train students' minds and equip them with a comprehensive set of thought processes. As mentioned earlier, a prevailing issue in current computational thinking education is the overemphasis on programming and debugging, while neglecting other cognitive processes like decomposition, abstraction, algorithmic thinking, and pattern recognition. This one-sided approach hinders students from developing a systematic computational thinking framework.

Furthermore, when students are coding, their thought processes are implicitly embedded in their work, making it challenging for teachers to pinpoint which specific aspect of the cognitive process is problematic for individual students. Consequently, it becomes difficult to identify students' weaknesses across different dimensions. To address these challenges, we must leverage tools that enhance students' capabilities in all dimensions of computational thinking and visualize these thought processes. By doing so, not only can teachers better understand the intricacies of each student's cognitive journey, but they can also tailor instruction to address specific weaknesses, thereby fostering a more holistic and effective development of computational thinking skills.

2.2 Tools for cultivating computational thinking

While there are numerous tools available for fostering computational thinking, given the advantages of programming in this regard, our focus lies primarily on programming-related tools.

Programming learning tools focused on computational thinking primarily encompass graphical programming (such as Scratch, APP Inventor), text-based programming (such as Python, C), open-source hardware programming (such as Arduino), gaming (such as Penguin Go), and more. Additionally, mathematical teaching tools like wxMaxima can be utilized to cultivate students' problem-solving and modeling abilities (Karjanto, 2021; Karjanto and Husain, 2021). Among these, research on graphical programming holds an absolute advantage (Tikva and Tambouris, 2021). This is due to the "low floor, high ceiling" nature of graphical programming, which encapsulates code within blocks, allowing students to create programs simply by dragging and dropping these blocks. Consequently, graphical programming does not require extensive knowledge of programming syntax rules, enabling students to complete a project in mere minutes. This ease of use and brevity make it highly accessible for students. By eliminating the need for strict syntax and foundational programming prerequisites, students can devote more energy to honing their thinking skills. This type of tool is particularly well-suited for primary and secondary school students looking to enhance their computational thinking abilities.

Existing research has demonstrated that utilizing graphical programming tools can significantly enhance students' computational thinking skills. Graphical programming exerts a notable influence on students' computational concepts, practices, and perspectives. Specifically, it has been shown to be highly effective in mastering computational concepts such as sequence, loop, condition, and event that are integral to computational thinking (Meerbaum-Salant et al., 2010; Sevillano García and Sáez López, 2016; Giordano and Maiorana, 2014). Furthermore, graphical programming significantly promotes computational practices related to computational thinking, including abstraction and debugging (Statter and Armoni, 2017; Webb and Rosson, 2013). Tsai, C. Y. conducted a quasi-experimental study, where the experimental group used graphical programming tools while the control group received traditional instruction. The results revealed that the experimental group had a better understanding of programming concepts compared to the control group (Tsai, 2019). Additionally, numerous studies have confirmed the positive impact of graphical programming on computational thinking from perspectives such as creative thinking, critical thinking, and problem-solving abilities (Ma et al., 2021).

It can be seen that existing research on computational thinking primarily unfolds from two perspectives. The first perspective explores students' learning outcomes in terms of creative thinking, critical thinking, algorithmic thinking, and other dimensions. The second perspective examines the learning outcomes of computational thinking based on the three dimensions proposed by Brennan and others. In the empirical research conducted so far, there has been little examination of the cultivation effects of different tools from the angle of the cognitive processes involved in computational thinking. Therefore, this study analyzes the cultivation effects of various tools and strategies by focusing on the cognitive processes associated with computational thinking, such as abstraction, decomposition, algorithmic thinking, pattern recognition, and programming debugging.

2.3 Mind mapping

Mind mapping is defined as "a visual, nonlinear representation of ideas and their relationships" (Biktimirov and Nilson, 2003). It is a method invented by Buzan to concretize and visualize divergent thinking, enabling the visualization and expression of the cognitive structures within the brain (Buzan, 2006). Mind mapping employs shapes, images, and keywords to represent the relationships between conceptual ideas (Rostron, 2002). This approach aids in knowledge retention, organization, nurturing creative thinking, and assisting students in describing the relationships between complex ideas. When students can express complex thought relationships graphically, they are more likely to comprehend those relationships, further analyze their components, and facilitate deeper learning. Thus, processing or supplementing ideas through mind mapping can enhance students' learning outcomes. Research indicates that taking notes using mind mapping positively impacts students' conceptual learning and their attitudes towards courses (Al-Jarf, 2009).

Recent studies have shown that incorporating mind mapping into graphical programming significantly improves students' creative thinking, critical thinking, and algorithmic thinking, thereby enhancing computational thinking skills among primary school students. Some research has also confirmed the impact of mind mapping on the computational thinking of university students. However, there is a lack of empirical studies investigating the role of mind mapping in graphical programming among middle school students, as well as its effects on computational thinking skills and self-efficacy (Sari et al., 2021).

2.4 Self-efficacy

Bandura defines self-efficacy as an individual's belief in their ability to master or accomplish a task, which influences the choices they make, the effort they exert, and their perseverance in the face of difficulties when completing tasks (Bandura and Wessels, 1997). Research indicates that students with high self-efficacy perceive difficulties as challenges that arise during task completion, thereby affecting their level of effort in various contexts (Gandhi and Varma, 2010). Bandura emphasizes the existence and significance of domain-specific self-efficacy. Consequently, analyzing programming self-efficacy is crucial in fostering computational thinking through graphical programming. Programming is a complex and challenging process, and programming self-efficacy emerges as a pivotal variable in the learning journey when tackling problems through programming. Studies reveal that negative attitudes and low self-efficacy in programming training can act as barriers to learning (Hongwarittorrn and Krairit, 2010), whereas higher programming self-efficacy ensures success in programming endeavors (Yağcı, 2016). Hence, in utilizing programming to cultivate computational thinking among students, our primary focus should be on exploring strategies to enhance their programming self-efficacy.

Studies have confirmed that the application of mind mapping strategies in flipped classrooms significantly enhances academic performance and self-efficacy among second-year university students (Zheng et al., 2020). Helen Semilarski and colleagues utilized mind maps and concept maps to support students in integrating interdisciplinary learning, and their findings revealed that the employment of such visualization strategies notably boosted students' self-efficacy in the domains of life and earth sciences, as well as in the utilization of models and systems (Semilarski et al., 2022). Based on these findings, we hypothesize that the use of mind mapping strategies

in the cultivation of computational thinking can elevate students' programming self-efficacy. Currently, there is a lack of empirical evidence demonstrating the impact of mind mapping on students' self-efficacy specifically within the context of computational thinking development. Therefore, in this study, we conduct an experiment to investigate whether mind mapping can enhance students' domain-specific self-efficacy in the process of fostering computational thinking.

2.5 Research objectives and questions

This study primarily explores the impact of different strategies on students' computational thinking from the perspective of its cognitive processes, including abstraction, decomposition, pattern recognition, algorithmic thinking, programming debugging, and so forth. Additionally, existing research has confirmed that the use of mind maps in programming can enhance computational thinking skills among primary school students and university students. However, there have been few experimental studies examining the influence of mind maps on middle school students' computational thinking skills and their self-efficacy in computational thinking. Therefore, this study aims to investigate the impact of mind maps on middle school students' computational thinking skills and self-efficacy in the context of graphical programming. The following questions are posed to guide the research:

> Question 1: Can mind mapping enhance middle school students' computational thinking skills from the perspective of its cognitive processes (dimensions of abstraction, decomposition, pattern recognition, algorithmic thinking, and programming debugging)?
>
> Question 2: Can mind mapping improve middle school students' self-efficacy in computational thinking?

3 Method

3.1 Research hypotheses

Based on the above discussion, the following research hypotheses are formulated for this study:

a When using mind mapping for programming learning, students' computational thinking skills will show more significant improvement, with effects observed across all dimensions of the cognitive processes of computational thinking (including abstraction, decomposition, pattern recognition, algorithmic thinking, and programming debugging).
b When using mind mapping for programming learning, students' self-efficacy in computational thinking will experience a more significant enhancement.

3.2 Experimental subject

This study was conducted in the spring of 2024 at an urbanized junior high school. The participants were first-year junior high school students enrolled in the programming club during the semester, with an average age of 13 years old. The study involved an experimental group of 20 students and a control group of 17 students. None of the students in either the experimental or control group had prior exposure to graphical programming during their primary school years or before.

Prior to the instructional experiment, a pre-test was administered to both the experimental and control groups on March 21st, 2024, using the Computational Thinking Skills and Self-Efficacy Measurement Scale via an online survey platform. A total of 37 questionnaires were collected for both the computational thinking skills and attitude sections, all of which were deemed valid, resulting in a 100% response rate.

After the completion of twelve 1-h sessions, a post-test was conducted on June 20th, 2024, using the same measurement scales. Again, 37 questionnaires were collected from both groups for both sections, all of which were considered valid, maintaining a 100% response rate.

The collected data were statistically analyzed using SPSS 20.0 software. In the measurement scale for computational thinking skills, the independent sample t-test revealed a p-value of 0.075, indicating that there is no significant difference in computational thinking skills between the experimental group and the control group. Similarly, in the measurement scale for self-efficacy in computational thinking, the independent sample t-test showed a p-value of 0.094, suggesting that there is no significant difference in self-efficacy in computational thinking between the experimental group and the control group. Moreover, both the experimental and control groups completed programming tasks in groups of two to three students.

3.3 Learning content

As previously mentioned, this study conceptualizes computational thinking as a cognitive process encompassing five dimensions: decomposition, abstraction, algorithmic thinking, pattern recognition, and programming debugging. Therefore, fostering computational thinking necessitates a focus on these five components. The research plan leverages mind mapping as a tool to aid students in understanding and mastering the cognitive processes of computational thinking.

Students first gain an understanding of the project to be completed in each activity. Subsequently, under the guidance of the teacher, they engage in discussions to analyze the roles, variables, and contexts of the project. The outcomes of this decomposition are then presented using mind maps (as illustrated in Figures 1, 2). This step helps students break down complex projects, thereby fostering their ability to decompose problems, a key aspect of computational thinking.

Next, students articulate the functions and roles of the decomposed parts based on the teacher's demonstrations. This activity aims to encourage students to abstract phenomena, stripping away non-essential details to grasp the essence of the problem, thereby nurturing their ability to abstract. Students are then prompted to analyze which building blocks or modules should be used to implement the different roles and functions. The process of recalling and imagining suitable building blocks fosters algorithmic thinking and pattern recognition skills. Finally, students work in groups to write code and complete the project.

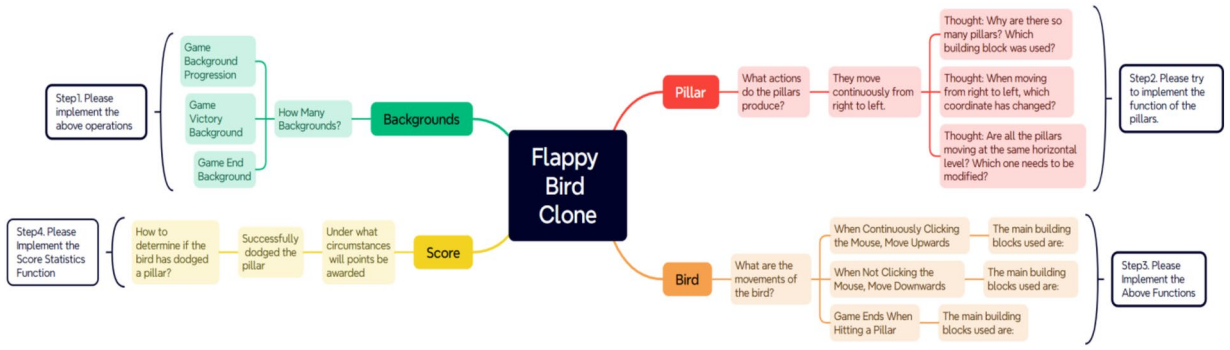

FIGURE 1
Mind map illustrating the cognitive processes of computational thinking.

By using mind maps to decompose tasks, students are guided to think about problems step-by-step, abstract the essence of the problem, match the problem with specific building blocks or modules, and ultimately solve the problem. By unfolding the cognitive processes of computational thinking through mind mapping, this experimental approach aims to cultivate students' computational thinking abilities.

Furthermore, the 12 projects selected for the experiment were designed by the researchers, taking into account the students' proficiency levels. These projects encompass various program structures and building blocks in graphical programming, including "Big Fish Eats Little Fish," "Guess Idioms from Pictures," "Flappy Bird," "Fruit Crush," "Whack-a-Mole," "Tank Battle," "Pole Climbing Race," "Racing Game," "Monster Hunt," "Dress-Up Game," "Jump Game," and "Airplane Battle."

3.4 Experimental procedure

The experimental procedures are illustrated in Figure 3. Both the experimental group and the control group were taught by the same instructor, with sessions held once a week, each lasting for an hour, over a total of 16 weeks. During the first 2 weeks, students were introduced to the Scratch graphical programming interface and building blocks, as well as the X-mind mind mapping software. In the third week, pre-tests were conducted to assess students' computational thinking skills and self-efficacy.

From the fourth week to the fifteenth week, the teaching experiments commenced. For the experimental group, the teaching process entailed the following steps: the instructor demonstrated case studies, then the instructor and students jointly analyzed and decomposed these cases using mind maps, guiding students to identify key logics and Scratch blocks. Students engaged in discussions among themselves to refine their mind maps, and subsequently collaborated to write the program based on the prompts from the mind maps. Finally, they presented their work and summarized their learning.

The teaching process for the control group was largely similar to that of the experimental group, with the notable exception of the absence of mind mapping. Specifically, the instructor demonstrated case studies, and then the instructor and students analyzed the cases together. Students then collaborated to complete the cases, followed by presentations and summaries.

3.5 Instrument

3.5.1 Computational thinking skills

To assess students' computational thinking skills, we employed The Bebras CT Challenge as our measurement tool. The Bebras CT Challenge is an internationally renowned online competition designed to promote computer science and computational thinking among students aged 10 to 19, and it has proven to be highly effective (Boom et al., 2022; Dagiene and Jevsikova, 2012; Román-González et al., 2017). This competition categorizes students into six age groups. Given that the average age of the students in our experiment was 13, we selected questions from the 12–14 age group. Each age group's questions are divided into three levels of difficulty: A-level, B-level, and C-level, each targeting different sub-skills of computational thinking. Specifically, A-level comprises 6 questions worth 2 points each, assessing algorithmic thinking and modeling capabilities; B-level includes 4 questions worth 4 points each, evaluating pattern recognition and evaluation skills; and C-level consists of 2 questions worth 6 points each, measuring abstraction and decomposition abilities. We first translated the questions into Chinese and then had two students read through them to analyze any potential linguistic barriers in comprehension. It was found that the Chinese translations did not pose any comprehension difficulties for the students.

3.5.2 Computational thinking self-efficacy

To measure students' self-efficacy in computational thinking, we utilized the Computational Thinking Scale adapted by Korkmaz and Bai (2019). The original Computational Thinking Self-Efficacy Scale developed by Korkmaz and colleagues has gained widespread application globally. For this study, we employed the Chinese version of the CTS, which has been extensively used in China and recognized for its effectiveness in measuring self-efficacy in computational thinking. The Computational Thinking Self-Efficacy Scale employs a Likert five-point scale ranging from 1 = Strongly Disagree to 5 = Strongly Agree. It assesses five dimensions of computational thinking: creativity, algorithmic thinking, collaboration ability, critical thinking, and problem-solving ability, with a total of 22 items.

FIGURE 2
Students using mind maps to train their thinking process.

4 Results

4.1 Analyzing the impact of mind mapping on computational thinking skills

Regarding the first research question, we first conducted independent sample t-tests on the pre-test and post-test data from the experimental and control classes to determine whether there were any differences in computational thinking skills between the two classes before the teaching experiment began and whether there were any differences after the teaching experiment was implemented. The results are presented in Tables 1, 2. Subsequently, we performed paired sample t-tests on the pre-test and post-test data of both the experimental and control classes separately to verify the effectiveness of the teaching experiment's intervention. The results of these analyses are shown in Tables 3, 4.

Before the experiment, through conducting an independent sample t-test on the pre-test data, we can conclude (as shown in Table 1) that the levels of computational thinking skills between the experimental class and the control class were essentially the same, with no significant difference ($p = 0.075 > 0.05$). After a semester of instruction, we performed paired sample t-tests on the pre-test and post-test data of both groups. The data indicated (as shown in Tables 3, 4) that within the experimental class, there was a significant difference before and after the experiment ($p < 0.001$), indicating an extremely significant improvement in computational thinking skills as a result of the teaching experiment. Similarly, within the control class, there was also a significant difference ($p = 0.002$), suggesting a notable enhancement in computational thinking skills following the teaching experiment, albeit to a lesser extent compared to the experimental group.

When conducting an independent sample *t*-test on the post-test data, the results (as shown in Table 2) indicated an extremely significant difference ($p < 0.001$) between the experimental class and the control class, suggesting that the experimental class outperformed the control class in computational thinking skills. We further analyzed the differences across the three dimensions of computational thinking and found that the experimental group significantly surpassed the control group in two dimensions: algorithmic thinking and modeling capabilities ($p = 0.046$), as well as measurement, pattern recognition, and evaluation abilities ($p = 0.004$). However, there was no significant difference in the dimension of abstraction and decomposition ($p = 0.059$).

4.2 Analyzing the impact of mind mapping on self-efficacy in computational thinking

Addressing the second research question, we employed the Computational Thinking Scale to conduct both independent sample t-tests and paired sample t-tests to detect whether there were significant differences between the experimental group and the control group before and after the experiment. Prior to the experiment, we conducted a pre-test on both the experimental and control groups. The results of the independent sample *t*-test (as shown in Table 5) indicated that the experimental group and the control group were essentially the same in terms of self-efficacy in computational thinking, with no significant difference ($p = 0.094$). After the teaching experiment, paired sample *t*-tests were performed separately on the experimental and control groups to analyze the changes in both groups. The data revealed (as shown in Table 6) that there was a significant difference in the experimental class before and after the experiment ($p < 0.001$), indicating a remarkable enhancement in the attitudes toward computational thinking among the experimental group through the teaching experiment. In contrast, no significant difference was found in the control class ($p = 0.092$). Although the average score of self-efficacy in computational thinking among the control group increased slightly compared to the pre-test, this improvement did not reach statistical significance (Table 7).

Further analysis was conducted to examine the differences between the two groups across various dimensions. Based on the results of the independent sample t-test (as shown in Table 8), it can be observed that there was an extremely significant difference ($p < 0.001$) between the experimental class and the control class after the implementation of the teaching experiment. Specifically, significant differences of varying degrees were found in five dimensions: creativity, algorithmic thinking, collaboration ability, critical thinking, and problem-solving.

5 Discussion

Programming serves as an ideal tool for enhancing students' computational thinking, and through specific strategic support in this process, students can attain a higher level of proficiency (Hooshyar, 2022; Rodríguez-Martínez et al., 2020; Zhang et al., 2023). Furthermore, each step in the cognitive process of computational thinking has a crucial impact on problem-solving abilities, making it significant to leverage tools to advance students' cognitive processes related to computational thinking. Thus, it is necessary to explore supportive strategies for fostering the cognitive processes of computational thinking.

In this study, mind mapping was employed as a supportive strategy and a cultivation tool for the cognitive processes of computational thinking, to investigate its impact on computational thinking skills and self-efficacy. After a 12-week experiment, post-test data revealed that both the experimental group and the control group

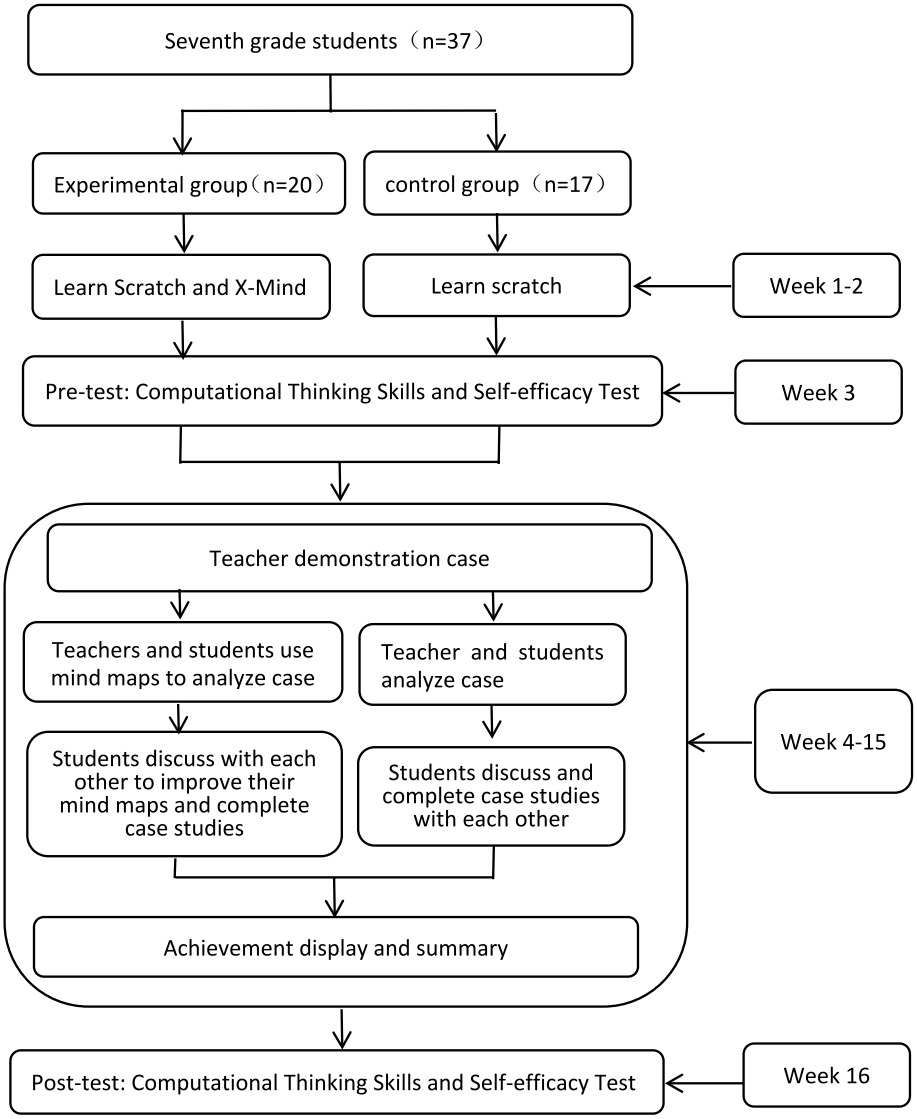

FIGURE 3
Experimental procedure.

TABLE 1 Measurement of computational thinking skills in experimental group and control group (Bebras) pre-test comparison (df = 35).

	f	Experimental group (*n* = 20)	Control group (*n* = 17)	*t*	*p*
		M ± SD	M ± SD		
Computational thinking skills (Bebras)	0.396	21.3 ± 1.718	16.9 ± 1.601	1.833	0.075

TABLE 2 Measurement of computational thinking skills in experimental group and control group (Bebras) post-test comparison (df = 35).

The Bebras CT challenge	Group	*N*	*M*	SD	*t*	*p*
Total scores	EG	20	32.550	1.2967	3.997	0.000
	CG	17	24.676	1.4963		
Algorithmic thinking and modeling capabilities	EG	20	9.60	0.450	2.070	0.046
	CG	17	8.24	0.481		
Pattern recognition and evaluation skills	EG	20	13.40	0.727	3.047	0.004
	CG	17	9.88	0.915		
Abstraction and decomposition abilities	EG	20	6.90	0.788	1.949	0.059
	CG	17	4.94	0.572		

showed improvements in computational abilities, but the effect was more pronounced in the experimental group. The control group utilized graphical programming tools to cultivate students' computational thinking, demonstrating that visual programming can significantly enhance students' computational thinking skills. This finding corroborates existing research, reinforcing the positive influence of programming tools on computational thinking through

TABLE 3 Comparison of pre and post tests of the computational thinking skills measurement scale in the experimental group (n = 20, df = 19).

	Pre-test	Post-test	t	p
	M ± SD	M ± SD		
The Bebras CT challenge	21.3 ± 1.718	32.5 ± 1.297	−6.577	0.000

TABLE 4 Comparison of pre and post tests of the computational thinking skills measurement scale in the control group (n = 17, df = 16).

	Pre-test	Post-test	t	p
	M ± SD	M ± SD		
The Bebras CT challenge	16.94 ± 1.601	24.68 ± 1.496	−3.737	0.002

TABLE 5 Comparison of pre-test scores on the computational thinking self-efficacy scale (CTS) between the experimental group and the control group (df = 35).

	f	EG (n = 20)	CG (n = 17)	t	p
		M ± SD	M ± SD		
CT self-efficacy	2.720	72.00±1.814	66.12±3.040	1.720	0.094

TABLE 6 Comparison of post-test scores on the computational thinking self-efficacy scale (CTS) between the experimental group and the control (df = 35).

CT self-efficacy	Group	N	M	SD	t	p
Total scores	EG	20	88.90	2.650	4.932	0.000
	CG	17	72.71	1.714		
Creativity	EG	20	16.45	0.605	2.807	0.008
	CG	17	14.00	0.624		
Algorithmic thinking	EG	20	15.65	0.678	3.337	0.002
	CG	17	12.12	0.826		
Collaboration ability	EG	20	26.00	0.827	4.079	0.000
	CG	17	20.59	1.061		
Critical thinking	EG	20	15.60	0.705	2.056	0.047
	CG	17	13.47	0.758		
Problem-solving	EG	20	15.20	0.863	2.415	0.021
	CG	17	12.53	0.637		

TABLE 7 Comparison of pre-test and post-test scores on the computational thinking self-efficacy scale (CTS) for the experimental group (n = 20, df = 19).

	Pre-test	Post-test	t	p
	M ± SD	M ± SD		
CT self-efficacy	72.0 ± 1.814	88.9 ± 2.649	−6.577	0.000

TABLE 8 Comparison of pre-test and post-test scores on the computational thinking self-efficacy scale (CTS) for the control group (n = 17, df = 16).

	Pre-test	Post-test	t	p
	M ± SD	M ± SD		
CT self-efficacy	66.1 ± 3.040	72.71 ± 1.714	−1.791	0.092

data. Below is a discussion on the research questions based on the study's findings.

Research Question 1: Can mind mapping enhance middle school students' computational thinking skills from the perspective of the cognitive processes of computational thinking (dimensions of abstraction, decomposition, pattern recognition, algorithmic thinking, and programming debugging)? The results indicate that the experimental group supported by mind mapping exhibited more significant improvements in computational thinking skills. Further analysis reveals that, compared to the control group, students showed notable differences in the dimensions of algorithms and modeling, as well as pattern recognition and evaluation. However, there were no significant differences in the dimensions of abstraction and decomposition.

As mentioned earlier, during the teaching process, students in both the experimental and control groups were led by teachers to analyze and decompose cases, with the teachers' explanations predominating. However, in the experimental group, after presenting the decomposed results using mind maps, students continued to use mind maps to analyze the specific steps for implementing each small problem. This process was crucial for enhancing their algorithmic modeling skills. Additionally, during this process, students also associated the specific code blocks they used with previously learned cases, serving as a form of recall and cognitive reinforcement, ultimately improving their pattern recognition abilities. Upon further analysis of the experimental process, it was observed that after presenting cases, teachers led students to decompose the cases and analyze the problems together. Therefore, no significant differences were observed in the dimensions of decomposition and abstraction. In the future, an attempt could be made to allow students to use mind maps independently to decompose cases and analyze problems, thereby fostering their abilities in decomposition and abstraction. The experiment confirmed previous research findings (Basu et al., 2017; Ismail et al., 2010) that mind mapping has a positive impact on the computational thinking skills of university students and primary school students. Simultaneously, this study extended this discovery to middle school students.

Research Question 2: Can mind mapping enhance middle school students' self-efficacy in computational thinking? We have obtained a positive answer to this question. The data indicated that the experimental group showed significant improvements across all five dimensions of computational thinking self-efficacy. This result aligns with previous research (Malycha and Maier, 2017; Rahmidani, 2019), suggesting that mind mapping positively impacts students' creativity, critical thinking, algorithmic thinking, problem-solving skills, and collaboration abilities. In the context of this experiment, when students used mind maps to analyze project-based tasks, they generated diverse ideas and multiple solutions to the same problem. This process effectively promoted their creative thinking, algorithmic thinking, and

collaboration skills. Furthermore, the variety of approaches to solving the same problem necessitated analysis, discussion, and selection among students, which contributed to the development of their critical thinking. In contrast, in the control group, individual ideas were implicit within the programming modules, hindering students from analyzing the differences between various methods. Consequently, using mind maps to discuss algorithms and visualizing thinking facilitated student communication and discussion, ultimately enhancing their computational thinking self-efficacy.

This finding corroborates previous research, demonstrating that mind mapping can significantly enhance students' self-efficacy in flipped classrooms and interdisciplinary teaching. The current study extends these results by showing that mind mapping can also improve students' computational thinking self-efficacy in the context of graphical programming. Furthermore, research indicates that low self-efficacy is a significant barrier in programming learning, whereas students with high self-efficacy tend to perform better in programming. This explanation sheds light on why the experimental group students demonstrated superior computational thinking skills compared to the control group. By fostering a sense of accomplishment and confidence through the use of mind maps, students in the experimental group likely felt more empowered to tackle programming challenges, leading to their improved performance.

6 Conclusion and limitations

This study explored the strategy of utilizing mind maps to enhance middle school students' computational thinking skills and self-efficacy in graphical programming. By visualizing the cognitive processes of computational thinking through mind maps, the teaching experiment conducted over a semester revealed that this strategy significantly improved students' computational thinking skills, particularly in the dimensions of algorithmic modeling and pattern recognition and evaluation. Regarding computational thinking self-efficacy, students demonstrated notable enhancements across five dimensions: creativity, algorithmic thinking, critical thinking, collaboration skills, and problem-solving abilities. This research holds significant theoretical and practical implications. Theoretically, this study validates the role of mind mapping as an instructional strategy in fostering computational thinking in programming education. By experimentally verifying the positive impact of mind mapping on computational thinking self-efficacy, it expands upon previous research on mind mapping. Practically, this experiment was conducted in an authentic teaching environment, making it feasible for frontline teachers to adopt and implement the strategy in their own classrooms. This finding offers a practical tool for educators to enhance students' computational thinking skills and self-efficacy, ultimately leading to improved learning outcomes in programming education.

There are several limitations to this study that warrant consideration. Firstly, the sample was drawn from urban schools in western China, where students had no prior exposure to graphical programming before middle school. Future research could expand to economically developed provinces in central and eastern China to increase the diversity of the sample. Secondly, the sample students were voluntarily enrolled in the graphical programming club, indicating a high likelihood of their interest in computer-related activities. Additionally, the majority of the participants were male, and the study did not account for gender factors. Future research should broaden the scope of participants and consider multiple factors such as interest and gender. Thirdly, different forms of mind mapping, such as digital creation versus hand-drawn, can influence student learning. However, this study only utilized digital mind mapping. Further research could explore the effects of various mind mapping methods on students' learning outcomes. Lastly, the study found no significant difference in the decomposition and abstraction dimensions of computational thinking. Further investigation is needed to explore potential reasons for this outcome and refine the experimental design. Addressing these limitations in future research will contribute to a more comprehensive understanding of the effectiveness of mind mapping in enhancing computational thinking skills and self-efficacy among students.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

Ethics statement

Ethical approval was not required for the study involving human samples in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin. Ethical approval was not required for the study involving animals in accordance with the local legislation and institutional requirements. Written informed consent was obtained from the individual(s), and minor(s)' legal guardian/next of kin, for the publication of any potentially identifiable images or data included in this article.

Author contributions

RG: Writing – original draft, Writing – review & editing. YZ: Writing – original draft, Data curation. HM: Writing – original draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Aksit, O., and Wiebe, E. N. (2020). Exploring force and motion concepts in middle grades using computational modeling: a classroom intervention study. *J. Sci. Educ. Technol.* 29, 65–82. doi: 10.1007/s10956-019-09800-z

Al-Jarf, R. (2009). Enhancing freshman students' writing skills with a mind-mapping software. In Conference proceedings of eLearning and Software for Education (eLSE) (Vol. 5, No. 01, pp. 375–382). Available at: https://ssrn.com/abstract=3901075

Atmatzidou, S., and Demetriadis, S. (2016). Advancing students' computational thinking skills through educational robotics: a study on age and gender relevant differences. *Robot. Auton. Syst.* 75, 661–670. doi: 10.1016/j.robot.2015.10.008

Bandura, A., and Wessels, S. (1997). Self-efficacy. Cambridge: Cambridge University Press, 4–6.

Barr, V., and Stephenson, C. (2011). Bringing computational thinking to K-12: what is involved and what is the role of the computer science education community? *ACM Inroads* 2, 48–54. doi: 10.1145/1929887.1929905

Basogain Olabe, X., Olabe Basogain, M. Á., Olabe Basogain, J. C., and Rico, M. J. (2017). Computational thinking in pre-university blended learning classrooms

Basu, S., Biswas, G., and Kinnebrew, J. S. (2017). Learner modeling for adaptive scaffolding in a computational thinking-based science learning environment. *User Model. User-Adap. Inter.* 27, 5–53. doi: 10.1007/s11257-017-9187-0

Batdi, V. (2015). A meta-analysis study of mind mapping techniques and traditional learning methods. *Anthropologist* 20, 62–68. doi: 10.1080/09720073.2015.11891724

Biktimirov, E. N., and Nilson, L. B. (2003). Mapping your course: designing a graphic syllabus for introductory finance. *J. Educ. Bus.* 78, 308–312. doi: 10.1080/08832320309598618

Boom, K. D., Bower, M., Siemon, J., and Arguel, A. (2022). Relationships between computational thinking and the quality of computer programs. *Educ. Inf. Technol.* 27, 8289–8310. doi: 10.1007/s10639-022-10921-z

Brennan, K., and Resnick, M. (2012). New frameworks for studying and assessing the development of computational thinking. In Proceedings of the 2012 annual meeting of the American educational research association, Vancouver, Canada (Vol. 1, p. 25).

Buzan, T. (2006). Use your head. *Pearson Educ.* 5:333. doi: 10.1016/0029-1021(72)90055-2

Cui, Z., and Ng, O. L. (2021). The interplay between mathematical and computational thinking in primary school students' mathematical problem-solving within a programming environment. *J. Educ. Comput. Res.* 59, 988–1012. doi: 10.1177/0735633120979930

Dagiene, V., and Jevsikova, T. (2012). Reasoning on the content of informatics education for beginners. *Soc. Sci.* 78, 84–90. doi: 10.5755/j01.ss.78.4.3233

Davies, M. (2011). Concept mapping, mind mapping and argument mapping: what are the differences and do they matter? *High. Educ.* 62, 279–301. doi: 10.1007/s10734-010-9387-6

Demir, F. (2022). The effect of different usage of the educational programming language in programming education on the programming anxiety and achievement. *Educ. Inf. Technol.* 27, 4171–4194. doi: 10.1007/s10639-021-10750-6

Gandhi, H., and Varma, M. (2010). Strategic content learning approach to promote self-regulated learning in mathematics. *Proceed. epiSTME* 3, 119–124.

Giordano, D., and Maiorana, F. (2014). "Use of cutting edge educational tools for an initial programming course" in *In 2014 IEEE global engineering education conference (EDUCON). 3–5 April 2014, Military Museum and Cultural Center*, (Harbiye, Istanbul, Turkey: IEEE) 556–563.

Hongwarittorrn, N., and Krairit, D. (2010). Effects of program visualization (jeliot3) on students' performance and attitudes towards java programming. In The spring 8th international conference on computing, communication and control technologies (Vol. 69).

Hooshyar, D. (2022). Effects of technology-enhanced learning approaches on learners with different prior learning attitudes and knowledge in computational thinking. *Comput. Appl. Eng. Educ.* 30, 64–76. doi: 10.1002/cae.22442

Hsu, T. C., Chang, S. C., and Hung, Y. T. (2018). How to learn and how to teach computational thinking: suggestions based on a review of the literature. *Comput. Educ.* 126, 296–310. doi: 10.1016/j.compedu.2018.07.004

Ismail, M. N., Ngah, N. A., and Umar, I. N. (2010). The effects of mind mapping with cooperative learning on programming performance, problem solving skill and metacognitive knowledge among computer science students. *J. Educ. Comput. Res.* 42, 35–61. doi: 10.2190/EC.42.1.b

Israel-Fishelson, R., and Hershkovitz, A. (2022). Studying interrelations of computational thinking and creativity: a scoping review (2011–2020). *Comput. Educ.* 176:104353. doi: 10.1016/j.compedu.2021.104353

Karjanto, N. (2021). Calculus and digital natives in rendezvous: wxMaxima impact. *Educ. Sci.* 11:490. doi: 10.3390/educsci11090490

Karjanto, N., and Husain, H. S. (2021). Not another computer algebra system: highlighting wxMaxima in calculus. *Mathematics* 9:1317. doi: 10.3390/math9121317

Korkmaz, Ö., and Bai, X. (2019). Adapting computational thinking scale (CTS) for chinese high school students and their thinking scale skills level. *Participatory Educ. Res.* 6, 10–26. doi: 10.17275/per.19.2.6.1

Ma, H., Zhao, M., Wang, H., Wan, X., Cavanaugh, T. W., and Liu, J. (2021). Promoting pupils' computational thinking skills and self-efficacy: a problem-solving instructional approach. *Educ. Technol. Res. Dev.* 69, 1599–1616. doi: 10.1007/s11423-021-10016-5

Malycha, C. P., and Maier, G. W. (2017). Enhancing creativity on different complexity levels by eliciting mental models. *Psychol. Aesthet. Creat. Arts* 11, 187–201. doi: 10.1037/aca0000080

Meerbaum-Salant, O., Armoni, M., and Ben-Ari, M. (2010). Learning computer science concepts with scratch. In Proceedings of the Sixth international workshop on Computing education research (pp. 69–76).

Mladenović, M., Žanko, Ž., and Aglić Čuvić, M. (2021). The impact of using program visualization techniques on learning basic programming concepts at the K–12 level. *Comput. Appl. Eng. Educ.* 29, 145–159. doi: 10.1002/cae.22315

Rahmidani, R. (2019) Improving students' motivation and learning creativity through mind mapping learning method. In 2nd Padang International Conference on Education, Economics, Business and Accounting (PICEEBA-2 2018) (pp. 881–889)

Rodríguez-Martínez, J. A., González-Calero, J. A., and Sáez-López, J. M. (2020). Computational thinking and mathematics using scratch: an experiment with sixth-grade students. *Interact. Learn. Environ.* 28, 316–327. doi: 10.1080/10494820.2019.1612448

Román-González, M., Pérez-González, J. C., and Jiménez-Fernández, C. (2017). Which cognitive abilities underlie computational thinking? Criterion validity of the computational thinking test. *Comput. Hum. Behav.* 72, 678–691. doi: 10.1016/j.chb.2016.08.047

Rostron, S. S. (2002). Accelerating performance: Powerful new techniques to develop people. London: Kogan Page Publishers.

Sari, R., Sumarmi, S., Astina, I., Utomo, D., and Ridhwan, R. (2021). Increasing students critical thinking skills and learning motivation using inquiry mind map. *Int. J. Emerg. Technol. Learn.* 16, 4–19. doi: 10.3991/ijet.v16i03.16515

Selby, C. (2013). Computational thinking: the developing definition. University of Southampton. Available at: https://eprints.soton.ac.uk/356481/1/Selby_Woollard_bg_soton_eprints.pdf (Accessed January, 2013).

Semilarski, H., Soobard, R., Holbrook, J., and Rannikmäe, M. (2022). Expanding disciplinary and interdisciplinary core idea maps by students to promote perceived self-efficacy in learning science. *Int. J. STEM Educ.* 9:57. doi: 10.1186/s40594-022-00374-8

Sevillano García, M. L., and Sáez López, J. M. (2016). Sensors, programming and devices in art education sessions. One case in the context of primary education. *Cult. Educ.* 29, 350–384. doi: 10.1080/11356405.2017.1305075

Shi, Y., Yang, H., Dou, Y., and Zeng, Y. (2023). Effects of mind mapping-based instruction on student cognitive learning outcomes: a meta-analysis. *Asia Pac. Educ. Rev.* 24, 303–317. doi: 10.1007/s12564-022-09746-9

Silva, R., Fonseca, B., Costa, C., and Martins, F. (2021). Fostering computational thinking skills: a didactic proposal for elementary school grades. *Educ. Sci.* 11:518. doi: 10.3390/educsci11090518

Statter, D., and Armoni, M. (2017). Learning abstraction in computer science: a gender perspective. In Proceedings of the 12th Workshop on Primary and Secondary Computing Education (5–14).

Stokhof, H., De Vries, B., Bastiaens, T., and Martens, R. (2020). Using mind maps to make student questioning effective: learning outcomes of a principle-based scenario for teacher guidance. *Res. Sci. Educ.* 50, 203–225. doi: 10.1007/s11165-017-9686-3

Sullivan, A. A., Bers, M. U., and Mihm, C. (2017). Imagining, playing, and coding with KIBO: Using robotics to foster computational thinking in young children. Hong Kong: Siu-cheung KONG The Education University of Hong Kong, 110.

Tikva, C., and Tambouris, E. (2021). Mapping computational thinking through programming in K-12 education: a conceptual model based on a systematic literature review. *Comput. Educ.* 162:104083. doi: 10.1016/j.compedu.2020.104083

Tsai, C. Y. (2019). Improving students' understanding of basic programming concepts through visual programming language: the role of self-efficacy. *Comput. Hum. Behav.* 95, 224–232. doi: 10.1016/j.chb.2018.11.038

Webb, H., and Rosson, M. B. (2013). Using scaffolded examples to teach computational thinking concepts. In Proceeding of the 44th ACM technical symposium on Computer science education (pp. 95–100).

Wing, J. M. (2006). Computational thinking. *Commun. ACM* 49, 33–35. doi: 10.1145/1118178.1118215

Yağcı, M. (2016). Effect of attitudes of information technologies (IT) preservice teachers and computer programming (CP) students toward programming on their perception regarding their self-sufficiency for programming Bilişim teknolojileri (BT) öğretmen adaylarının ve bilgisayar programcılığı (BP) öğrencilerinin programlamaya karşı tutumlarının programlama öz yeterlik algılarına etkisi. *J. Human Sci.* 13, 1418–1432. doi: 10.14687/ijhs.v13i1.3502

Yang, T. C., and Lin, Z. S. (2024). Enhancing elementary school students' computational thinking and programming learning with graphic organizers. *Comput. Educ.* 209:104962. doi: 10.1016/j.compedu.2023.104962

Zhang, X., Tlili, A., Guo, J., Griffiths, D., Huang, R., Looi, C. K., et al. (2023). Developing rural Chinese children's computational thinking through game-based learning and parental involvement. *J. Educ. Res.* 116, 17–32. doi: 10.1080/00220671.2023.2167798

Zhao, L., Liu, X., Wang, C., and Su, Y. S. (2022). Effect of different mind mapping approaches on primary school students' computational thinking skills during visual programming learning. *Comput. Educ.* 181:104445. doi: 10.1016/j.compedu.2022.104445

Zheng, X., Johnson, T. E., and Zhou, C. (2020). A pilot study examining the impact of collaborative mind mapping strategy in a flipped classroom: learning achievement, self-efficacy, motivation, and students' acceptance. *Educ. Technol. Res. Dev.* 68, 3527–3545. doi: 10.1007/s11423-020-09868-0

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Video games and metacognition in the classroom for the development of 21st century skills: a systematic review

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Introduction: Game-based learning is a methodology that has gained importance in the world of education due to the benefits of implementing ICT in the classroom. Due to the intellectual and competence demands that some commercial video games promote, they can be very valuable tools to stimulate and promote metacognitive abilities in students. Therefore, this paper aimed to analyze the use of commercial video games in educational contexts and their impact on the development of metacognitive skills.

Methods: For the analysis of the study, a systematic review of the literature was carried out following the PRISMA statement. Specialized databases such as Scopus, WoS, PsyInfo, PubMed, SciELO, and Eric were consulted, which helped capture the essence of the problem between 2004 and 2024.

Results: The review was then carried out on 10 selected articles. The results obtained show the following evidence: (a) commercial video games, together with the use of metacognitive strategies, enrich academic and social aspects as well as the metacognitive level, and (b) commercial video games are as effective in promoting metacognition as other more traditional methodologies or tools.

Discussion: Finally, there is a need to rethink the implications of the use of video games in the classroom if we want students to acquire skills that will be essential to successfully respond to the demands and challenges of their academic and professional future.

KEYWORDS

commercial video games, 21st century skills, metacognition, systematic review, education

Introduction

Play and its cultural and educational impact

Play is essential to understanding what it means to be human. It has always been a fundamental part of life, present in every culture and situation. Through play, people have learned important life skills, and it has shaped the identity of each society while continuously contributing to the development of culture (Andrade, 2020; Delgado, 2011; Montero, 2017). In education, the role of games in the classroom is changing, largely due to advancements in information and communication technologies (ICT) and the need to improve learning processes. To address these changes, methods such as game-based learning (GBL) have emerged, integrating video games into educational settings to meet specific learning goals (Pegalajar Palomino, 2021; Torres et al., 2019). GBL uses video games as powerful tools to

create engaging and innovative learning environments, especially as they are often the first digital technology that children access directly (Gee, 2007; Levis, 2013; Tokarieva et al., 2019) and are highly popular among this age group (Kahila et al., 2020).

Among the different types of video games, commercial games are the most commonly used by children and young people. They have several advantages over educational games, including being developed independently of specific educational goals, being easy to access, not requiring programming skills, allowing learning to happen outside the classroom, and being widely appealing due to their entertainment value (Connolly et al., 2012; Gee, 2011; Kahila et al., 2023). Beyond their ability to create engaging and innovative learning environments, commercial video games also have great potential to develop metacognitive skills. Metacognition—defined as the ability to reflect on, regulate, and plan one's own thinking processes (Flavell, 1979)—is essential for independent and effective learning. These games present complex and dynamic scenarios where players must constantly evaluate their choices, plan strategies, and adapt to new challenges. This continuous process helps build key metacognitive skills, such as self-monitoring and flexible thinking (Schrader et al., 2020). Moreover, commercial video games are often the first type of digital technology that children interact with directly and personally (Gee, 2007; Levis, 2013; Tokarieva et al., 2019). Their widespread popularity among young users makes them an excellent tool for promoting autonomous, self-regulated learning—both essential 21st-century skills (Kahila et al., 2020). By encouraging players to reflect on their thinking during gameplay and adjust their strategies, these games play a key role in developing metacognitive abilities.

In this context, digital and playful environments have great potential to cultivate key 21st-century skills, as highlighted by recent scientific literature (Kickmeier-Rust and Albert, 2012; Sourmelis et al., 2017; Erstad and Voogt, 2018; Erstad et al., 2021; Zimmerman, 2008). Beyond fostering creativity, motivation, and social skills (Ames and Burrell, 2017; Hall et al., 2020; Sánchez-Rodríguez et al., 2010; Diaz-López et al., 2023), these digital environments play a pivotal role in enhancing metacognition. Studies show that engaging with video games helps players build cognitive flexibility, self-monitoring, and strategic thinking, all of which are core components of metacognitive growth (Ouellette, 2019; Squire, 2011; Taub et al., 2018; Yoon and Baek, 2018; Teng, 2024; Mitsea et al., 2024). Mastering digital literacy demands the development of sophisticated cognitive skills (Henderson, 2005; Weber and Greiff, 2023). Video games are particularly powerful tools in this regard because they provide dynamic scenarios where players must regulate their thought processes to succeed. This makes the field of metacognitive research, especially relevant, as it allows us to examine how players develop metacognitive strategies, such as planning, evaluating, and adjusting their actions to achieve in-game objectives (Bullard, 2013; Carter, 2015; Donaldson, 2017; Chatzivasileiou and Drigas, 2022; Pillay et al., 1999; Mayor et al., 1993).

The role of video games in developing metacognitive skills

Metacognition refers to the knowledge and control individuals have over their cognitive and behavioral processes (Flavell, 1979; Ford et al., 1998; Hughes et al., 2013; Fleming, 2024). It can be divided into two key dimensions: metacognitive knowledge and metacognitive control. Metacognitive knowledge includes three components: (1) declarative knowledge—what one knows about their cognitive abilities and strategies, (2) procedural knowledge—how to apply these strategies, and (3) conditional knowledge—when and why specific strategies should be used (Baker and Brown, 1984; Efklides, 2008; Pérez and González, 2020). Metacognitive control, on the other hand, involves three processes: (1) planning, which occurs before starting a task and involves setting goals and selecting strategies, (2) monitoring, which entails tracking progress and adjusting strategies while performing the task, and (3) evaluation, where the effectiveness of strategies is assessed after the task is completed.

Metacognitive development also encompasses behavioral aspects, including emotional and social factors. Flavell (1979) recognized the role of affect in metacognitive processes, proposing that individuals can develop their cognitive skills autonomously by exercising control over their mental states and processes. This highlights the critical role of self-awareness and self-regulation in metacognition. Metacognition has been defined as an individual's ability to actively monitor, regulate, and organize cognitive processes to achieve specific goals (García Madruga et al., 2002). Within this framework, two essential concepts emerge: (1) knowledge of one's cognitive system, which is divided into awareness of one's abilities (person), understanding task objectives and complexity (task), and identifying the necessary strategies to succeed (strategies) (Gandini, 2018); and (2) metacognitive control, which focuses on the actions needed to complete a task effectively. Moreover, Brown (1978) introduced the concept of conditional knowledge, emphasizing its importance in recognizing the optimal conditions for applying strategies. For example, understanding when and why to use specific study techniques when preparing for an examination enhances strategic learning. This integration of knowledge and regulation underscores the central role of metacognition in fostering independent, effective learning.

Recent research underscores the importance of how cognitive processes interact with specific tasks, which often evoke emotions such as familiarity, confidence, and satisfaction (Pérez and González, 2020; Fernández Velasco and Loev, 2024). In this context, metacognitive models currently integrate emotional self-regulation alongside knowledge and cognitive control. Emotional self-regulation involves managing affective factors during planning, monitoring, and evaluation processes (Efklides, 2009; Pintrich et al., 2000; Zimmerman, 2000; Zhu et al., 2024). In particular, ineffective regulation of emotions can contribute to cognitive-attentional syndrome (CAS), a condition where maladaptive patterns, such as persistent negative thoughts and avoidance of positive ones, dominate mental processes, potentially leading to psychological disorders such as anxiety and depression (Wells, 2009). Research suggests that metacognitive beliefs about uncontrollability and perceived danger are central indicators of these conditions (Cano-López et al., 2022).

In this sense, play is a powerful tool for developing metacognitive skills. It involves rules, objectives, feedback, problem-solving, competition, and challenges—all of which require players to engage in cognitive processes such as planning, monitoring, and adjusting strategies. These activities activate critical cognitive functions, including working memory, attention, processing speed, and abstract reasoning (Wilson et al., 2023). Video games, as a form of play, further amplify these metacognitive processes by providing immersive, interactive environments that encourage learners to apply their knowledge in enjoyable and

Abbreviations: RPG, Role-playing game.

meaningful ways (Valencia-Molina et al., 2017). The bidirectional relationship between play and metacognition means that each gaming experience strengthens learner's ability to regulate and reflect on their cognitive processes. In the social dimension, metacognition has traditionally focused on individual self-awareness (Hadwin and Järvellä, 2011; Pérez and González, 2020). However, studies show that collaboration within peer groups enhances the metacognitive processes of planning, monitoring, and evaluating knowledge (McCaslin and Hickey, 2001; Schunk, 2001; Zimmerman, 2000; Sun et al., 2022). Group interactions provide opportunities for learners to develop a shared understanding, refine strategies, and co-regulate their learning, thereby strengthening both individual and collective metacognitive skills.

Research on commercial video games and metacognitive processes in education

The implementation of tools such as video games can effectively target and enhance the previously mentioned metacognitive factors. From a sociocultural perspective on development (Gauvain, 2020; Hu and Luo, 2024), metacognitive processes related to knowledge (e.g., what do I know and how do I know it) and control (the regulation of what I know) can be enhanced, as the use of video games necessitates ongoing digital literacy (Henderson, 2005). Moreover, factors such as interest, satisfaction, engagement (Bond et al., 2020), and perceived difficulty play a crucial role in shaping learning experiences. Interest drives curiosity and sustained attention, satisfaction reinforces motivation and a sense of achievement, and engagement ensures active participation and immersion in the activity. However, perceived difficulty can influence the learner's emotional state—moderate difficulty may encourage persistence, whereas excessive difficulty might induce anxiety, thereby hindering metacognitive processes (Misak, 2018; Moncarz, 2011; Monem, 2015; Naeimi and Rafezi, 2023).

Among other benefits, such as fostering emotional awareness and promoting reflective thinking, this approach would enhance students' ability to recognize their emotional states, enabling them to more effectively address behavioral aspects in the classroom and guiding them toward improved emotional self-regulation (Broadbent and Poon, 2015). Additionally, video games possess an interactive capability that promotes coordination among students when collaborating to achieve a common goal (Vlachopoulos and Makri, 2017). Research on video games for educational purposes or "serious games" and metacognition has covered various aspects, with the most notable focusing on motivation and feedback (Kapp et al., 2019; Zumbach et al., 2020; Singh and Muis, 2024), robotics, design, and collaborative learning (Yoon and Baek, 2018; Li et al., 2024), scientific reasoning and self-regulated learning (Taub et al., 2018; Dörrenbächer-Ulrich et al., 2024), or English language acquisition (Mahayanti et al., 2020; Tan et al., 2022; Zhang, 2024).

However, the application of commercial video games in the classroom to enhance metacognitive processes remains insufficiently explored in the scientific literature. Limited research has examined the presence of dynamic stimuli within these multimodal, interactive, and multisensory tools, which can promote both self-scaffolding and metacognitive awareness (Monem, 2015), as well as support self-regulation, planning, and continuous monitoring of one's actions (Lickteig, 2020). Therefore, it seems necessary to deepen our understanding of the current state of research, and a systematic review of the existing literature would be a good approach.

The general objective of this study was to analyze the role of video games in fostering metacognitive skills within classroom settings and their contribution to the development of essential 21st-century skills, such as critical thinking, problem-solving, and self-regulated learning, through a comprehensive review of existing literature and evidence-based practices. This general objective is specified in two specific objectives: (1) to analyze the use of commercial video games in education and how they stimulate metacognition and (2) to explore whether commercial video games are capable of fostering metacognitive abilities in the same way as other more traditional tools or methodologies. To answer these objectives, the following research question has been posed: (1) What impact do commercial video games have on metacognitive skills?

Methodology

To achieve the research objectives and provide answers to the questions formulated, a systematic review of the literature was carried out (Medina et al., 2020; Páramo, 2020; Sánchez-Meca, 2010). This review is proposed with the purpose of analyzing and specifying those studies that analyze the inclusion of commercial video games in the classroom and their impact on metacognitive skills and competencies necessary for the citizens of the 21st century (Prendes Espinosa et al., 2017).

Protocol and record-keeping

A series of guidelines and guidelines proposed by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology (Liberati et al., 2009; Page et al., 2020) for scientific systematic reviews were established, as well as some of the definitions and elements recommended by the Cochrane Collaboration (Urrútia and Bonfill, 2010), in order to carry out methodical planning (Hutton et al., 2015).

Procedure

The literature search completed during the months of June and July 2024, consulted the following electronic databases: *Scopus©, Web of Science©, PsycInfo©, PubMed©, Scielo©, and Eric©*. In addition, the different thesauruses provided by the different databases were considered, which helped broaden the search and better synthesize the results. The search for published scientific articles began in 2004 and ended in May 2024, with the purpose of extracting as many documents as possible on the research problem addressed.

Search strategy

To optimize the search and target the selection more specifically, a series of inclusion and exclusion criteria were used (Table 1). Some of these filters were provided by the databases themselves (article, year of publication, book, conference proceedings, press, or language), and others were proposed to narrow down the overview of the study as

TABLE 1 Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
a. Review articles b. Completed doctoral theses	a. Conference proceedings, books, and press. b. Other areas
c. Publications from 2004 to 2024	c. Theoretical studies or narrative reviews.
d. Language: English or Spanish	d. Languages other than English or Spanish.
e. The sample is composed of students: kindergarten, elementary school, middle school, high school, and university.	e. The sample is composed of non-student participants: adults, professional video game players, senior citizens, etc.
f. Video games must be either casual or commercial.	f. The video games are formal and educational, developed for the study itself, or belong to the classification of "serious games."
g. Studies that focus on the subject of the research or object of analysis: education, metacognition, and video games.	g. Studies that do not focus on the analysis of the variables presented in the research.
h. Studies with qualitative, quantitative, or mixed methodology.	

much as possible (methodology, sample, subject matter, and duplicate articles).

Study selection

As a result of applying these search strategies, a total of 545 articles were obtained from the different databases mentioned above. As can be seen in Figure 1, all these articles went through different vetting phases, eliminating any article that was affected by the exclusion criteria and admitting those that matched the inclusion criteria and the research topic (Table 1). Articles addressing aspects of metacognition, the use of digital educational games, or variations of analytics based on a learning or cognitive framework were collected. To define the target population, labels indicating the intended medium (e.g., educational video games) were applied. The outcome section was defined by keywords aimed at capturing the overarching cognitive and learning focus of this review (e.g., cognition and learning). Finally, the comparison component, which involves directly contrasting the effectiveness of commercial video games with traditional educational tools or methodologies, could not be included in this review because no specific empirical procedures, such as experimental or control group setups, had been pre-established; instead, this component served as a focal point of interest for the review. In order to simplify the search in each of the databases consulted, the following keywords and Boolean operators were used to obtain as many articles as possible, as well as to narrow the search in order and structure: ("videogame" or "game" or "digital games") and ("metacognition" or "metacognitive" or "metagame").

The final result of the whole process produced a total of 19 items for detailed review and analysis.

Data analysis

A database was generated to record and systematize the following information of the selected articles: title of the study, author/s, year and place of publication, study sample, objectives, methodology, design and data collection instruments, and results of the study, thus following the PICoS strategy (Pertegal-Vega et al., 2019) through Rayyan Intelligent Systematic Review© software. We then used Review Manager 5.4© software to examine, code, and categorize in detail the most relevant information units of the final sample selected.

Evaluation of methodological quality

Independently selected articles ($n = 348$) were evaluated in the eligibility phase through Rayyan Intelligent Systematic Review© software. In situations of disagreement, the judgment of a third person from the research team was requested. For the methodological review of the studies, the articles were evaluated based on satisfactory compliance with the criteria indicated.

Results

Publications

In addressing the research problem and adhering to the proposed eligibility criteria, the final sample size ($n = 19$) demonstrates that the use of commercial video games as a tool to develop metacognitive skills in the classroom remains a relatively unexplored area in the scientific literature. However, this limited number of studies should not be interpreted as a lack of relevance or interest in the subject. On the contrary, the emerging data suggest a growing awareness of the potential that these digital tools hold in educational contexts. As illustrated in Figure 2, the number of articles published on the topic has grown exponentially in recent years ($n = 348$). This trend underscores an increasing recognition of the critical role video games may play in fostering metacognitive processes. Although the existing literature is still in its infancy, the surge in academic publications signals a shift toward exploring how video games can serve not only as entertainment but as powerful vehicles for developing essential 21st-century skills, such as critical thinking, problem-solving, and self-regulated learning.

The significance of this study lies precisely in the current gap within literature. The intersection of metacognition and video games is an innovative area with untapped potential, where empirical evidence is gradually emerging but remains insufficient to fully understand the depth and scope of this relationship. This underrepresentation in the scientific discourse highlights the necessity for further research and

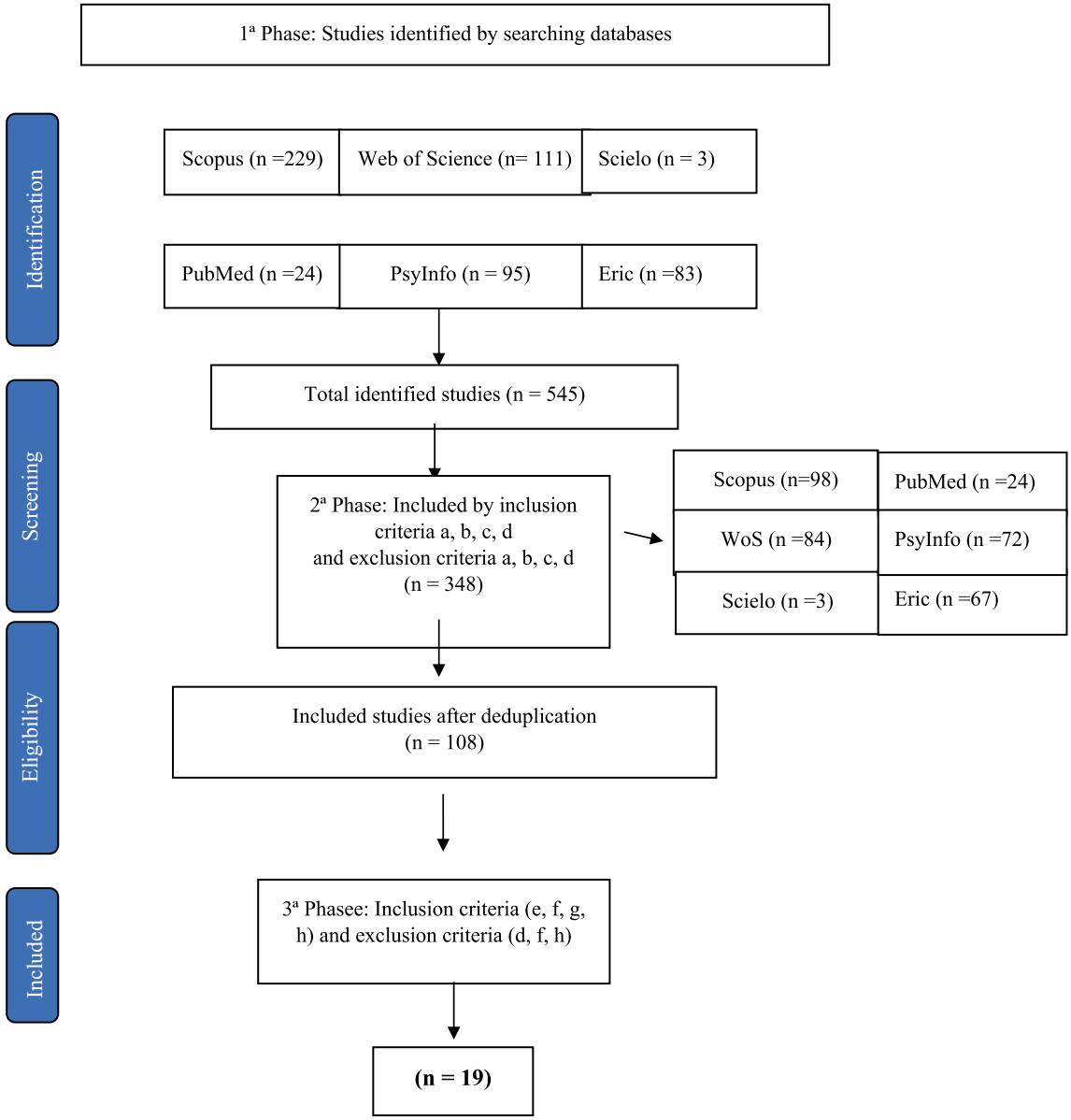

FIGURE 1
Flow diagram of the systematization of the review.

makes this study particularly relevant. By contributing to this nascent field, the present research sheds light on how commercial video games can be harnessed to promote metacognitive skills, thereby enriching both educational theory and practice. Moreover, the growing body of work emphasizes that the use of commercial video games goes beyond mere engagement. It intersects with cognitive and emotional dimensions, providing students with opportunities to practice planning, monitoring, and evaluating their learning processes in real time. Therefore, the importance of continuing to explore this relationship cannot be overstated, as it holds the potential to transform traditional educational methodologies and foster more holistic learning experiences.

Specifically, with regard to the systematic and individual analysis of each of the articles that form the basis of this study, the most important aspects are analyzed in detail below, in accordance with the inclusion criteria of the study: objectives, research design, instruments used, main results and conclusions, limitations, and practical applications in the educational setting. The process of obtaining the sample was carried out by generating a database to record and systematize the most relevant information contained in the selected articles (Table 2).

Sample characteristics

The studies reviewed encompass a wide range of sample sizes, ages, and designs, reflecting the diversity of research on metacognition and cognitive skills in video game contexts. Sample sizes varied significantly, from single-case studies such as Monem (2015), who observed a 16-year-old player's self-scaffolding in an MMORPG, to large-scale studies such as Hardy et al. (2015), with 4,715 participants exploring the impact of cognitive training versus crossword puzzles on neuropsychological performance. Most studies targeted adolescents and young adults, with average ages often ranging from 10 to 20 years,

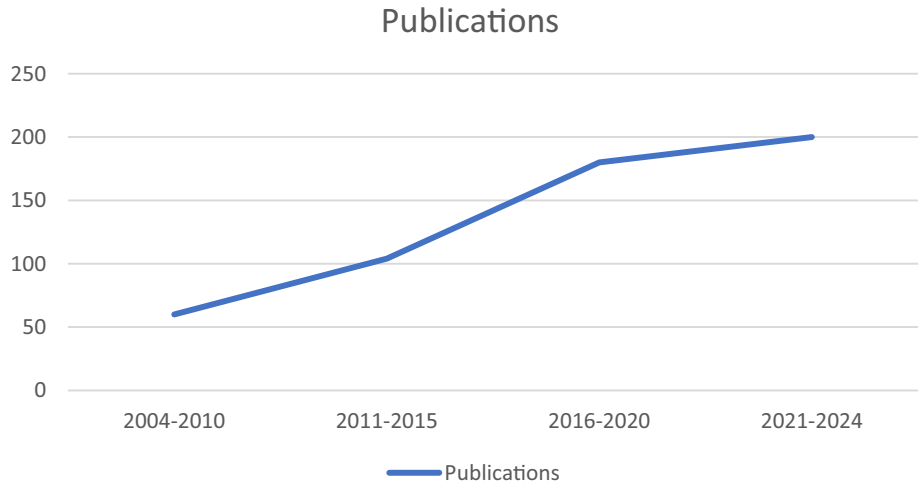

FIGURE 2
Temporal evolution of the use of video games in education.

including a notable sample of 285 university students in Shaw (2022) who used *Minecraft* to examine cognitive predictors of creativity. Only a few studies focused on children, such as Harris et al. (2008), who analyzed goal-oriented problem-solving in a sample of 48 nine-year-olds, and Ricker and Richert (2021), who assessed metacognitive awareness in 103 children averaging 8 years of age. Additionally, Valentine and Jensen (2021) used a phenomenological approach with 30 *Pokémon Go* players over a period of 4 to 12 months, examining how augmented reality plays influences social and cultural interactions.

Across these studies, research designs varied from qualitative approaches, such as Luang-Ng et al. (2022), observing vocabulary learning in four MMORPG players, to experimental and quasi-experimental designs, exemplified by Tangkui and Keong (2023) with a sample of five students learning fractions using *Minecraft*. Mixed-methods designs were also prevalent, enabling researchers to capture both quantitative and qualitative aspects of gameplay. Certain studies, like Wilson et al. (2022) with *The Sims 4*, used pre-test/post-test evaluations to assess changes in vocabulary and metacognitive awareness among 65 students. In contrast, some studies focused on specific cognitive assessments, such as Imanian et al. (2024), which evaluated attention, working memory, and cognitive flexibility in 40 participants through *FIFA*, noting differences between single-player and cooperative play modes. This diverse array of samples and methodologies highlights the breadth of current research exploring how video games impact metacognitive and cognitive skills across varied populations and gaming environments.

Research design and methodology overview

Regarding the aim of the studies, one of these is to use metacognitive strategies and commercial video games as a support to improve relevant educational aspects, such as academic performance, social problem-solving, narrative skills, or motivation (Valentine and Jensen, 2021; Shaw, 2022; Garcia Martinez, 2014; Kim et al., 2009). Other studies establish correlations between the metacognitive construct, the difficulty of video game practice, and participants' mental ability (Tangkui and Keong, 2023; Hardy et al., 2015; Hughes et al., 2013) or analyze the process students use to achieve an educational goal with respect to their level of metacognitive awareness and regulation (Piédalue, 2022; Lickteig, 2020; Michael et al., 2012; Harris et al., 2008). In terms of research design, the sample of studies used both qualitative and quantitative methodology, as well as mixed methodology designs, with no clear predominance, as can be seen in Figure 3.

Quantitative designs also played a central role, with many studies implementing pre-test/post-test structures to assess the impact of video games on cognitive and metacognitive abilities. Wilson et al. (2022) used such a design to measure the effects of *The Sims 4* on vocabulary acquisition and metacognitive awareness in an undergraduate sample. In another quantitative approach, Piédalue (2022) employed a questionnaire and observational measures to analyze executive functioning in children with ADHD using *Minecraft*. Mixed-methods designs, such as the quasi-experimental structure by Tangkui and Keong (2023), allowed for a comprehensive comparison of traditional teaching methods with video game-based learning in a small sample of Year 5 students. Additionally, Hardy et al. (2015) utilized a randomized control design to compare cognitive training in the *Lumosity* program with a crossword puzzle control group, examining neuropsychological outcomes across a large sample of over 4,000 participants. This methodological diversity highlights the adaptable nature of video game research in capturing complex cognitive and metacognitive phenomena across varied contexts and participant groups.

The remaining studies aim to understand the metacognitive dimension. For instance, Wilson et al. (2023) found that using *The Sims 4: Get to Work* in a Business English course enhanced students' metacognitive skills—such as planning, monitoring, and evaluating—while also improving their use of Business English in practical, goal-oriented tasks; Lickteig (2020) defined the phenomenon known as *metagaming*, highlights how players leverage external information and strategies beyond the game itself to optimize their experience. A compelling example is the

TABLE 2 Selection of articles to be analyzed in the systematic review.

Article	Goal	Sample (n=)	Methodology	Video games	Metacognitive measures and instruments	Results
		Age (x=)				
Harris et al. (2008)	Investigates the influence of mastery and performance goals on the nature of children's collaborative participation while playing a problem-solving computer game with a peer.	n = 48 x = 9	Qualitative research. Two groups: 1) Strong personal goal preferences (n = 14). 2) No consistent bias for either mastery or performance goals (n = 34).	Logical Journey of the Zoombinis	1) Level of argument 2) Metacognitive awareness 3) Metacognitive regulation 4) Metacognitive control 5) Brief response	Children who were assigned mastery goals engaged in significantly more elaborated problem-solving discussion while children who were assigned performance goals engaged in more executive help-seeking and displayed lower levels of metacognitive control.
Kim et al. (2009)	Explore the effects of the metacognitive strategies (self-recording, modeling, and thinking aloud) on academic and gaming achievements and the effects of those achievements on social problem-solving.	n = 132 x = 15.50	Pre-test/post-test evaluation, between 10 weeks playing 45 min per day	Gersang	1) Economy concepts: *Gersang* 2) Metacognitive strategies 3) Social problem-solving abilities: *social problem-solving inventory—revised (SPSI-R) by* D'Zurilla et al. (2002). 4) Academic achievement: *by the Incheon Metropolitan Office of Education.* 5) Game Ability: *measured by the game's level scores*	Thinking aloud strategy is the most influential variable in social problem-solving ability. The least influential variable is 'self-recording', where students record their play activities during breaks.
Michael et al. (2012)	Investigates how the difficulty of learner-controlled practice influences the training of a complex task, focusing on cognitive and motivational mechanisms.	n = 112 x = 21.50	Three framing conditions: 1) Positive error framing 2) Negative error framing 3) No error framing	Unreal Tournament 2004	1) Self-efficacy: *12-item self-report* (Bell and Kozlowski, 2002). 2) Metacognition: *Eleven items adapted from* Ford et al. (1998). 3) Self-evaluation: self-report 4) General Mental Ability (GMA): *Raven Advanced Progressive Matrices (APM)* (Raven et al., 1998). 5) Videogame experience: *Two items were used to measure participants prior videogame experience.* 6) Task knowledge: *16-item multiple-choice test.*	GMA was directly related to learner-controlled practice difficulty even after controlling for its effects on pre-training skills. A positive relationship between pre-training self-efficacy and learner-controlled practice difficulty. Positive but not negative error framing during training was directly related to learner-controlled practice difficulty. This study has demonstrated that error-framing interventions can be used in the context of complex tasks.

(Continued)

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TABLE 2 (Continued)

Article	Goal	Sample (n=)	Methodology	Video games	Metacognitive measures and instruments	Results
		Age (x=)				
Monem (2015)	Analyses how an adolescent uses metacognition and self-scaffolding while playing an MMORPG. It focuses on the strategies he employ to overcome challenges and improve his performance in the game.	n = 1 x = 16	Observational case study approach Observed 120 min, divided into four 30-min sessions	Massively Multiplayer Online Role-Playing Game (MMORPG)	1) Self-scaffolding of directions 2) Stating existing self-knowledge 3) Questioning self-knowledge • External audit • Reflective journaling • Triangulation of data sources • Member checking	Self-scaffolding strategies include repeating missions to master specific skills, collaborating with other players to gain knowledge, and using online resources such as forums and guides. The player employs self-scaffolding techniques to facilitate his or her own learning and progression in the game. This includes breaking down complex tasks into more manageable parts, seeking additional information, and practicing specific skills.
Li et al. (2015)	Develop and validate an online tool designed to assess individuals' metacognitive planning abilities.	Two studies 1) n = 71 $x = 20$ 2) n = 440 $x = ?$	First study: Proposed as a phase of the instrument development study. Second Study: Scale Validation	Sokoban	First study: 1) metacognitive planning a) absolute planning time b) ratio between planning time and total time.Second study: 1) Time Ratio: *Tower of London (ToL), intelligence test, and academic achievement.*	The results showed that valid inference could be made from the time ratio score. After controlling for demographic variables, intelligence, and motivation, the time ratio score still accounted for a significant proportion of the variance in Sokoban's performance. The time ratio score was also found to increase with age.
Hardy et al. (2011)	The study evaluated an online cognitive training program comprised of 49 exercises targeting a variety of cognitive capacities. The cognitive training program was compared to an active control condition in which participants completed crossword puzzles.	n = 4.715 x = 39.0	Two groups: 1) Crossword puzzles control 15 min per session. Instructed to complete as many crossword puzzles as possible. (n = 2.048). 2) Cognitive training treatment. Trained in Lumosity Program where they should resolve 49 cognitive tasks (n = 2.667).		Neuropsychological assessment battery 1) Forward 2) Reverse memory 3) Grammatical reasoning was based on Baddeley's grammatical reasoning test 4) Progressive matrices 5) Go/No-Go was designed to assess response inhibition and processing speed 6) Arithmetic reasoning was designed to assess numerical problem-solving ability 7) Two-target search was created for the purposes of the study	Participants randomly assigned to the treatment group improved significantly more on the primary outcome measure, an aggregate measure of neuropsychological performance, than did the active control group. Treatment participants showed greater improvements than controls on speed of processing, short-term memory, working memory, problem-solving, and fluid reasoning assessments.

(Continued)

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TABLE 2 (Continued)

Article	Goal	Sample (n=)	Methodology	Video games	Metacognitive measures and instruments	Results
		Age (x=)				
Lickteig (2020)	Explore how learning occurs during iterative experiences within a game-based environment, using constructivist learning theories as a basis.	n = 8 x = 15	Qualitative research; 6-week program.	Magic: The Gathering	1. Mechanical metagame. 2. Social metagame. 3. Reflective Journaling.	Participants showed a high incorporation and practice of skills through different forms of engagement with the game. Learning related to direct interaction with game systems, mechanics and processes, where players analyze and synthesize complex systems to inform their future play.
Ricker and Richert (2021)	Two studies 1. Examine the different types of digital games to which children are exposed to assess the opportunities for metacognitive experience that they provide. 2. investigate whether exposure to these different games is differentially associated with children's metacognitive awareness	n = 103 x = 8	Qualitative research. The study examined 15 interactive games to assess their levels of adaptability.	Wii Sports FIFA Sims Virtual-Families Angry-birds Super-Mario Lego-City Just-Dance Farmville Tetris Candy-Crush Bubble-Shooter Mario-Kart 64 Cars-Racers	1) Interactive Gaming Exposure. 2) Metacognitive Awareness: Metacognitive Awareness Inventory *(Jr. MAI;* Sperling et al., 2002).	The study suggests that assessing adaptability, player control, and feedback in interactive games can provide a deeper understanding of the metacognitive opportunities available to children during play.
Valentine and Jensen (2021)	Explores the embodied nature of play, specifically in the context of the location-aware augmented reality mobile game Pokémon Go.	n = 30 x =?	Phenomenological study. 4–12 months of program	Pokémon Go	1) Reflexive practice	Technology entanglements, detailing the simultaneous emergence of virtual and real spaces, variant modes of embodied mobility, the way players shaped physical spaces, and the emergence of human–technology relations. Community that emerged among Pokémon Go players, helping characterize embodiment as it permeates social and cultural aspects of play.

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TABLE 2 (Continued)

Article	Goal	Sample (n=)	Methodology	Video games	Metacognitive measures and instruments	Results
		Age (x=)				
Luang-Ng et al. (2022)	The study investigates the impact of Massively Multiplayer Online Role-Playing Game (MMORPG) on players' application of vocabulary learning strategies	n = 4 x = 23	Qualitative research. Video and audio recordings of the 12-h game-play sessions	Guild Wars 2	1) Vocabulary Learning: Semi-Structured Online Interviews.	Four factors that affect the vocabulary language learning experience of the players. 1) The role of game storylines in enhancing MMORPG gaming immersion. 2) Freedom to learn while being away from classroom-related rules. 3) Social interaction that enriches players' learning experience. 4) Role of collaboration among the MMORPG community in enriching learning experience.
Piédalue (2022)	Assess executive functioning difficulties in children diagnosed with Attention-Deficit/Hyperactivity Disorder (ADHD) using task performance in the popular video game Minecraft.	n = 26 x = 10	Quantitative analysis	Minecraft	1) Questionnaire for the Parent/Legal Guardian: containing demographic questions about the child and few questions about ADHD. 2) Minecraft measures: Few factors were assessed, observing the time to solve and the steps needs to reach the end.	The ADS scores predicted two of the four measures. The distance walked measure and the chest time measure were predicted by ADS scores, whereas the construction measure and the distraction measure were not predicted by ADS scores.
Shaw (2022)	This study explored the predictive effects of cognitive abilities and Big Five personality traits on creativity and its two aspects in addition to the intercorrelations between creativity, novelty, and usefulness in a Minecraft building task	n = 285 x = 20	Quantitative analysis	Minecraft	1) SAT Total Scores: the standardized test of college students' academic/intellectual aptitude, one's SAT total score could serve as a suboptimal substitute for direct measurement of general intelligence (Frey, 2019). 2) International Personality Item Pool (IPIP; Goldberg et al., 2006) inventory was used for measuring the Big Five personality traits. 3) Alternate Uses Task (AUT; Guilford, 1967) Consensual Assessment Technique (CAT; Amabile, 1988, 1996), to asses Divergent Thinking Task. 4) Minecraft Task.	Minecraft creativity was predicted by divergent thinking SAT scores and openness to experience supporting the standing beliefs regarding individual antecedents of creativity. Personal characteristics had different predictive effects on the two components of creativity, in that novelty was predicted by divergent thinking SAT scores and openness to experience whereas usefulness was predicted by openness to experience. Intercorrelations among creativity and its two subdimensions, novelty and usefulness, were found to be highly correlated with each other and were also both highly related to creativity

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TABLE 2 (Continued)

Article	Goal	Sample (n=)	Methodology	Video games	Metacognitive measures and instruments	Results
		Age (x=)				
Wilson et al. (2022)	To determine whether The Sims 4 has an effect on ESP undergraduates' acquisition of English vocabulary. To determine whether The Sims 4 has an effect on ESP undergraduates' metacognitive awareness.	n = 65 x = 14	Game-based learning program Pre-test and post-test evaluation Two groups, the experimental group had to survive and establish a business plan, and then a control group.	Sims 4	1) Metacognitive Awareness: Metacognitive *Awareness Inventory (MAI)* Schraw and Dennison (1994). 2) Language proficiency.	The experimental group has shown significant improvement in English vocabulary and greater metacognitive awareness from the instruments administered.
Tangkui and Keong (2023).	Analyze the effect of using Minecraft on Year 5 pupils' higher order thinking skills (HOTS) in fractional problem-solving.	n = 5 x = 65	Quasi-experimental design Two groups, the experimental group had to survive and establish a business plan, and then a control group	Minecraft	1) Higher order thinking skills (HOTS) 2) Problem-solving abilities. Malaysian Year 5 Mathematics Curriculum and Assessment Standard Document and textbook.	Significant difference in the ability to solve fractional problems which requires the use of HOTS between pupils who were exposed to the teaching and learning of fractions using Minecraft and pupils who were exposed to the teaching and learning of fractions using conventional methods
Wilson et al. (2023)	Explores the learners' experiences with using the digital simulation video game to support their learning of Business English and develop their metacognition.	n = 25 x =?	Qualitative case study Three phases 1) Phase 1, players need to establish a retail store including selecting the location of the retail store, hiring employees, selecting the sales percentage, and price markup for the items in the retail store. 2) Phase 2, players make decisions on the best marketing strategies and manage their employees. 3) Phase 3. Players were given tasks on handling business operation and expansion such as managing employee's attitude, performance of sales, and expansion of their business.	SIMS 4: Go to work	Knowledge of Cognition 1) Declarative Knowledge 2) Procedural Knowledge 3) Conditional Knowledge Regulation of cognition 1) Information management strategies and planning 2) Comprehension monitoring, debugging strategies, and evaluation	Findings revealed that learners displayed declarative knowledge, procedural knowledge, and conditional knowledge of metacognitive processes during the game play and indicated the ability to regulate their cognitive processes to achieve the business goals of the retail simulation game while using Business English

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TABLE 2 (Continued)

Article	Goal	Sample (n=)	Methodology	Video games	Metacognitive measures and instruments	Results
		Age (x=)				
Von Gillern and Stufft (2023)	The study examines how 31 middle-school children conducted multimodal analyses of video games	n = 31 x =?	Qualitative case study Over 4 consecutive days, students played video games for 30 min and then wrote reflections about the multimodal symbols within the game and how these symbols influenced their interpretation and decision-making processes during gameplay.	Minecraft Zoo Tycoon: Ultimate Animal Collection Lego Worlds	1) Interpreting 2) Decision-making 3) Dynamic visuals 4) Still images 5) Audio 6) Oral language 7) Written language 8) Abstract symbols 9) Tactile experiences	The study highlights the relationship between students' understanding of multimodal symbols and their decision-making during gameplay, contributing valuable insights to literacy research. The research found that students focused more on dynamic visuals and written language than on audio or tactile experiences, reflecting the salience of these modes in games.
Sobocinski et al. (2024)	The study examines the embodied ways in which learners monitor their cognition while learning about exponential functions in an immersive virtual reality (VR) based game, Pandemic by Prisms of Reality	n = 15 x = 29	The data were collected in a research laboratory infrastructure. The think-aloud protocol and participants' movement were captured via a video camera, which provided a bird's eye view	Pandemic by Prisms of Reality	1) Think aloud data—qualitative coding: participant monitored their cognition, including task understanding, previous knowledge, task product, content understanding, or procedural knowledge 2) Motion detection. To quantify the amount of movement of the participants, we conducted an optical flow analysis using FlowAnalyzer package	Findings demonstrated a temporal interplay among cognitive load, metacognitive monitoring, and motion during VR-based learning. Specifically, cognitive load, indicated by the low- and high-frequency heart rate variability index, predicted instances of metacognitive monitoring, and monitoring predicted learners' motion while interacting with the VR environment.
Imanian et al. (2024)	Explore the effects of esports in the cognitive skills of attention, working memory, and cognitive skills among gamers	n = 40 x = 20	Quantitative analysis Two groups: 1) Single players (n = 20) 2) Coplayers (n = 20); 8 weeks.	FIFA	1) Stroop Task (Stroop, 1935). 2) N-Back Task (Overall, 1958). 3) Wisconsin Card Test (Grant and Berg, 1948).	The findings suggested that FIFA can improve attention and working memory in both single-player and co-player groups. However, cognitive flexibility was only improved for the co-player group.

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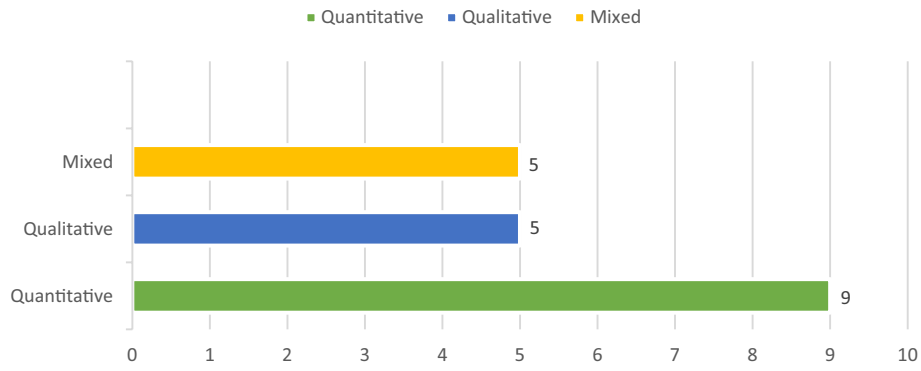

FIGURE 3
Representation in percentages of the methodology applied.

introduction of patient-accessible online medical records, which function as a metacognitive extension of the game, transforming player interaction while enhancing self-regulation and strategic planning—skills essential not only in gameplay but also in real-world applications; in Monet's study (2015), the focus was on how an adolescent male gamer in an MMORPG developed metacognitive skills, self-awareness, and a virtual identity, highlighting the use of self-scaffolding strategies within immersive digital environments. On the other hand, other studies validate an instrument in relation to metacognition and a video game (Imanian et al., 2024; Li et al., 2015). In the study by Imanian et al. (2024), the effects of esports on cognitive skills were analyzed with 40 undergraduate students. Participants played FIFA for 8 weeks, in either single-player or co-player mode. Results showed improvements in attention and working memory for both groups, while cognitive flexibility improved only in the co-player group. These findings suggest that esports can enhance cognitive skills with potential applications in learning and instruction. Finally, highly interactive digital games enhance metacognitive awareness in children aged 6–10 years, while less interactive games show no such effect. Game preferences do not vary by age or sex, highlighting differences in cognitive opportunities across game types (Ricker and Richert, 2021).

Within the quantitative studies, pre-test/post-test designs predominate (Shaw, 2022; Piédalue, 2022; Hardy et al., 2015; Harris et al., 2008; Hughes et al., 2013; Kim et al., 2009), using control and experimental (Wilson et al., 2022; Harris et al., 2008) or quasi-experimental groups (Tangkui and Keong, 2023).

In terms of qualitative studies, we find an observational case study (Monem, 2015), an action research study (Imanian et al., 2024; Wilson et al., 2023), and a study based on focus group interviews (Lickteig, 2020). The forms of qualitative data collection are audio (Luang-Ng et al., 2022), journals, or reflections (Von Gillern and Stufft, 2023). With respect to the target population of the different studies, it is noteworthy that the male university population occupies a large part of the total sample. The predominance of male university students in the sample aligns with the objective of the study because men are generally more engaged in commercial video games, particularly in highly interactive genres (Gisbert-Pérez et al., 2024).

Analysis of video game types and genres used

The range of video games used across the studies reviewed reflects a diverse approach to examining the effects of different game types on metacognitive and cognitive skills. Popular sandbox and simulation games such as *Minecraft* and *The Sims 4* were frequently employed due to their open-ended structures, which encourage problem-solving, strategic planning, and cognitive flexibility. *Minecraft* was notably used in studies by Piédalue (2022), focusing on executive functioning in children with ADHD, and by Shaw (2022), examining the relationships between cognitive abilities, personality traits, and creativity. Similarly, *The Sims 4* was implemented by Wilson et al. (2022) and Wilson et al. (2023) to assess its effects on vocabulary acquisition, metacognitive awareness, and Business English learning, given its potential for simulating real-world scenarios that require both language skills and metacognitive regulation.

Other studies explored the impact of specific genres such as massively multiplayer online role-playing games (MMORPGs) and strategy games, as these genres are known for their emphasis on complex, multi-layered decision-making and social interactions. For example, *Guild Wars 2* was used by Luang-Ng et al. (2022) to study vocabulary acquisition, highlighting how MMORPGs foster social and collaborative learning environments. *Unreal Tournament 2004*, used by Michael et al. (2012), allowed for the examination of error framing in a fast-paced gaming context, providing insight into motivational mechanisms and self-efficacy. Additionally, games with distinct educational and problem-solving elements, such as *Logical Journey of the Zoombinis* by Harris et al. (2008) and *Pandemic by Prisms of Reality* by Sobocinski et al. (2024), were chosen for their capacity to facilitate cognitive monitoring and metacognitive awareness. Even classic games such as *FIFA* (Imanian et al., 2024) and *Pokémon Go* (Valentine and Jensen, 2021) were analyzed for their unique contributions to cognitive skills such as attention, working memory, and spatial awareness. This variety of game types and genres highlights the tailored approach researchers take in selecting games that align with specific cognitive and metacognitive constructs under investigation, thus offering insights into how different gaming environments can enhance or influence metacognitive processes and learning outcomes.

Assessments instruments and tools

Some of the assessment tools used in each of the investigations were Sperling's Metacognitive Awareness Inventory (Jr. MAI; Sperling et al., 2002) (Wilson et al., 2022; Ricker and Richert, 2021), General Mental Ability (GMA): Raven Advanced Progressive Matrices (APM) (Raven et al., 1998; Michael et al., 2012), Alternative Uses Task (AUT; Guilford, 1967), Consensual Assessment Technique (CAT; Amabile, 1988, 1996), to assess Divergent Thinking Task (Shaw, 2022) as well as the modification of others (Hardy et al., 2015; Li et al., 2015) to adapt the procedure, methodology, sample, etc., to the object of research. In qualitative studies, there is an almost unique use of techniques such as interviews, field or reflective diaries (Lickteig, 2020; Monem, 2015), modeling, think-alouds, and recordings (Harris et al., 2008; Kim et al., 2009; Misak, 2018).

Main findings by study focus

Metacognitive awareness and self-regulation enhancement

Many studies demonstrated that video games effectively enhance metacognitive awareness, helping players become more conscious of their thought processes and learning strategies. Wilson et al. (2022) found that *The Sims 4* facilitated significant gains in metacognitive awareness among undergraduate students, particularly in vocabulary acquisition, by requiring players to continuously monitor and adjust their in-game actions to achieve goals. Similarly, Piédalue (2022) reported that children with ADHD displayed improved metacognitive regulation when using *Minecraft*, as the game encouraged them to plan, track progress, and make strategic adjustments. These findings underscore the role of video games in fostering self-awareness and self-regulation—skills critical for effective learning in educational contexts.

Integration of metacognitive strategies within gameplay

Studies indicated that games designed with complex problem-solving or open-ended tasks promote active engagement with metacognitive strategies, such as planning, evaluating, and revising approaches. For instance, Kim et al. (2009) found that players using strategies such as thinking aloud and self-modeling in *Gersang* showed significant improvements in social problem-solving skills. This demonstrates how integrating explicit metacognitive strategies within gameplay can create an environment where players naturally engage in cognitive monitoring, which reinforces learning processes.

Decision-making and problem-solving as vehicles for metacognitive growth

Games that require players to make decisions in real time or solve multifaceted problems provide ideal conditions for practicing metacognitive regulation. Harris et al. (2008), who used the *Logical Journey of the Zoombinis* with children, observed that participants with mastery goals engaged more in reflective problem-solving discussions, enhancing metacognitive control. Additionally, studies on RPGs and MMORPGs, such as Monem (2015) and Luang-Ng et al. (2022), showed that these genres facilitate self-scaffolding as players manage complex in-game scenarios, make decisions under pressure, and seek resources collaboratively. Such dynamic problem-solving environments allow learners to apply and refine metacognitive skills, making them more adept at managing cognitive challenges in both gaming and educational settings.

Role of game difficulty and error feedback in metacognitive engagement

Research on game difficulty and error management suggests that carefully calibrated challenges and error feedback within games can foster metacognitive reflection and adaptation. Michael et al. (2012) highlighted that positive error framing in *Unreal Tournament 2004* helped participants develop resilience and self-efficacy, key components of metacognitive regulation. The need to confront and learn from errors creates a cycle of self-monitoring and strategy adjustment, which mirrors effective learning practices. This controlled introduction of error-based learning within games can thus cultivate a mindset beneficial for academic learning, where resilience and adaptive thinking are essential.

Metacognitive benefits of collaborative gameplay

The social aspect of certain games enhances metacognitive engagement through peer interaction, feedback, and collective problem-solving. Luang-Ng et al. (2022) showed that *Guild Wars 2* encouraged players to adopt metacognitive strategies through collaboration, with players gaining insights into their own learning processes while observing others' strategies. This aligns with findings from Harris et al. (2008), where collaborative problem-solving in children led to higher levels of metacognitive engagement, particularly for those oriented toward mastery goals. These social dynamics promote reflective thinking, mutual regulation, and shared goal-setting, all of which are foundational metacognitive skills relevant to group-based academic tasks.

Transfer of metacognitive skills to academic contexts

Several studies suggest that video games serve as a bridge for transferring metacognitive skills into academic settings. For example, Tangkui and Keong (2023) demonstrated that students using *Minecraft* for fraction problem-solving developed higher order thinking skills that are directly applicable to classroom tasks. This transferability was also evident in studies using *The Sims 4*, where students not only improved vocabulary but also gained a heightened sense of self-regulation, aiding their learning in formal settings (Wilson et al., 2023). These findings emphasize that video games can be powerful tools for cultivating metacognitive skills with real-world educational applications, promoting strategic thinking, persistence, and adaptability.

Limitation of the studies

Regarding the limitations of the different studies, the most significant ones were found with respect to the measurement of the metacognitive construct (Hardy et al., 2015), due to the use of a type of questionnaire that attended more to metacognitive knowledge than to metacognitive regulation, the latter option being more relevant to the objective of the study. In this sense, there could be some mismatch in the results if the same psychometric items were applied to participants of different ages (Li et al., 2015). On the other hand, it is not possible to clarify,

based on the results of the different studies, whether subjects with high metacognitive levels tend to choose a particular type of video game or, on the contrary, it is the video game itself that develops these metacognitive skills in the subject (Ricker and Richert, 2021). However, there seems to be a correlation between the type of video game chosen and the metacognitive level developed (Moncarz, 2011). Similarly, the authors acknowledge some sociodemographic limitations within their studies such as sex (Hardy et al., 2015; Hughes et al., 2013; Lickteig, 2020), sample representation (Harris et al., 2008; Monem, 2015; Ricker and Richert, 2021), or age (Harris et al., 2008; Hughes et al., 2013; Moncarz, 2011).

Finally, when considering future practical applications on the use of video games in formal educational contexts, the articles highlight the importance and difficulty of including these cultural tools in classrooms (Hughes et al., 2013; Monem, 2015). The causes of this reluctance could be explained by the teachers' need for specific training in these tools, which are essential for them to be able to value the positive educational aspects of video games (Martín del Pozo et al., 2017; De Sousa and Rasmussen, 2019). In this way, methodological initiatives could be promoted where video games are the protagonists, with the aim of achieving both curricular objectives and the development of transversal cognitive and metacognitive competencies within their teaching practice (Kim et al., 2009; Lickteig, 2020). This prior training would also be useful to select which video game is the most appropriate to include in classrooms (Hughes et al., 2013; Lickteig, 2020), thus establishing a forecast on what cognitive or metacognitive abilities each one develops and thus making the best choice within the large existing offer (Moncarz, 2011; Ricker and Richert, 2021).

Discussion and conclusions

One of the primary outcomes of this systematic review is the identification of limited studies explicitly examining the relationship between commercial video games and metacognitive skill development, despite a growing body of research on video games in other educational contexts. This scarcity may stem from the challenges associated with integrating commercial games in educational settings (Marín-Díaz, 2019; Quesada and Tejedor, 2016) and the lack of consensus on defining and measuring metacognitive constructs (Gaviria, 2019; Huertas et al., 2014; Li et al., 2015; Mariano and González, 2020). However, the studies reviewed provide insights into how specific game genres and in-game features can stimulate metacognitive processes, offering clear but preliminary answers to the research questions.

For the first objective—understanding how commercial video games in education might foster metacognition—findings indicate that games facilitate a range of metacognitive activities, such as planning, self-monitoring, and evaluation (Wilson et al., 2022; Kim et al., 2009; Lickteig, 2020). Several studies focused on integrating metacognitive strategies such as reflective journaling, modeling, and verbalization (Kim et al., 2009; Li et al., 2015; Misak, 2018), while others found that orienting educational goals toward mastery supports deeper metacognitive engagement (Harris et al., 2008). Additionally, some researchers highlighted the impact of game genres and specific mechanics (e.g., RPGs, MMORPGs, and sandbox games) in promoting metacognitive skills through decision-making and collaborative problem-solving (Monem, 2015; Ricker and Richert, 2021). These findings suggest that well-chosen commercial games can support metacognitive development, though targeted research on genre-specific effects is needed to strengthen this conclusion.

In relation to the second objective—assessing whether commercial video games can cultivate both metacognitive and other cognitive skills—the evidence suggests that video games indeed support broader educational outcomes. Games were shown to enhance critical thinking, problem-solving, self-regulation, and engagement in learning tasks (Coutinho and Neuman, 2008; Kleitman and Gibson, 2011; Klimenko and Alvares, 2009; Schraw et al., 2006; Sungur, 2007). Specific examples, such as the increased self-monitoring and regulation observed in players of *The Sims 4* and *Minecraft* (Wilson et al., 2022; Piédalue, 2022), align with Flavell's (1979) definition of metacognition as active monitoring and control of cognition, suggesting that commercial games do not hinder but rather promote valuable learning and motivational benefits in educational contexts.

However, this review reveals notable limitations, as highlighted in some studies (Hughes et al., 2013; Kim et al., 2009; Ricker and Richert, 2021), including the lack of standardized psychometric tools for assessing metacognitive processes in gaming contexts. Although six major databases were searched, the few studies meeting the inclusion criteria reflect limited research on the impact of commercial video games on metacognition, suggesting a need for further exploration, potentially including doctoral dissertations and unpublished studies. Another limitation concerns the reliability of existing measures for metacognition, underscoring the importance of validating tools that capture metacognitive elements specific to interactive gaming environments.

In conclusion, the metacognitive dimension, with its potential to enhance educational outcomes, aligns well with the engaging and dynamic environments created by commercial video games. Integrating these tools could significantly support metacognitive development alongside traditional academic skills, advocating a pedagogical shift toward more reflective and controlled learning experiences (Osses Bustingorry and Jaramillo Mora, 2008; Roque-Herrera et al., 2018). To fully leverage this potential, further research is necessary to identify effective game genres, validate psychometric tools, and establish instructional frameworks that incorporate video games into curricula, ultimately fostering a participatory and self-regulated learning process that meets contemporary educational needs.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

MC-R: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project

administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. JG-L: Investigation, Resources, Supervision, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Amabile, T. M. (1988). "A model of creativity and innovation in organizations" in Research in organizational behavior, vol. 10. eds. B. M. Staw and L. L. Cummings (Greenwich, CT: JAI Press), 123–167.

Amabile, T. M. (1996). Creativity in context: update to "the social psychology of creativity.". Boulder, CO: Westview Press.

Ames, M. G., and Burrell, J. (2017) 'Connected learning' and the equity agenda: a microsociology of Minecraft play. In Proceedings of the 2017 ACM conference on computer supported cooperative work and social computing, 446–457.

Andrade, A. (2020). El juego y su importancia cultural en el aprendizaje de los niños en educación inicial. *J. Sci. Res.* 5, 132–149.

Baker, L., and Brown, A. (1984). "Metacognitive skills and reading" in Handbook of Reading research. eds. D. Pearson, R. Barr, M. L. Kamil and P. Mosenthal (New York, EE.UU: Longman), 353–394.

Bell, B. S., and Kozlowski, W. J. (2002). Goal orientation and ability: Interactive effects on self-efficacy, performance, and knowledge. *J. Appl. Psychol.* 87:497. doi: 10.1037/0021-9010.87.3.497

Bond, M., Buntins, K., Bedenlier, S., Zawacki-Richter, O., and Kerres, M. (2020). Mapping research in student engagement and educational technology in higher education: a systematic evidence map. *Int. J. Educ. Technol. High. Educ.* 17, 1–30. doi: 10.1186/s41239-019-0176-8

Broadbent, J., and Poon, W. (2015). Self-regulated learning strategies & academic achievement in online higher education learning environments: a systematic review. *Internet High. Educ.* 27, 1–13. doi: 10.1016/j.iheduc.2015.04.007

Brown, A. (1978). "Knowing when, where, and how to remember: a problem of metacognition" in Advances in instructional psychology. ed. R. Glaser (Hillsdale, Michigan: Erlbaum), 77–165.

Bullard, J. (2013). Playfully serious information for serious play: the integration of community values in an information resource. iConference 2013 Proceedings (pp. 389–397).

Cano-López, J. B., García-Sancho, E., Fernández-Castilla, B., and Salguero, J. M. (2022). Empirical evidence of the metacognitive model of rumination and depression in clinical and nonclinical samples: a systematic review and meta-analysis. *Cogn. Ther. Res.* 46, 367–392. doi: 10.1007/s10608-021-10260-2

Carter, M. (2015). Emitexts and Paratexts: propaganda in EVE online. *Games Culture* 10, 311–342. doi: 10.1177/1555412014558089

Chatzivasileiou, P., and Drigas, A. (2022). ICTs for the development of the cognitive and metacognitive abilities of the students with specific learning disorder in mathematics. *Technium Soc. Sci. J.* 31, 131–152. doi: 10.47577/tssj.v31i1.6484

Connolly, T. M., Boyle, E. A., MacArthur, E., Hainey, T., and Boyle, J. M. (2012). A systematic literature review of empirical evidence on computer games and serious games. *Comput. Educ.* 59, 661–686. doi: 10.1016/j.compedu.2012.03.004

Coutinho, S., and Neuman, G. (2008). A model of metacognition, achievement goal orientation, learning style and self-efficacy. *Learning Environ. Res.* 11, 131–151. doi: 10.1007/s10984-008-9042-7

D'Zurilla, T. J., Nezu, A. M., and Maydeu-Olivares, A. (2002). Social problem-solving inventory - revised (SPSI-R™): Manual. Washington, DC: APA PsycTests.

De Sousa, F., and Rasmussen, I. (2019). Productive disciplinary engagement and videogames: a teacher's educational design to engage students with ethical theories in citizenship education. *Nordic J. Digit. Lit.* 14, 99–116. doi: 10.18261/issn.1891-943x-2019-03-04-02

Delgado, I. (2011). Juego infantil y su metodología. Paraninfo 2011.

Diaz-López, A., Maquilón-Sánchez, J. J., and Mirete-Ruiz, A. B. (2023). Validation of the Ud-TIC scale on the problematic use of mobile phones and video games as mediators of social skills and academic performance. *Rev. Esp. Pedagog.* 80:11. doi: 10.22550/REP80-3-2022-06

Donaldson, S. (2017). Mechanics and metagame: exploring binary expertise in league of legends. *Games Cult.* 12, 426–444. doi: 10.1177/1555412015590063

Dörrenbächer-Ulrich, L., Dilhuit, S., and Perels, F. (2024). Investigating the relationship between self-regulated learning, metacognition, and executive functions by focusing on academic transition phases: a systematic review. *Curr. Psychol.* 43, 16045–16072. doi: 10.1007/s12144-023-05551-8

Efklides, A. (2008). Metacognition: defining its facets and levels of functioning in relation to self-regulation and co-regulation. *Eur. Psychol.* 13, 277–287. doi: 10.1027/1016-9040.13.4.277

Efklides, A. (2009). "The new look in metacognition: from individual to social, from cognitive to affective" in Metacognition: New research developments. ed. C. Larson (New York, EE.UU: Nova Science Publishers), 137–151.

Erstad, O., Kjällander, S., and Järvelä, S. (2021). Facing the challenges of 'digital competence' a Nordic agenda for curriculum development for the 21st century. *Nordic J. Digit. Lit.* 16, 77–87. doi: 10.18261/issn.1891-943x-2021-02-04

Erstad, O., and Voogt, J. (2018). "The twenty-first century curriculum: issues and challenges" in Second handbook of information technology in primary and secondary education. eds. J. Voogt, G. Knezek, R. Christensen and K. Lai (Berlin: Springer), 19–36.

Fernández Velasco, P., and Loev, S. (2024). Metacognitive feelings: a predictive-processing perspective. *Perspect. Psychol. Sci.* 1–23. doi: 10.1177/17456916231221976

Flavell, J. (1979). Metacognition and cognitive monitoring: a new area of cognitive—developmental inquiry. *Am. Psychol.* 34, 906–911. doi: 10.1037/0003-066X.34.10.906

Fleming, S. M. (2024). Metacognition and confidence: a review and synthesis. *Annu. Rev. Psychol.* 75, 241–268. doi: 10.1146/annurev-psych-022423-032425

Ford, J., Smith, E., Weissbein, D., Gully, S., and Salas, E. (1998). Relationships of goal orientation, metacognitive activity, and practice strategies with learning outcomes and transfer. *J. Appl. Psychol.* 83, 218–233. doi: 10.1037/0021-9010.83.2.218

Frey, M. C. (2019). What we know, are still getting wrong, and have yet to learn about the relationships among the sat, intelligence and achievement. *J. Intell.* 7:26. doi: 10.3390/jintelligence7040026

Gandini, F. (2018). Metacognición y aprendizaje. In: A.M. Palacios, M.A. Pedragosa y M. Querejeta (Coords.). Encuentro en la encrucijada: Psicología, Cultura y Educación. La Plata: EDULP. (Libros de Cátedra. Sociales). En Memoria Académica. Available at: https://www.memoria.fahce.unlp.edu.ar/libros/pm.4860/pm.4860.pdf

García Madruga, J. A., Gutierrez Martinez, F., and Carriedo López, N. (2002). "El desarrollo de los conocimientos y habilidades metacognitivas" in Psicología Evolutiva II. Desarrollo Cognitivo y lingüístico. Volumen 1 (Madrid: Universidad Nacional de Educación a Distancia).

Garcia Martinez, S. (2014). Using commercial games to support teaching in higher education (unpublished doctoral dissertation). Quebec, Canada: Concordia University.

Gauvain, M. (2020). Vigotsky on learning and development. In Developmental Psychology: Revisiting the classic studies, slater, M., y Quinn, P. Chapter 6, 89–101. Editorial sage. 2° Edición.

Gaviria, C. (2019). Pensar la historia con el deseo: metacognición, motivación y comprensión histórica. *Rev. Col. Psicol.* 28, 147–164. doi: 10.15446/rcp.v28n1.70763

Gee, J. P. (2007). Good video games + good learning: collected essays on video games, learning and literacy: 27 (new literacies and digital epistemologies). Peter Lang Publishing Inc (Eds).

Gee, J. P. (2011). "Reflections on empirical evidence on games and learning" in Computer games and instruction. eds. S. Tobias and J. Fletcher (Greenwich, GB: Information Age Publishing), 223–232.

Gisbert-Pérez, M., López-Fernández, O., and Griffiths, M. D. (2024). Gender differences in internet gaming among university students: a discriminant analysis. *Front. Psychol.* 15, 1–10. doi: 10.3389/fpsyg.2024.1412739

Goldberg, R. F., Perfetti, C. A., and Schneider, W. (2006). Perceptual knowledge retrieval activates sensory brain regions. *J. Neurosci.* 26, 4917–4921. doi: 10.1523/JNEUROSCI.5389-05.2006

Grant, D. A., and Berg, E. (1948). A behavioral analysis of degree of reinforcement and ease of shifting to new responses in a Weigl-type card-sorting problem. *J. Exp. Psychol. 38*, 404–411. doi: 10.1037/h0059831

Guilford, J. P. (1967). Creativity: Yesterday, today and tomorrow. *J. Creative Behav.* 1, 3–14. doi: 10.1002/j.2162-6057.1967.tb00002.x

Hadwin, A., and Järvellä, S. (2011). Social aspects of self-regulated learning: where social and self-meet in the strategic – regulation of learning. *Teach. Coll. Rec.* 113, 235–239. doi: 10.1177/016146811111300201

Hall, J., Stickler, U., Herodotou, C., and Iacovides, I. (2020). Player conceptualizations of creativity in digital entertainment games. *Convergence* 26, 1226–1247. doi: 10.1177/1354856519880791

Hardy, J. L., Drescher, D., Sarkar, K., Kellett, G., and Scanlon, M. (2011). Enhancing visual attention and working memory with a web-based cognitive training program. *Mensa Res. J. 42*, 13–20.

Hardy, J. L., Nelson, R. A., Thomason, M. E., Stern, E., and Sable, J. J. (2015). Enhancing cognitive abilities with comprehensive training: A large, online, randomized, active-controlled trial. *PLOS One* 13:e0204667. doi: 10.1371/journal.pone.0134467

Harris, A., Yuill, N., and Luckin, R. (2008). The influence of context-specific and dispositional achievement goals on children's paired collaborative interaction. *Br. J. Educ. Psychol.* 78, 355–374. doi: 10.1348/000709907X267067

Henderson, L. (2005). Video games: a significant cognitive artifact of contemporary youth culture. DiGRA Proceedings, 2, 1–14.

Hu, W., and Luo, Y. (2024). Chinese English language learners' vocabulary retention: investigating the effectiveness of neuro/metacognitive and socio-cultural strategies. *BMC Psychol.* 12:113. doi: 10.1186/s40359-024-01612-0

Huertas, P., Vesga, G., and Galindo, M. (2014). Validación del intrumento "inventario de habilidades metacognitivas (MAI) con estudiantes colombianos. *Praxis Saber* 5, 55–74. doi: 10.19053/22160159.3022

Hughes, M., Day, E., Wang, X., Schuelke, M., Arsenault, M., Harkrider, L., et al. (2013). Learner-controlled practice difficulty in the training of a complex task cognitive and motivational mechanisms. *J. Appl. Psychol.* 98, 80–98. doi: 10.1037/a0029821

Hutton, B., Salanti, G., Caldwell, D. M., Chaimani, A., Schmid, C. H., Cameron, C., et al. (2015). The PRISMA extension statement for reporting of systematic reviews incorporating network meta-analyses of health care interventions: checklist and explanations. *Ann. Intern. Med.* 162, 777–784. doi: 10.7326/M14-2385

Imanian, M., Khatibi, A., Heydarinejad, S., Saemi, E., and Veisia, E. (2024). Effects of electronic sports on the cognitive skills of attention, working memory, and cognitive flexibility: Research Square.

Kahila, J., Tedre, M., Kahila, S., Vartianen, H., Valtonen, T., and Mäkitalo, K. (2020). Children's gaming involves much more than the gaming itself: a study of the metagame among 12 to 15 year old children. *Convergence*, 20, 1–19. doi: 10.1177/1354856520979482

Kahila, J., Valtonen, T., López-Pernas, S., Saqr, M., Vartiainen, H., Kahila, S., et al. (2023). A typology of metagamers: identifying player types based on beyond the game activities. *Games Cult.* 20, 38–58. doi: 10.1177/15554120231187758

Kapp, F., Spangenberg, P., Kruse, L., and Narciss, S. (2019). Investigatin changes in self-evaluation of technical competences in the serious games Serena Supergreen: findings, challenges, and lesson learned. *Metacogn. Learn.* 14, 387–411. doi: 10.1007/s11409-019-09209-4

Kickmeier-Rust, M. D., and Albert, D. (2012). Educationally adaptive: balancing serious games. *Int. J. Comput. Sci. Sport* 11, 1–10.

Kim, B., Park, H., and Baek, Y. (2009). Not just fun, but serious strategies: using meta-cognitive strategies in game-based learning. *Comput. Educ.* 52, 800–810. doi: 10.1016/j.compedu.2008.12.004

Kleitman, S., and Gibson, J. (2011). Metacognitive beliefs, self-confidence and primary learning environment of sixth grade students. *Learn. Individ. Differ.* 21, 728–735. doi: 10.1016/j.lindif.2011.08.003

Klimenko, O., and Alvares, J. (2009). Aprender cómo aprendo: la enseñanza de estrategias metacognitivas. *Educ. Educ.* 12, 11–28.

Levis, D. (2013). Los videojuegos, un fenómeno de masas. Sivel.

Li, W., Liu, C. Y., and Tseng, J. C. (2024). Development of a metacognitive regulation-based collaborative programming system and its effects on students' learning achievements, computational thinking tendency and group metacognition. *Br. J. Educ. Technol.* 55, 318–339. doi: 10.1111/bjet.13358

Li, J., Zhang, B., Du, H., Zhu, Z., and Ming-Li, Y. (2015). Metacognitive planning: development and validation of an online measure. *Psychol. Assess.* 27, 260–271. doi: 10.1037/pas0000019

Liberati, A., Altman, D., Tetzlaff, J., Mulrow, C., Gøtzsche, P., Ioannidis, J., et al. (2009). The PRISMA statement for reporting systematic reviews and Meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *PLoS Med.* 6:e1000100. doi: 10.1371/journal.pmed.1000100

Lickteig, S. J. (2020). Metagaming: Cognition in gaming environments and systems. [Tesis de doctorado, Kansas State University]. Repositorio Institucional Universidad Kansas State University.

Luang-Ng, L., Sharieful-Azizie, R., and Yi-Chew, S. (2022). Factors influencing ESL players' use of vocabulary learning strategies in massively multiplayer online role-playing games (MMORPG). *Asia Pac. Educ. Res.* 31, 369–381. doi: 10.1007/s40299-021-00578-6

Mahayanti, N. W. S., Kusuma, I. P. I., and Wibawa, S. (2020). Digital game-based learning in EFL: its effect on young. *Asian ESP J.* 16, 5–30.

Mariano, L., and González, F. (2020). Metacognición aplicada: Estrategias para aprender a aprender. Barcelona: Editorial Octaedro.

Marín-Díaz, V. (2019). ¿El poder de la gamificación educativa? *Rev. Educ. Mediá. TIC* 7, I–IV. doi: 10.21071/edmetic.v7i2.11146

Martín del Pozo, M., Basilotta Gómez-Pablos, V., and García-Valcárcel Muñoz-Repiso, A. (2017). A quantitative approach to pre-service primary school teachers' attitudes towards collaborative learning with video games: previous experience with video games can make the difference. *Int. J. Educ. Technol. High. Educ.* 14:11. doi: 10.1186/s41239-017-0050-5

Mayor, J., Suengas, A., and González-Marqués, J. (1993). Estrategias Metacognitivas. Aprender a aprender y aprender a pensar. Síntesis Psicología.

McCaslin, M., and Hickey, D. T. (2001). "Self-regulated learning and academic achievement: a Vygotskian view" in Self-regulated learning and academic achievement: Theoretical perspectives. eds. B. Zimmerman and D. Schunk. *2nd* ed. (Mahwah, NJ: Lawrence Erlbaum Associates), 227–252.

Medina, I., Palacios, R., and Dejo, L. (2020). La revisión sistemática de literatura como evidencia del desempeño de competencias profesionales. *Rev. Epistemia* 5.

Michael, J., Ford, P., and Kozlowski, S. W. (2012). Error framing and learner-controlled practice in training. *Hum. Factors* 54, 56–67. doi: 10.1037/a0029821

Misak, J. (2018). A virtual bridge not too far: teaching narrative sense of place with virtual reality. *Comput. Compos.* 50, 39–52. doi: 10.1016/j.compcom.2018.07.007

Mitsea, E., Drigas, A., and Skianis, C. (2024). Well-being technologies and positive psychology strategies for training metacognition, emotional intelligence and motivation Meta-skills in clinical populations: a systematic review. *Psych* 6, 305–344. doi: 10.3390/psych6010019

Moncarz, H. (2011). The relationship between playing games and metacognitive awareness [Tesis de doctorado, George Mason University]. Repositorio Educational Resources Information Center.

Monem, R. (2015). Metacognition and self-scaffolding in MMORPGs: a case study of an adolescent male gamer. *Qual. Rep.* 20, 454–465. doi: 10.46743/2160-3715/2015.2121

Montero, B. (2017). Aplicación de juegos didácticos como metodología de enseñanza: Una revisión de la literatura. *Experiencias docentes* 1, 75–92.

Naeimi, S., and Rafezi, Z. (2023). The role of mindfulness, metacognitive beliefs and self-control in predicting job satisfaction of Tehran airlines employees. *Psychol. Res. Manage.* 9, 99–118. doi: 10.22034/jom.2023.703855

Osses Bustingorry, S., and Jaramillo Mora, S. (2008). Metacognición: un camino para aprender a aprender. *Estud. Pedagóg.* 34, 187–197. doi: 10.4067/S0718-07052008000100011

Ouellette, M. (2019). I'm controlling and composing: the role of metacognition in the incredible machine. *Invisible Culture* 30, 1–22. doi: 10.47761/494a02f6.a04844c6

Page, M., McKenzie, J., Bossuyt, P., Boutron, I., Hoffmann, T. C., Mulrow, C. D., et al. (2020). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *bmj.* 372. doi: 10.1186/s13643-021-01626-4

Páramo, P. (2020). Cómo elaborar una revisión sistemática. Universidad Pedagógica Nacional. doi: 10.13140/RG.2.2.31465.85608

Pegalajar Palomino, M. C. (2021). Implicaciones de la gamificación en Educación Superior: una revisión sistemática sobre la percepción del estudiante. *Rev. Investig. Educ.* 39, 169–188. doi: 10.6018/rie.419481

Pérez, G., and González, L. (2020). Una posible definición de metacognición para la enseñanza de las ciencias. *Investig. Ensino Ciênc.* 25, 384–404. doi: 10.22600/1518-8795.ienci2020v25n1p384

Pertegal-Vega, M. Á., Oliva-Delgado, A., and Rodriguez-Meirinhos, A. (2019). Systematic review of the current state of research on online social networks: taxonomy on experience of use. *Comunicar* 27, 81–90. doi: 10.3916/C60-2019-08

Piédalue, C. (2022). Assessment of executive functioning difficulties among ADHD children through task performance in Minecraft (Master's thesis, Queen's University (Canada).

Pillay, H., Brownlee, J., and Wilss, L. (1999). Cognition and recreational computer games: implications for educational technology. *J. Res. Comput. Educ.* 32, 203–216. doi: 10.1080/08886504.1999.10782624

Pintrich, P., Wolters, C., and Baxter, G. (2000). "Assessing metacognition and self-regulated learning" in Issues in the measurement of metacognition. eds. G. Schraw and J. Impara (Taylor & Francis, Ltd, Buros Institute of Mental Measurements), 43–97.

Prendes Espinosa, M. P., Martínez Sánchez, F., and Gutiérrez Porlán, I. (2017). Competencia digital: una necesidad del profesorado universitario en el siglo XXI. *Rev. Educ. Distancia*. 2:22. doi: 10.6018/red/56/7

Quesada, A., and Tejedor, S. (2016). Aplicaciones educativas de los videojuegos: el Caso de world of Warcraft. *Rev. Medios Educ.* 48, 187–196. doi: 10.12795/pixelbit.2015.i48.12

Raven, B. H., Schwarzwald, J., and Koslowsky, M. (1998). Conceptualizing and measuring a power/interaction model of interpersonal influence. *J. Appl. Soc. Psychol.* 28, 307–332. doi: 10.1111/j.1559-1816.1998.tb01708.x

Ricker, A., and Richert, A. (2021). Digital gaming and metacognition in middle childhood. *Comput. Human Behav.* 115:106593. doi: 10.1016/j.chb.2020.106593

Roque-Herrera, Y., Valdivia, P., Alonso, S., and Zagalaz, M. (2018). Metacognición y aprendizaje autónomo en la educación superior. Educ. Méd. Sup., 32, 293–302.

Sánchez-Meca, J. (2010). Cómo realizar una revisión sistemática y un meta-análisis. *Aula Abierta* 38, 53–64. Available at: https://www.um.es/metaanalysis/pdf/5030.pdf

Sánchez-Rodríguez, P. A., Alfageme-González, M. B., and Serrano-Pastor, F. J. (2010). Aspectos sociales de los videojuegos. *Rev. Latinoam. Tecnol. Educ.* 9:4352.

Schrader, P. G., Carroll, M. C., McCreery, M. P., and Head, D. L. (2020). Mixed methods for human–computer interactions research: An iterative study using Reddit and social media. *J. Educ. Comput. Res. 58*, 818–841. doi: 10.1177/0735633119878066

Schraw, G., Crippen, K., and Hartley, K. (2006). Promoting self-regulation in science education: metacognition as part of a broader perspective on learning. *Res. Sci. Educ.* 36, 111–139. doi: 10.1007/s11165-005-3917-8

Schraw, G., and Dennison, R. S. (1994). Assessing metacognitive awareness. *Contemp. Educ. Psychol.* 19, 460–475. doi: 10.1006/ceps.1994.1033

Schunk, D. (2001). "Social cognitive theory and self-regulation" in Selfregulated learning and academic achievement. eds. B. Zimmerman and D. Schunk (Mahwah, NJ: Lawrence Erlbaum Associates).

Shaw, J. (2022). Cognitive predictors of creativity: exploring relationships in minecraft. *Creat. Res. J.* 34, 15–29. doi: 10.1080/10400419.2022.2061172

Singh, C. A., and Muis, K. R. (2024). An integrated model of socially shared regulation of learning: the role of metacognition, affect, and motivation. *Educ. Psychol.* 1-18. doi: 10.1080/00461520.2023.2294881

Sobocinski, M., Dever, D., Wiedbusch, M., Mubarak, F., Azevedo, R., and Järvelä, S. (2024). Capturing self-regulated learning processes in virtual reality: causal sequencing of multimodal data. *Br. J. Educ. Technol.* 55, 1486–1506. doi: 10.1111/bjet.13393

Sourmelis, T., Ioannou, A., and Zaphiris, P. (2017). Massively multiplayer online role playing games (MMORPGs) and the 21st century skills: a comprehensive research review from 2010 to 2016. *Comput. Hum. Behav.* 67, 41–48. doi: 10.1016/j.chb.2016.10.020

Sperling, R. A., Howard, L. H., Miller, L. A., and Murphy, C. (2002). Measures of children's knowledge and regulation of cognition. *Contemp. Educ. Psychol.* 27, 51–79. doi: 10.1006/ceps.2001.1091

Squire, K. (2011). Video games and learning: Teaching and participatory culture in the digital age. Cambridge, MA: Teachers College Press.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *J. Exp. Psychol.* 18:643. doi: 10.1037/h0054651

Sun, M., Wang, M., Wegerif, R., and Peng, J. (2022). How do students generate ideas together in scientific creativity tasks through computer-based mind mapping? *Comput. Educ.* 176:104359. doi: 10.1016/j.compedu.2021.104359

Sungur, S. (2007). Modeling the relationships among students' motivational beliefs, metacognitive strategy use, and effort regulation. *Scand. J. Educ. Res.* 51, 315–326. doi: 10.1080/00313830701356166

Tan, W., Supian, N., and Cheah, K. S. (2022) Game-based learning in improving English vocabulary and detecting metacognitive awareness among English for specific purposes undergraduates. In 2nd international conference on social science, humanities, education and society development (ICONS 2021), Atlantis Press, pp. 135–140.

Tangkui, R. B., and Keong, T. C. (2023). The effect of Minecraft on Learners' higher-order thinking skills in fractional problem-solving. *Anatol. J. Educ.* 8, 1–20. doi: 10.29333/aje.2023.821a

Taub, M., Zevedo, R., Bradbury, A., Millar, G., and Lester, J. (2018). Using sequence mining to reveal the efficiency in scientific reasoning during STEM learning with a game-based learning environment. *Learn. Instr.* 54, 93–103. doi: 10.1016/j.learninstruc.2017.08.005

Teng, M. F. (2024). Metacognition and autonomy in building a community for language learning through VR digital gaming. *Comput. Educ. X Reality* 4, 100060–106780. doi: 10.1016/j.cexr.2024.100060

Tokarieva, A. V., Volkova, N. P., Harkusha, I. V., and Soloviev, V. N. (2019). Educational digital games: models and implementation. *Educ. Dimension* 1, 5–26. doi: 10.31812/educdim.v53i1.3872

Torres, A., Ramírez, M., and Romero, L. (2019). Valoración y evaluación de los Aprendizajes Basados en Juegos (GBL) en contextos e-learning. *Educ. Knowl. Soc.* 19, 109–128. doi: 10.14201/eks2018194109128

Urrútia, G., and Bonfill, X. (2010). Declaración PRISMA: una propuesta para mejorar la publicación de revisiones sistemáticas y metaanálisis. *Med. Clin.* 135, 507–511. doi: 10.1016/j.medcli.2010.01.015

Valencia-Molina, T., Serna-Collazos, A., Ochoa-Angrino, S., Caicedo-Tamayo, A., Montes-González, J., and Chávez-Vescance, J. (2017). Competencias y estándares TIC desde la dimensión pedagógica: una perspectiva desde los niveles de apropiación de las TIC en la práctica educativa docente. Pontificia Universidad Javeriana.

Valentine, K. D., and Jensen, L. J. (2021). Mobile entanglements and communitas: the embodied nature of play in Pokémon Go. *Educ. Technol. Res. Dev.* 69, 1955–1985. doi: 10.1007/s11423-020-09930-x

Vlachopoulos, D., and Makri, A. (2017). The effect of games and simulations on higher education: a systematic literature review. *Int. J. Educ. Technol. High. Educ.* 14:22. doi: 10.1186/s41239-017-0062-1

Von Gillern, S., and Stufft, C. (2023). Multimodality, learning and decision-making: children's metacognitive reflections on their engagement with video games as interactive texts. *Literacy* 57, 3–16. doi: 10.1111/lit.12304

Weber, A. M., and Greiff, S. (2023). ICT skills in the deployment of 21st century skills: a (cognitive) developmental perspective through early childhood. *Appl. Sci.* 13:4615. doi: 10.3390/app13074615

Wells, A. (2009). Metacognitive therapy for anxiety and depression. New York: Guilford Press.

Wilson, R. J., Hannon, D., and Martens, R. (2022). Enhancing metacognitive awareness in ESP learners through gameplay. *J. Lang. Teach. Res.* 10, 285–300.

Wilson, T., Supian, N., and Sung, C. K. (2023). Using game-based learning in developing metacognition among ESP students: a case study. *Asian J. Univ. Educ.* 19, 506–518. doi: 10.24191/ajue.v19i3.23495

Yoon, M., and Baek, J. (2018). Development and application of the steam education based on the soccer robot for elementary students. *Int. J. Mob. Blended Learn.* 10, 11–22. doi: 10.4018/IJMBL.2018070102

Zhang, X. (2024) Exploring cognitive and language acquisition processes in second language learning of English. In 3rd international conference on education, language and art (ICELA 2023), Atlantis Press, pp. 248–254. doi: 10.2991/978-2-38476-214-9_32

Zhu, G., Zheng, J., Ratner, K., Li, Q., Estevez, M., and Burrow, A. L. (2024). How trait and state positive emotions, negative emotions, and self-regulation relate to adolescents' perceived daily learning progress. *Contemp. Educ. Psychol.* 77:102275. doi: 10.1016/j.cedpsych.2024.102275

Zimmerman, B. (2000). "Attaining self-regulation: a social cognitive perspective" in Handbook of self-regulation. eds. M. Boekaerts, M. Pintrich and M. Zeidner (San Diego, CA: Academic Press), 13–39.

Zimmerman, E. (2008). "Gaming literacy: Game design as a model for literacy in the twenty-first century" in The video game theory reader (vol. 2). eds. B. Perron and Y. M. Wolf, 23–33.

Zumbach, J., Rammerstorfer, L., and Deibl, I. (2020). Cognitive and metacognitive support in learning with a serious game about demographic change. *Comput. Human Behav.* 103, 120–129. doi: 10.1016/j.chb.2019.09.026

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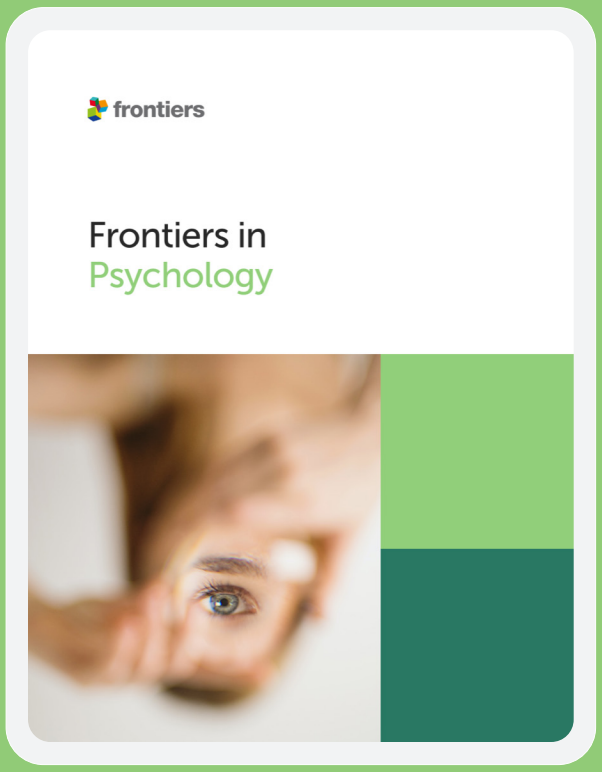

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