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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,

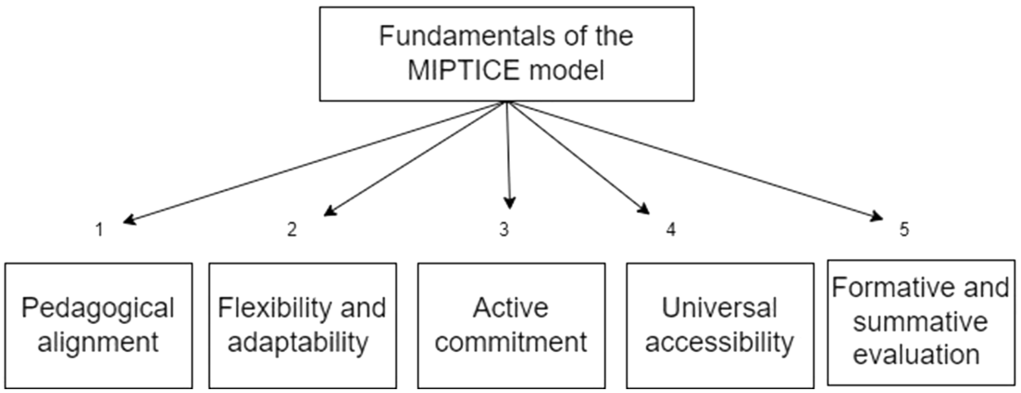

FIGURE 1
The five principals for implementing the MPTICE model in the Learning environment.

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.

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).
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).

6.3 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

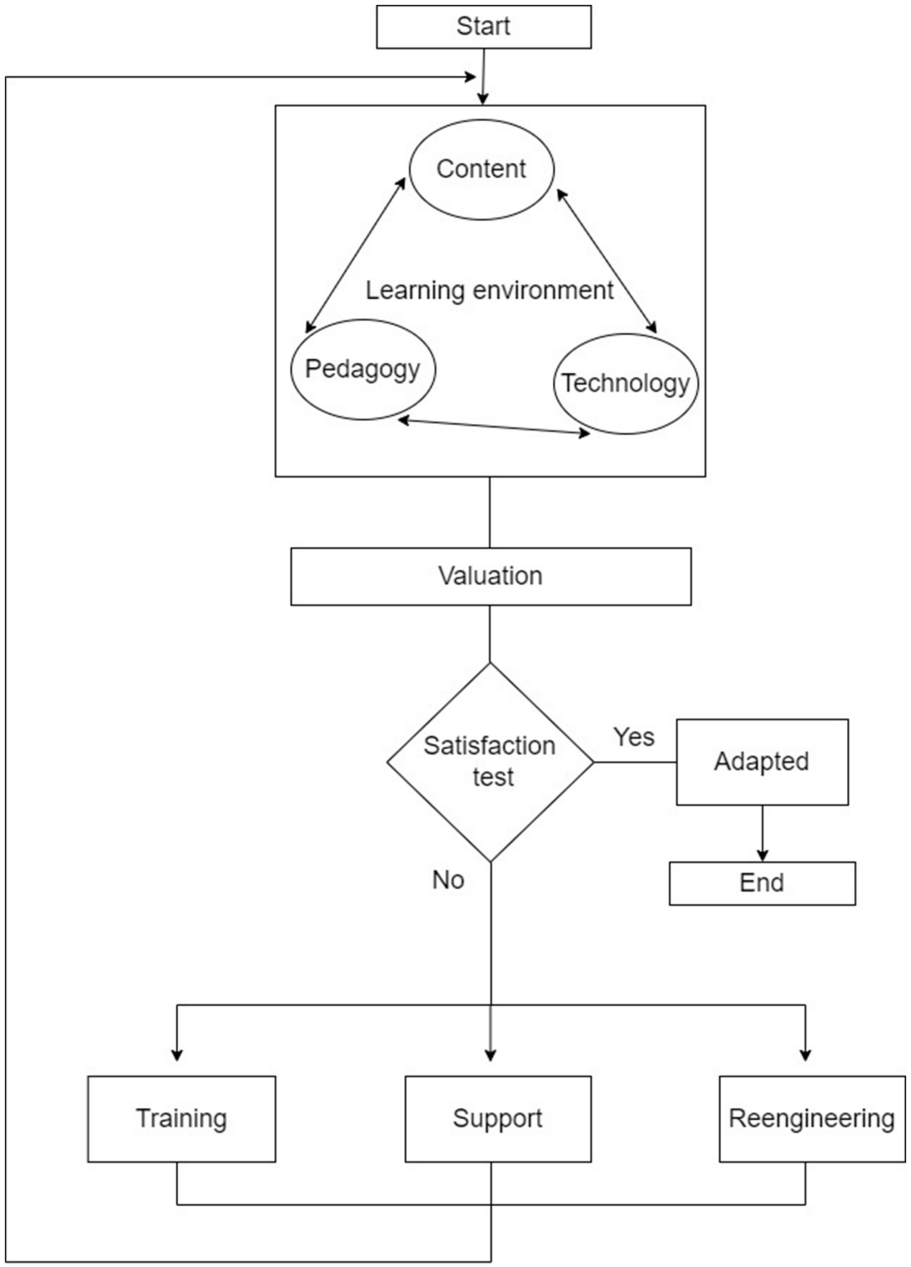

FIGURE 2
Presentation of the MPTICE model.

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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