Research Topics

Digital collaborative learning in general, higher, and business education

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Digital collaborative learning in general, higher, and business education

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Table of contents

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Editorial: Digital collaborative learning in general, higher, and business education

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Editorial on the Research Topic
Digital collaborative learning in general, higher, and business education

Virtual collaboration and digital learning in higher education have become pivotal in recent years, fueled by rapid advancements in technology and an increasing emphasis on interdisciplinary approaches to problem-solving. While cooperative working or learning in general contributes to with the expectation that people will achieve more together than alone (Järvelä et al., 2015; Johnson et al., 2000; Rosé et al., 2008), if there is an appropriate composition of teams and the participation of each team member through communication (written, verbal, or non-verbal), in the form of diverse and elaborate sharing of ideas, experiences and knowledge (Bellhäuser et al., 2018; Müller et al., 2024a,b; Siegfried, 2021; Tsovaltzi et al., 2019). The advent of the World Wide Web and other digital technologies has significantly transformed cooperation. The Internet's constant connectivity enables individuals to engage with peers—including family, friends, and colleagues—at any time and from anywhere through various communication media, apps, and web-based tools (Lane et al., 2024). Moreover, asynchronous collaboration, supported by digital tools for recording and revising speech and writing, encourages thoughtful reflection before contributions are shared with the team (Chi, 2009). These technologies also facilitate the externalization of thought processes by allowing individuals to structure and visualize their ideas, making them more accessible and comprehensible to team members (Jessop, 2008). Additionally, digital collaboration helps reduce social isolation, a prevalent challenge in virtual learning environments, while enhancing satisfaction by fostering meaningful interaction and engagement (Efimov et al., 2022).

At the same time, the potentials of digital cooperative working and learning mentioned above are not (or cannot) always be realized. Reasons for this lie not only in often inadequate technical equipment (Jeong and Hmelo-Silver, 2016), but also in the competencies required by this new form of cooperation, which are not or insufficiently trained on the part of the users (Beek et al., 2020; Theobald et al., 2023). So far, however, there have only been isolated findings with regard to the potential and the challenges of digital collaborative learning and working.

Accordingly, this Research Topic aims to bring together research from different disciplines. Thus, the collection of papers in this Research Topic explores a variety of themes surrounding virtual collaboration and digital learning in higher education, with a focus on the challenges, strategies, and outcomes associated with the use of digital platforms for collaborative learning and teamwork. By looking at the dynamics of interdisciplinary collaboration, the contributions highlight both the potential and limitations of digital environments for fostering meaningful learning experiences.

For instance, one paper emphasizes the difficulties faced by interdisciplinary academics in adapting to virtual collaboration, noting issues such as technical limitations, management challenges, and cultural differences that influence virtual teamwork dynamics.

Some studies explore how specific preparation tasks or communication styles impact learning outcomes. For example, one paper examines how different levels of generative preparation tasks, such as note-taking and explanation activities, affect students' deep comprehension during digital collaborative learning, finding that prior knowledge and task structure play significant roles in learning outcomes. Similarly, another study investigates the relationship between students' achievement goals and collaborative activities, revealing that learning-oriented goals enhance students' ability to sequentially organize collaboration efforts, ultimately improving knowledge acquisition.

The influence of personality traits and social dynamics in collaborative environments is also addressed. One paper uses the TREO framework to show how individual personality traits and team roles affect communication patterns in collaborative problem-solving tasks, while another study focuses on non-verbal behaviors, such as nodding and leaning forward, to understand how these actions foster engagement in virtual learning.

Some studies focus on specific groups or contexts, like non-traditional students facing social identity threats in computer-supported collaborative learning (CSCL) environments. These students' sense of belonging and motivation are challenged by stereotypes, impacting their engagement and collaboration effectiveness. Another paper examines doctoral students' experiences in virtual communities of practice, emphasizing the role of distributed leadership, shared goals, and collaborative support in enhancing remote learning experiences.

Furthermore, the papers address practical implications, such as the need for digital competences and technological-pedagogical knowledge. Tools and methods, such as coding manuals and content analysis, are developed to quantify transactive communication and problem-solving activities, providing insights into students' cognitive and metacognitive engagement in tasks like glossary creation and concept mapping.

Overall, the studies presented in this Research Topic contribute to understanding how digital collaborative environments affect learning outcomes, highlighting the importance of structured tasks, social dynamics, and technological support in maximizing the effectiveness of virtual collaboration in education.

Author contributions

HB: Conceptualization, Writing – original draft, Writing – review & editing. CS: Conceptualization, Writing – review & editing. RR: Conceptualization, Writing – original draft, 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.

Generative AI statement

The author(s) declare that Gen AI was used in the creation of this manuscript. Generative AI was used to summarize the submitted papers of the Research Topic. The generated summaries were used to get an overview and to formulate parts of the editorial. The resulting text was written and revised by the author(s) of this manuscript.

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Virtual interdisciplinary collaboration during the COVID-19 pandemic: pain and joy in an international joint university

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Background: The COVID-19 pandemic has brought interdisciplinary academics and research students many uncertainties and challenges in adapting to new communication styles. Compared with other academics in the same field, interdisciplinary academics might face more challenges in transitioning from traditional face-to-face communication to virtual communication.

Objective: This study aimed to explore the pain and joy of using Western and Chinese localized communication channels in experienced interdisciplinary academics ($N = 10$) and young research students ($N = 14$) during the pandemic. Among them, 14 are Europeans and 10 are Chinese.

Method: Meeting records and participants' reflective writing were used as qualitative data.

Results: We identified five key themes: two were tied to personal and behavioral issues, two were involved in management issues, and one dealt with topic choice issues.

Conclusion: Considering that virtual interdisciplinary teamwork is likely to continue in the post-pandemic period, it is necessary to implement measures such as technical training and voluntary assistants to help alleviate some of the issues that make virtual meetings difficult for participants. Study limitations and future directions are also discussed.

KEYWORDS

interdisciplinary collaboration, video meeting, remote work, technology, learning management platforms

1. Introduction

Interdisciplinary collaboration is not a new topic. In the past few decades, several studies have measured the effectiveness and popularity of virtual and face-to-face communication channels, particularly, during the pandemic period. The COVID-19 pandemic and the resulting lockdown, stay-at-home lifestyle, and quarantine accelerated the trend of virtual interaction and communication. People speedily adopted social media technologies for formal and informal meetings, sharing information, and learning and teaching. Recent studies show that virtual meeting platforms, such as Google Meet, Microsoft Teams, and VooV, saw a significant increase in the number of daily users (Peters, 2020; Thorp-Lancaster, 2020). Scholars (Standaert et al., 2021) believed that virtual meetings will continue and become a widely popular method of communication in interdisciplinary collaboration in the post-pandemic era.

Interdisciplinary collaboration has been examined through the use of different digital technologies (e.g., Fosslien and Duffy, 2020; Strassman, 2020) and demonstrated benefits for both young scholars and experienced senior academics (e.g., Pérez-Mateo and Guitert, 2007; Bottoms et al., 2013; Tur and Urbina, 2016). For example, interdisciplinary research teams have more productive discussions on key issues and make decisions efficiently when members are in different geographical locations (Klonek et al., 2022). Interdisciplinary collaboration can be complicated, but essential for young scholars to develop their social networks and learn from senior academics (Rhoten and Andrew, 2004; Moore et al., 2018). In the collaborative process, diverse interdisciplinary team members could bring a broad range of skills and knowledge to help young scholars deal with complex issues (Gehlert et al., 2014; Graesser et al., 2018).

Compared to face-to-face interaction, digital technologies promote team collaboration through in-time networking, which is more affordable for university staff with limited budgets (Tur and Urbina, 2016). In addition, digital technologies enable both young scholars and senior academic staff to easily interact and share knowledge in virtual meetings; consequently, it might enhance team members' creativity and work productivity (e.g., Remmik et al., 2011; Stoszkowski et al., 2017). More recently, Lu (2020) examined WeChat as an innovative social media tool that could enhance European and Chinese academics' research collaboration in the humanities and social sciences (HSS). In this study, Lu proposed that the potential advantages and uses of social media tools could be explored in a broader way by interdisciplinary researchers.

Concerns about using digital technologies in virtual meetings have been also discussed in recent years. For example, during the pandemic, university faculty and students expressed concerns that looking at computer screens for prolonged periods of time could have a detrimental effect on mental and physical health (Bailenson, 2020; Biemans and Taghizadeh, 2023). Another study specifically looked at meeting fatigue via video conferencing (Fosslien and Duffy, 2020). Another concern is that the size of the computer screen might trigger "biochemical changes" and "physiological states" (Karl et al., 2022, p. 344) that are correlated with fight or flight (Dijker, 2014). Interdisciplinary senior academics often communicate via videos and voices but young team members might post their opinions via the chat box due to computer issues, content distraction, and low self-confidence (Wiederhold, 2020).

It is likely that interdisciplinary collaboration via virtual meetings will continue and might become the dominant communication method in the post-pandemic era. Because interdisciplinary collaboration is essential for knowledge production, this study aimed to examine both young scholars' and senior researchers' pain and joy when undertaking collaborative work while using digital technologies to communicate and meet. In the following sections, I will first review the relevant literature on knowledge production and then discuss media naturalness theory to provide a theoretical framework for understanding the inherent benefits and issues of using a virtual channel for communication.

2. Literature review

2.1. The new production of knowledge

In the 21st century, globalization has not only increased travel and immigration but also has brought about significant social change. Baber's *The New Production of Knowledge* maps "changes in the mode of knowledge production and the global impact of such transformations" (Baber, 1995, p. 751). Mode 2 (Gibbons et al., 1994) emphasizes a specific mode of scientific production in order to broaden knowledge sharing, transition, and collaboration—all of which are essential in society. This requires global academics to be more involved in the knowledge transition process and to also engage in a higher level of cooperation with their scientific peers. Mode 2 enables more people to be involved in the research process and improve their understanding of how science correlates with human movement. This new mode of knowledge production, which is reflexive, transdisciplinary, and heterogeneous (Gibbons et al., 1994), shows how these features connect with the changing role of knowledge in social relations. While the knowledge produced by research and development in science and technology is a central concern, Gibbons et al. (1994) outlined the changing dimensions of social science and humanities knowledge and the relation between the production of knowledge and its dissemination through education.

It is essential for young scholars and senior researchers to communicate and share information and knowledge in higher education. Lu (2020) believes that it is necessary for academics in scientific fields, such as Engineering, Architecture, and Mathematics, and those in Social Sciences to use social media technologies to enhance research collaboration. Studies show that social media tools are effective to improve HSS academics' research productivity and research collaboration across countries. More recently, a study (Haak et al., 2022) found that graduate students who were involved in a problem-based learning project were more motivated to engage with diverse stakeholders to drive transformational learning. Even though students were challenged to refine the conceptual model, they were able to develop a revised module conceptual framework that more accurately reflected the transdisciplinary nature of these interactions. However, most of these research studies were undertaken before the COVID-19 pandemic, and the interdisciplinary collaboration had occurred face-to-face. Little research has been conducted on completely virtual interdisciplinary collaboration.

2.2. Media naturalness theory

Based on Darwin's theory of evolution (Darwin, 1859), the human species survive and mate in a long process in which only the fittest and strongest offspring could live and further reproduce. This process thereby has enabled humans to propagate certain physical, behavioral, and cognitive traits (Kock, 2011). From an evolutionary view, co-located and synchronous communication has been the primary mode of communication for human beings, which means that humans are optimized for face-to-face interaction (Kock, 2009). Kock (2004) believes that face-to-face communication is a familiar mode for humans, which also means that a lower level of cognitive effort is required to use it. MNT identifies at least five key elements in human communication: (1) co-location, wherein individuals are present at a common place; (2) a high degree of synchronicity that allows individuals to exchange communicative stimuli quickly; (3) the ability to observe and express emotions through facial expressions; (4) the ability to observe and communicate through body language; and 5) the ability to use and listen to speech. Social media technologies can allow team members to communicate synchronously but it does not involve co-location and it is difficult to see facial expressions, especially if the video is small or unclear (Standaert et al., 2016, 2021). Consequently, virtual communication may feel unnatural and place more cognitive demands on users. Kock (2005) claims that individuals who used online media to perform collaborative tasks may achieve the same or better task-related outcomes than individuals using media with higher degrees of naturalness. However, others (Hantula et al., 2011) believe that MNT assumes that virtual communication could be too rich, leading to information overload, reduced productivity, and feeling overwhelmed. Recent studies (Torka, 2021) also found that virtual meetings were not that efficient for supervising teams online; that is, it is more difficult to sustain online team-based supervision than online one-on-one supervision as participants fail to adapt their interactions to the virtual format. Joylessness and meeting fatigue in staff are other points of criticism raised in recent scholarly work (Watson and Ireland, 2022).

2.3. Study context

This study is based on a teaching development program that aims to enhance interdisciplinary collaboration between academic staff and research students at X university, an international joint university in China. X university is an innovative joint university with a partnership in the UK. Compared with most Chinese public universities, X university has a large number of international staff, innovative teaching methods, and plenty of interdisciplinary collaboration. Moreover, staff at X university use a wide range of Western and Chinese digital technologies to collaborate in virtual meetings, such as Zhumu (Zoom), VooV, WeChat, university videoconference, and Microsoft Team. As virtual meetings are expected to become more common in the post-pandemic era, it is important to understand how senior researchers and young scholars engage in interdisciplinary collaboration via virtual meetings. As a variety of tools and technologies are used by staff and students, and they come from varied social and cultural backgrounds, it is assumed that their individual experiences, that is, the pains and joys they encountered in interdisciplinary collaboration during the pandemic might be different. More specifically, based on the literature review, we pursue the following research questions:

- What are the advantages offered by the use of digital technologies and virtual meetings in interdisciplinary collaboration?
- How do virtual meetings compare to face-to-face meetings?
- What are the major challenges faced by individuals in virtual meetings held for interdisciplinary collaboration (e.g., COVID-19, technology, and participant behavior)?

3. Research method

3.1. Research design and sample

Both young scholars ($N = 14$) and senior experienced researchers ($N = 10$) joined in the study. Among them, 14 are Europeans and 10 are Chinese. The data for this study were obtained from meeting minutes of 14 weeks of virtual meeting recordings in a semester (Zhumu, VooV, and Team), young scholars' reflections on their E-portfolios (University LM platform), and comments of meeting participants. All the texts were categorized into different topics, cut and pasted into an Excel Spreadsheet (Karl et al., 2022), such as "project application writing up," "reading resource," and "managing teaching schedule." Texts ($N = 503$) obtained between May 2022 and January 2023 were included in the analysis.

To extract topics from the textual data, latent semantic analysis (LSA) in SAS Enterprise Miner was used. This is a powerful text-mining tool that uncovers underlying semantic concepts (i.e., topics) in a corpus. LSA is based on singular value decomposition, which is an extension of principal component analysis (Evangelopoulos et al., 2012). This is an appropriate method for understanding the thematic structure in textual data, and also for clustering and categorization. LSA has been widely used in different disciplines, such as computer-mediated communication (Cao et al., 2011; Xu, 2020), psychology (Arnulf et al., 2021), and quantitative reports and literature review (Jeyaraj and Zadeh, 2020). Hence, we decided that this method would be effective for uncovering the underlying topics related to participants' joy and pain in the virtual meeting environment.

First, the principal researcher preprocessed and cleaned the textual data by eliminating numbers and punctuations from the dataset. Moreover, based on Standard English stop word dictionary, the principal researcher excluded words such as "the," "an," and "a" from the dataset and reduced their dimensionality. Similar to Jeyaraj and Zadeh (2020), tokenization, lemmatization, stemming, spell-checking, and synonyms were examined in the process.

Second, following Shen and Ho (2020), a term-by-frequency matrix was created to parse the texts into a collection of terms. In a term-by-frequency matrix, each column of the matrix represents a unique word that appears across all textual data, and each row refers to each text. Each cell in the term-by-frequency matrix represents the number of times that a term (column) appears in a particular row (text). Using the term-by-frequency matrix, weighting alone cannot effectively distinguish different patterns of the textual data (Cao et al., 2011) because a term that appears commonly in a text may appear in other texts as well. For instance, in the virtual meeting recordings, the term "Zhumu" appeared in many texts, covering different topics or challenges related to Zhumu virtual meetings. To avoid such problems, the term frequencies were adjusted by the term frequency-inverse document frequency weighting scheme (TF-IDF).

To retain the intense and more meaningful topics in the data mining process, the principal researcher eliminated terms that appeared in less than four comments (Jeyaraj and Zadeh, 2020). The singular value decomposition (SVD) method was also adopted to reduce data dimensionality (Jeyaraj and Zadeh, 2020). The final step was to find the underlying dimensions linked to the theory in the LSA algorithm. As suggested by Evangelopoulos et al. (2012), the researchers used qualitative assessments to link the results to underlying theories. By using a qualitative content analysis method, researchers identified 12 possible topics in the corpus, using this number as the baseline to run the LSA algorithm. After the iterations in the qualitative analysis of categorizing texts, all the researchers agreed that the best degree of separation was when the LSA algorithm was run with five predefined topics.

4. Results

Five topic labels were identified after reviewing the topics in the rows. They are: *More effort and energy* ($n = 132$), *management skills* ($n = 120$), *technical knowledge* ($n = 90$), *unfamiliar field* ($n = 84$), and *discomfort* ($n = 77$). Participants' attitudes are shown in Table 1. The themes are presented in the following sections and tie the findings to the theory.

4.1. More effort and energy

The participants felt that they had to put more effort into virtual meetings than traditional face-to-face meetings. Sometimes, that would result in meeting fatigue and low energy. For instance, a young female scholar stated:

> I am a young researcher (research student) and felt that I could not do much if many more experienced scholar were involved in the same meeting. Personally, I know that I am introvert and as a consequence, I am not that open to share information with senior researchers. I am always afraid to make mistakes and lose face. Sitting in a long virtual meeting, I could feel that a holder and some key persons always talk but the others keep silent most of time. It did not allow young scholars to be fully engaged. If this meeting were held face-to-face, I would sit close to some peers who might be research students as well. Then I could communicate with them more comfortably and confidently [SIC].

Interdisciplinary senior researchers also reflected that they were easily exhausted in the virtual meetings when sharing practical skills. A participant with a background in engineering commented:

> When I presented a design model to the participants in virtual meetings, I found it difficult to interact as half of them were self-muted. I hardly knew people's reaction, not to mention their facial expressions. After finishing a virtual meeting, I need to grab a coffee immediately to refresh.

Others also expressed that they had concerns about joining meetings with someone that they have not collaborated with yet. Both senior researchers and young scholars prefer to have virtual meetings with people whom they already know or have some previous connections with at least. During the COVID-19 pandemic, they faced many challenges in their personal lives which made it harder to muster up the energy to communicate with people from their disciplines whom they did not know. Furthermore, a few young scholars thought that even though they put more effort into attending the virtual meetings, they obtained more information from other senior staff and peers. More specifically, they could send information via chatbox in the meetings, and gain constructive feedback synchronously.

4.2. Management skills

This theme included texts, comments, and reflections regarding meeting management skills and related issues, such as effective meeting schedules, participants' management, and multitasking in virtual meetings. Senior scholars believed that they needed to manage all the stakeholders in virtual meetings, including colleagues, young scholars, professional staff, and other invited guest speakers. They commented that they had to act as a "coordinator" rather than a single participant in most virtual meetings. For example, a senior scholar stated that it was difficult to keep everyone in the virtual meetings engaged, particularly, by using polls, document-sharing, and explaining questions in the chatbox. Young scholars also felt that they did not have any autonomy to check their availability before joining these virtual meetings as they mostly needed to follow the senior staff's schedule. This indicates that senior scholars had to manage many tasks including deciding the meeting dates, timelines, and number of participants, without any financial support.

Young scholars who engaged in interdisciplinary collaboration were eager to learn skills and obtain more experience from senior staff. However, due to the different time zones, some scholars had to sacrifice their spare time, such as late evenings after 10 p.m. or early mornings before 6 a.m., to join the virtual meetings. Moreover, they needed to undertake different tasks at the same time while joining the virtual meetings in the late evenings or early mornings. A young research student commented that she had a part-time job and it was hard to cope with so much multitasking in the virtual environment to finish collaborative work. A senior scholar shared his experience and made suggestions to enhance the effectiveness of virtual meetings in collaboration with others as follows:

> I would like to share my research and teaching experience with young scholars, particularly, research students, and I strongly believe that it is essential for us to collaborate with junior staff. Then it might lead to more potential projects, but I am not good at managing group virtual meetings. As we know, these virtual meetings usually depend on individual research interests rather than group research funded work. Hence, there is no manager or administrative staff to organize meetings in advance. In that case, I have to learn how to set an agenda and goals for each meeting. Also, following up on those who might be interested in interdisciplinary collaboration via the virtual meetings is also time-demanding.

TABLE 1 Participants' attitudes toward the adoption of digital technologies in virtual meetings.

Data source	Participants' attitudes	References
Topics in virtual meetings, E-portfolio reflections, and comments via LM	• Positive/negative perceptions toward communication in the process of interdisciplinary collaboration during the pandemic	Positive ($N = 245$) • Increased communication opportunities • Synchronized communication • Saving research budget Negative ($N = 270$) • Decreased communication efficiency • Lack of hands-on practice • Lack of rapport building • Lack of meeting management skills • Technical issues • Academic status concerns • Lack of family privacy
	• Positive/negative attitudes toward communication in the process of interdisciplinary collaboration before the pandemic period	Positive ($N = 138$) • Building mutual trust in a face-to-face format • Easy to communicate being in the same place • Only meeting during working hours Negative ($N = 97$) • Increased budget for international travel • Try to avoid communication with people who are not of the same background
	• Recommendations for the post-pandemic era	• Meeting assistants required. • IT support/training • Individual time management

Some young research students noted that they would like to make contributions to setting up meeting agendas, supporting senior staff to collaborate with collaborators, and enhancing participant engagement. Meanwhile, they suggested that some young scholars could voluntarily work as meeting assistants to support the stakeholders in the virtual environment.

In addition, some participants believed that the different monitoring surfaces of various meeting software might be another challenge. For example, a small window for a chatbox could be in different places depending on the meeting software. Moreover, upload and download buttons could be in different shapes, which might be confusing for first-time users.

4.3. Technical knowledge

Some participants voiced that they were not good at using a range of technical tools during COVID-19, particularly, in a quarantine environment. A senior researcher mentioned that he felt frustrated when there was a 4-week lockdown in the town. He needed to reorganize all the meetings using different tools. For example, his collaborators preferred using Microsoft Team to hold virtual meetings, but Chinese partners could not use it. Therefore, he often needed to learn different meeting tools and then choose the most convenient one for stakeholders. However, technical information and knowledge do not seem to be a major challenge for young scholars in the collaboration process. A young male student commented as follows:

> I am a born-digital generation and have gotten used to a range of digital products from an early stage. Personally, I think using a variety of digital technologies helped me become familiar with the virtual meeting environment, and also enhanced my digital skills and digital literacy. Take VOOV for example, Chinese researchers all used it via a Chinese Tencent, but it does not work for non-Chinese collaborators or someone who has not got a valid Chinese account. Before the meetings, I needed to give it a try by myself and report it to the meeting organizer if it did not work for my peers.

4.4. Unfamiliar field

Most young scholars reflected that they would struggle to be good icebreakers in virtual meetings with seniors or peers who were not in the same research field. Generally, scholars like sharing information and communicating with peers from their own fields because they have common interests and similar statuses (Wenger, 2010).

Young scholars found it difficult to interact with seniors in a virtual meeting if they were not from the same or a similar research field. They struggled to easily build rapport with senior staff to encourage smooth communication. Young researchers believe that a lack of rapport and comfort might easily make a virtual meeting an unpleasant or stressful experience. A junior staff with a background in humanity and social science stated:

> I am interested in obtaining more knowledge from the interdisciplinary team members, but I have not received enough pre-meeting introduction of these seniors' backgrounds. After looking them up on the Internet by myself, I may feel that I am not familiar with the topics they work with and gradually become absent-minded in the meeting. This is very common for young research students, and many won't voice it. If the meeting is in a face-to-face format, I am able to see the person and they might be able to hold my attention

> even though the topic may be unfamiliar for me. For me, seeing a person in real life is different from meeting him/her in the screen (SIC).

4.5. Discomfort

Most of the comments on this theme focused on behavioral issues in the virtual meetings. For example, the virtual background setting in the meeting should be more professional rather than a cartoon one. Moreover, due to the virtual meeting setting limitations, some staff could not change their background to be a virtual picture so that the chaos in their room might be seen by other participants. A senior staff reflected that his discomfort was because some participants ate during the meeting. He felt that he found that disrespectful and unprofessional. He illustrated his negative experience:

> The virtual meeting was around lunch time which was scheduled by an assistant. Half of the participants were having lunch in the meeting and the rest half did not turn on their cameras. Finally, I asked them to finish lunch first and then I would start to talk. It was so bad for me.

"I believe that if the meeting was booked at noon, it should be fine for participants to bring their lunch," commented by a junior staff. A small number of participants did not like their children and family members to be seen in the background during virtual meetings in order to protect their family's privacy. Overall, the view was that it is reasonable for participants to bring their lunch if the meeting is scheduled at noon.

5. Discussion

To answer the first research question, the qualitative results show that most participants believed that virtual meetings (WeChat) were only effective for improving higher education management. That is, management expenses are definitely decreased as academics do not have to travel for conferences, demos, and practical procedures as all activities are held online. Thus, traveling costs are not included in the project budget. However, individuals might need more professional skills such as virtual meeting management skills and long-distance rapport building. These skills might be related to individual personality, cultural background, and quality of peer relationships (Lu et al., 2021) rather than interdisciplinary academic skills. Mejias (2007) showed that when influential members dominate a group discussion, it decreases young researchers' motivation in joining the meetings and lowers meeting satisfaction, and this trend has prevailed even in virtual meetings.

To address the second question, academics believe that in some ways virtual meetings were not better than face-to-face meetings. They felt that the perceived benefits are mostly in the area of institutional budget, meeting expenses, and personal costs. However, some young researchers believed that virtual meetings could be less effective as experimental practice benefits from face-to-face communication. These results align with MNT which emphasizes the importance of co-location and human physical expression (facial, visual, and movement) in the process of communication (Kock, 2004, 2009). In virtual meetings, people need to put more effort into preparation, completion of tasks, and interactions. Qualitative research does not support the findings of a quantitative study (Klonek et al., 2022) which found that virtual teams improved their team processes in the late pandemic period as compared to the early pandemic period. This might be due to individuals' motivation level, profession, and career stage when they were engaged in virtual meetings (Kasimoḡlu et al., 2022). The results also add a new insight to Mode 2, which has not been investigated with regard to knowledge production in a completely virtual environment.

To address the third question, challenges were influenced by three factors: technology, individual behavior, and research field. The text-mining results suggest that most participants' frustrations were focused on technical issues. Within these comments, over 78% were about the different versions of meeting software being installed (e.g., Chinese version, English version, and international version), widgets, tool functions, and switching between different versions. Another common comment was about the virtual meeting background and privacy (e.g., munching, kids, and family members). However, some participants critically commented that eating was not an issue as lunch meeting allows them to bring their food. Building a rapport is not easy, and young staff need to be more open to maintaining a communication channel to exchange ideas and share information with senior researchers. These results echo the finding that people need to exert more effort in speaking and listening in virtual meetings, particularly those who are less proficient in using social media tools (Standaert et al., 2016, 2021).

6. Practical implications

The pandemic has brought many uncertainties to academics, particularly, international and mobile researchers. The decreased research budget and limited opportunities to communicate in person have made interdisciplinary collaboration challenging. In an international university context, the adoption of various virtual meeting tools helped enhance disciplinary collaboration and research productivity during the pandemic. It is essential to provide academics, including seniors and young researchers, with technology training for using software and tools required for attending virtual meetings, thereby minimizing their job-related stress during the pandemic (Rogelberg et al., 2006; Cheng et al., 2016; Lehmann-Willenbrock et al., 2018). These trainings and workshops should not only introduce the key features of the technology tools and platforms for virtual meetings (e.g., Zoom, Microsoft Teams, and Tencent) but also show demos of new features of these tools or apps that help enhance meeting effectiveness. For example, the international version of Tencent (VooV) needs more explanations for international researchers who have never used a Chinese version.

Moreover, the results suggest that academics may wish to consider how to set boundaries to maintain work–life balance. International academics working in local universities should be informed about expectations regarding how researchers should behave in virtual work meetings. In addition, senior researchers should ask for help from the faculty if they do not have personal assistants to help them set up virtual meeting facilities. In addition, they must consider attending virtual workshops to obtain guidance regarding using the necessary software. School managers and leadership roles are responsible for reinforcing the importance of these workshops/training sessions, as well as structuring the virtual meeting behavior. In this study, the findings also suggest that virtual meetings can lead to job fatigue and negative consequences. Therefore, organizations must carefully decide upon the frequency and length of virtual meetings.

7. Limitations and future research

Although this study yielded interesting results, it has three notable limitations. First, this study only focused on academic staff who have worked in an international university in China. The sample and the working climate might be different for public universities. Second, the data were mainly textual data, including comments, meeting record transcriptions, and personal reflections. In future, we will consider using a mixed research design to enhance the data resources. A mixed research design might help us understand how to enhance the work satisfaction and engagement of academics and the effectiveness of virtual meetings to ultimately improve research communication. Third, a snowball recruitment technique might have excluded participants who are shy and introverted but have a strong motivation for joining such research studies. In future, we might use a random sampling technique to recruit more suitable participants.

In this study, we found that work–life balance is essential for researchers in the pandemic. Future research could focus on examining if there is any gender difference in virtual meetings. Women might find it more difficult to balance work and life in the pandemic and post-pandemic era. Moreover, researchers could use social network analysis to explore more deeply the ways in which interdisciplinary teams collaborate in virtual environments. This might lead us toward further investigation from a cross-cultural perspective.

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

Ethical approval was provided for this study on human participants by Xi'an Jiaotong-Liverpool University. The patients/participants provided their written informed consent to participate in this study.

Author contributions

JL conceptualized the work, finished the data collection and analysis, and completed the article writing.

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Conflict of interest

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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Generative preparation tasks in digital collaborative learning: actor and partner effects of constructive preparation activities on deep comprehension

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Deep learning from collaboration occurs if the learner enacts interactive activities in the sense of leveraging the knowledge externalized by co-learners as resource for own inferencing processes and if these interactive activities in turn promote the learner's deep comprehension outcomes. This experimental study investigates whether inducing dyad members to enact constructive preparation activities can promote deep learning from subsequent collaboration while examining prior knowledge as moderator. In a digital collaborative learning environment, 122 non-expert university students assigned to 61 dyads studied a text about the human circulatory system and then prepared individually for collaboration according to their experimental conditions: the preparation tasks varied across dyads with respect to their generativity, that is, the degree to which they required the learners to enact constructive activities (note-taking, compare-contrast, or explanation). After externalizing their answer to the task, learners in all conditions inspected their partner's externalization and then jointly discussed their text understanding via chat. Results showed that more rather than less generative tasks fostered constructive preparation but not interactive collaboration activities or deep comprehension outcomes. Moderated mediation analyses considering actor and partner effects indicated the indirect effects of constructive preparation activities on deep comprehension outcomes via interactive activities to depend on prior knowledge: when own prior knowledge was relatively low, self-performed but not partner-performed constructive preparation activities were beneficial. When own prior knowledge was relatively high, partner-performed constructive preparation activities were conducive while one's own were ineffective or even detrimental. Given these differential effects, suggestions are made for optimizing the instructional design around generative preparation tasks to streamline the effectiveness of constructive preparation activities for deep learning from digital collaboration.

KEYWORDS

digital collaborative learning, prior knowledge, text comprehension, learning activities, knowledge acquisition

1 Introduction

This study aims to investigate whether having learners generate inferences from instructional material first on their own (i.e., enacting constructive activities) can prepare them for subsequently exploiting the potential benefits of digital collaboration in terms of using their co-learner's externalized knowledge as additional resource for own inferencing processes (i.e., interactive activities) in the service of in-depth knowledge acquisition (i.e., deep comprehension outcomes). In addition, the role of prior knowledge was taken into account.

To this end, we conducted a computer-supported collaborative learning (CSCL) experiment applying the so-called READ-script (Mende et al., 2017) where the members of learning dyads

a) read a text (reading phase),
b) prepared individually according to a certain preparation task (externalization phase),
c) exchanged each other's externalized task answers to inspect them (cognitive group awareness phase), and finally
d) entered a collaborative learning phase (discussion phase)

before answering a posttest capturing their deep text comprehension 1 week later. The type of the preparation task in the individual externalization phase was manipulated between experimental conditions in terms of the task generativity, that is, the extent of constructive preparation activities necessary to answer. Cognitive group awareness support was introduced in all conditions to facilitate dyad partner's immediate use of each other's preparation results for collaborative discussion, a strategy that has proven successful in research on individual preparation for collaborative learning (Mende et al., 2021).

We firstly ask, on a more general level, whether more rather than less generative tasks intended to induce constructive preparation activities are suited to increase the execution of interactive activities and deep comprehension achievement while considering prior knowledge as potential moderator (research question 1; Figure 1A). We secondly ask on a more detailed level for the indirect and direct effects of the actor's and partner's constructive preparation activities on deep comprehension outcomes while considering constructive and interactive activities enacted during collaboration as potential mediators and prior knowledge as potential moderator (research question 2; Figure 1B).

1.1 Research background and motivation

Collaborative learning yields great potential, especially for university education (e.g., Scager et al., 2016). Besides helping to prepare students for professional life, in which teamwork plays a key role (e.g., De Hei et al., 2015) this is mainly because collaborative learning offers individual learners with enhanced opportunities to develop a deep comprehension of the instructional material in terms of well-connected and flexibly applicable knowledge (Fischer et al., 2013; Chi et al., 2018). However, it is often a challenge for practitioners to design collaborative learning scenarios in such a way that learners actually take advantage of these opportunities (Kirschner et al., 2009; Andrews and Rapp, 2015; Nokes-Malach et al., 2015; Jeong and Hmelo-Silver, 2016). Further, university students often perform their group work outside of the classes and, thus, away from the direct influence of their lecturers (Scager et al., 2016).

In this regard the use of digital technologies is promising, since it promotes better knowledge acquisition, more positive student perceptions and more effective group work and interaction compared to analog collaborative learning (Bromme et al., 2005; Chen et al., 2018). This is partly because (a) digital technologies can provide tools that enable more effective communication and facilitate the sharing of ideas, (b) learners have more time to think about and reflect on what other learners have contributed before responding, and (c) shy or passive learners also participate more in the interaction due to reduced psychological barriers, which promotes more equal communication and deeper discussions (Chen et al., 2018, p. 829). However, designing such digital technologies for collaborative learning is rather challenging (Narciss and Koerndle, 2008). Accordingly, research on computer-supported collaborative learning (CSCL) environments reveals the need to better understand how and under what conditions digital collaboration can promote in-depth knowledge acquisition (Jeong et al., 2019; Lämsä et al., 2021).

Recent theoretical developments aim to assist practitioners and researchers in a systematic consideration of the factors and processes relevant to the success of (CS)CL. Input-process-outcome models (e.g., Dillenbourg et al., 2009; Deiglmayr et al., 2015; Janssen and Kirschner, 2020) emphasize that a given collaborative learning instruction (*input*) does not lead to deep comprehension (*outcome*) directly but mediated through the activities (*processes*) actually executed by the learners during collaboration. This points at the need to identify effective learning activities and to evaluate (a) whether the provided input actually induces learners to execute these activities during collaboration as well as (b) whether these activities actually promote deep comprehension outcomes. These input-process as well as process-outcome relationships may be moderated by further variables such as learner characteristics (e.g., Deiglmayr et al., 2015). Furthermore, information processing-oriented benefit-cost approaches (Nokes-Malach et al., 2015; Janssen and Kirschner, 2020; Mende et al., 2021) highlight that collaboration may not necessarily have only conducive but can also have hindering effects on the individual's learning. This should be considered as well to obtain a complete picture of why a collaborative learning instruction (does not) work and how to (further) optimize it.

In terms of processes, students can principally perform various learning activities during collaboration (e.g., Vogel et al., 2017). The ICAP framework (Chi, 2009) allows classifying these activities in order to derive predictions regarding their effects on learning. Thereby, so-called *constructive* and *interactive* activities are considered suitable to promote deep comprehension (Chi and Wylie, 2014). Both constructive and interactive activities involve the externalization of content-relevant information that is not originally given in the instructional material but is generated or inferred from it. Different to a constructive activity, an interactive activity is additionally characterized by taking into account or referring to a co-learner's externalized knowledge. That is, a learner is said to perform an interactive activity, when they refer to

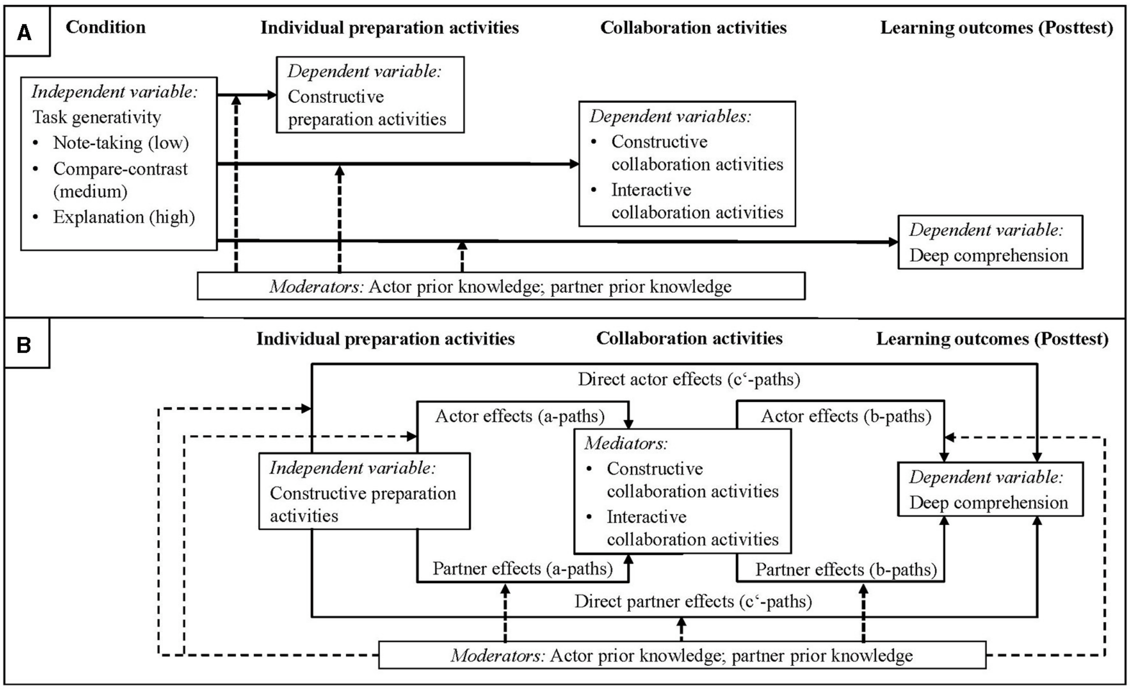


FIGURE 1
Summary of the relationships examined. **(A)** refers to research question 1. **(B)** refers to research question 2.

information contributed by a co-learner and, incorporating it, infer new information beyond what is already given. Hence, while constructive activities can be performed irrespective of whether learning alone or in a group, interactive activities presuppose a collaborative learning situation and are characterized herein by leveraging the knowledge of co-learners as a resource for own inferencing processes (Chi and Wylie, 2014; Chi et al., 2018).

Thus, adopting a benefit-cost perspective of the single learner working with other co-learners, the potential benefits of collaboration arise particularly from the co-learners constructive and/or interactive activities: they result in externalizations of new information not already contained in the presented instructional material which the learner could use as additional learning resource in the service of in-depth knowledge acquisition. Doing so requires the learner to actually execute interactive activities which can therefore be understood as the active process of using the potential benefits of collaboration (Fischer et al., 2013; Janssen and Kirschner, 2020; Chi, 2021).

At the same time, as already mentioned, collaboration yields not only potential benefits but also costs for the learners' information processing (e.g., Mende et al., 2021). These costs are associated with the presence as well as the use of externalizations from other co-learners: being exposed to the externalizations of co-learners yields the risk of interferences and being disrupted in one's own train of thought (e.g., Nijstad and Stroebe, 2006; Rajaram and Pereira-Pasarin, 2010; Nokes-Malach et al., 2015). Further, the dual task of processing not only the instructional material but also the information externalized beyond it by co-learners often challenges the individual learner's cognitive capacities (e.g., Dillenbourg and Betrancourt, 2006; Kolfschoten et al., 2014). Moreover, using co-learners' externalizations by executing interactive activities is associated with additional coordination and communication demands, further burdening the learners' information processing resources (Janssen et al., 2010; Janssen and Kirschner, 2020). This is even more crucial in university settings where learning partners are not permanently together in stable classes and, thus, not necessarily know each other before engaging in joint group work (Scager et al., 2016). Associated with this, university students often tend to focus primarily on the task and less on the team aspect of collaborative learning. However, the effectiveness of collaborative learning heavily depends on how the interaction between the learners as well as the individual accountability of the single learners for the group work is organized (Fransen et al., 2011; De Hei et al., 2015).

Therefore, collaborative learning does often not promote deep comprehension because learners cannot deal with the costs or doing so does prevail the potential benefits (Bromme et al., 2005; Nokes-Malach et al., 2015; Menekse and Chi, 2019; Janssen and Kirschner, 2020). This calls for support strategies that can help to raise the benefits and to reduce the costs, so that the execution of interactive activities is promoted and, thus, the collaborative learning potentials for in-depth knowledge acquisition can unfold.

In addressing these issues, a variety of support strategies have been developed in the last years. Digital technologies are even accelerating this trend, as they enable enhanced communication, increased productivity, flexibility, as well as scalability compared to analog solutions. This enables a more efficient and flexible implementation of more comprehensive forms of guidance, scaffolding and tools (Dillenbourg et al., 2009; Jeong and Hmelo-Silver, 2016). A frequently applied strategy consists in preceding collaborative learning with a phase in which learners first execute activities directed at processing the instructional material on their own such as writing down notes or explanations (i.e., individual preparation for collaborative learning; van Boxtel et al., 2000; Tsovaltzi et al., 2015; Lam and Kapur, 2017; Mende et al., 2021). This strategy is often complemented by a specific form of cognitive group awareness support (e.g., Janssen and Bodemer, 2013) in the sense of making the externalizations created during individual preparation (e.g., written notes or explanations) available to all learners in the group as a resource for the subsequent collaboration phase (e.g., Gijlers et al., 2013; Engelmann et al., 2014). The former targets at learners first activating their prior knowledge and building up an initial understanding of the instructional material without the additional demands of collaboration in order to have an expanded knowledge base and more free cognitive capacities to process and integrate co-learners' contributions in subsequent collaboration (Lam and Kapur, 2017; Tsovaltzi et al., 2017; Mende et al., 2021). The latter aims at providing learners with information about the knowledge, perspectives and ideas of their co-learners so that their individually externalized information can be accessed directly in collaboration and further the mutual communication and coordination is facilitated (e.g., Janssen and Bodemer, 2013; Noroozi et al., 2013; Erkens et al., 2016; Jeong and Hmelo-Silver, 2016). Hence, both strategies are intended to improve the benefit-cost ratio of executing interactive activities.

While research indicates the combined use of individual preparation and cognitive group awareness support to be suited to promote interactive activities during and deep comprehension outcomes from collaborative learning (Mende et al., 2021), an open question remains as to what kind of preparation activities learners should enact in such a setting. In principle, learners could execute a variety of activities that might be differently productive for (subsequent) learning. For example, they could restate what is already presented in the instructional material, an activity typically considered to correspond with more shallow information processing (e.g., King, 1999; Roscoe, 2014; Chi et al., 2018). In contrast, some recent work has argued that learners should engage in deeper information processing already during individual preparation by going beyond the given instructional material through the execution of constructive activities. Executing these constructive preparation activities is hypothesized to help learners exploiting the potential benefits of subsequent collaboration in terms of deep comprehension outcomes (Lam and Kapur, 2017; Lam and Muldner, 2017; cf. Mende et al., 2021). While these assumptions are well grounded in previous theoretical and empirical work concerned with individual learning (e.g., Wittrock, 1989; Schwartz et al., 2011; Kapur, 2015), they rarely have been subjected to an empirical investigation so far in CSCL research.

1.2 Research approach and objectives

The present study aims at contributing to extend the existing research by adopting a benefit-cost perspective considering input, processes, and outcomes. On the one hand, it is of interest how to induce learners to execute constructive activities during individual preparation as a prerequisite for the proposed beneficial effects on subsequent collaborative learning processes and outcomes coming into effect. In this regard some previous research has addressed the role of the preparation task *generativity*, that is, its potential to induce constructive activities (e.g., Lam and Kapur, 2017; Lam and Muldner, 2017). In addition, research has suggested that learners' capabilities to perform constructive activities is strongly affected by their prior knowledge (e.g., Kintsch, 2004; Best et al., 2005; McNamara and Magliano, 2009). Accordingly, the latter may moderate respective task effects.

On the other hand, it is of interest whether the execution of constructive activities during individual preparation indeed promotes the learner's personal exploitation of the potential collaboration benefits for in-depth knowledge acquisition. In order to obtain a comprehensive and informative picture we argue that an appropriate investigation of this question requires the consideration of the following three points: first, one's own and one's collaboration partner's enacted learning activities do not necessarily relate in the same way to one's personal collaboration benefits and costs (e.g., Vogel et al., 2016). Accordingly, it is necessary to examine the effects of each learners' preparation and collaboration activities both on their own and each other's subsequent learning processes and/or outcomes. Second, self-performed interactive activities are considered the personal process of actively using the potential benefits of collaboration for in-depth knowledge acquisition. Consequently, addressing the question of whether deep learning *from* collaboration can be fostered by one's own and/or one's co-learner's previously executed constructive *preparation* activities requires examining the latter two in view of their indirect effects on one's own deep comprehension outcomes that are mediated trough these self-performed interactive collaboration activities. Third, previous research suggests, among others, the learners' prior knowledge to be a crucial impact factor for the personal benefit-cost-ratio of collaborative learning (e.g., Nokes-Malach et al., 2012, 2015; Kirschner et al., 2018; Janssen and Kirschner, 2020). Consequently, prior knowledge should be taken into account as a potential moderator regarding the outlined relationships.

In order to comply with the analytical requirements described, we conducted moderated mediation analyses (e.g., Hayes, 2013) accounting for the distinct contributions of the learner's own as well as their co-learner's preparation and collaboration activities. For the case of dyads (i.e. groups of two) this differential consideration can be taken into account with the actor-partner interdependence model (Kenny et al., 2006). Within this analytic approach dyadic influences are differentiated in terms of actor and partner effects. Actor effects, on one hand, refer to *intrapersonal* relationships between variables within the same person, for example, the effect of self-performed constructive preparation activities on subsequently self-performed interactive collaboration activities. Partner effects, on the other hand, refer to *interpersonal* relationships between variables of different persons, for example, the effect of co-learner's constructive preparation activities on subsequently self-performed interactive collaboration activities or the effect of self-performed constructive preparation activities on co-learner's subsequent interactive collaboration activities, respectively (Kenny et al., 2006).

Before we showcase the present study we first discuss the effects of the preparation task generativity on the execution of constructive activities. Afterwards we address the complex dynamics that may underlie the effects of constructive preparation activities on deep learning from subsequent collaboration considering an actor and a partner perspective. This is followed by addressing the potentially moderating role of prior knowledge.

1.3 The effects of task generativity on constructive preparation activities

Constructive preparation activities can unfold their potential advantages for subsequent collaboration processes and outcomes only, if learners indeed enact them (cf. Chi and Wylie, 2014). Yet, learners often tend to restate information already given in the instructional material instead of drawing inferences going beyond, even when they are asked to do the latter (e.g., Chi et al., 2018; Chase et al., 2019). This raises the question of how and under what conditions learners are executing constructive preparation activities. One important variable in this regard is preparation task type (e.g., Lam and Kapur, 2017; Lam and Muldner, 2017).

Preparation tasks can differ in their potential to induce constructive activities. Inspired by Lam and Kapur (2017) we use the term preparation task *generativity* to this end, which could be defined as the extent to which the task requires the learner to infer and externalize information beyond the given instructional material by connecting the to-be-learned information with each other and/or with their pre-existing knowledge. In other words, the higher the task generativity, the more constructive activities are necessary to answer (e.g., Grabowski, 2004; Chin et al., 2016; Fiorella and Mayer, 2016; Brod, 2020; Morris and Chi, 2020).

Generative learning research has addressed various tasks differing in their generativity. One often considered task is note-taking (e.g., Grabowski, 2004; Stefanou et al., 2008; Fiorella and Mayer, 2016). Unless provided with further specifications, note-taking tasks do not explicitly require learners to go beyond what is already given in the instructional material. Accordingly, there is a huge variability concerning what learners actually do in response to such tasks. Though learners could, in principle, add new content when taking notes, for instance, in the form of inserting unstated links between the received information or writing down own examples for to-be-learned concepts or principles. However, learners often seem more prone to simply restate the information explicitly given in the instructional material (e.g., Grabowski, 2004; Igo et al., 2008; Miyatsu et al., 2018; Ponce et al., 2020).

Two other generative tasks commonly applied in individual learning research concerned with preparing students for learning target content from subsequent lectures are compare-contrast tasks and explanation tasks (cf. Roelle and Berthold, 2016). The former prompt learners to find similarities and differences between contrasting cases, concepts or the like (e.g., Schwartz and Bransford, 1998). The latter go beyond this by asking learners to generate an explanation for the similarities and differences (e.g., Schwartz and Martin, 2004). Thus, while both tasks require the execution of constructive activities to answer, explanation tasks do so to a higher extent than compare-contrast tasks since more inferences are required. This consideration is in line with research suggesting that explaining the relations between contrasting cases prepares better for subsequent deep learning than simply comparing contrasting cases (Sidney et al., 2015; Chin et al., 2016). Taken together, the three tasks could be arranged according to their relative generativity in increasing order from note-taking (low) to compare-contrast (moderate) to explanation (high).

1.4 The actor and partner effects of constructive preparation activities on post-collaborative deep comprehension outcomes: toward a moderated mediation model

Does the execution of constructive preparation activities indeed promote the individual learner's personal exploitation of the potential benefits of subsequent collaboration for in-depth knowledge acquisition? As outlined, we argue that this could only be said if, in the sense of indirect effects (formally called a*b-paths), the actors and/or the partner's constructive preparation activities actually foster the actor's interactive collaboration activities (a-paths) and the latter in turn indeed promote the actor's deep comprehension outcomes (b-path, Figure 1B). Investigating this question requires mediation analyses that examine the occurrence of such indirect effects while simultaneously controlling for the direct effects (c'-paths), that is, the effects of constructive preparation activities on deep comprehension outcomes that are not transmitted by the potential mediators under consideration (e.g., Zhao et al., 2010). Hence, in the following sections we elaborate on the potential actor and partner effects of (a) constructive preparation activities on interactive collaboration activities (a-paths) and (b) of interactive collaboration activities on deep comprehension outcomes (b-paths).

1.4.1 Actor and partner effects of constructive preparation activities on interactive collaboration activities (a-paths)

As described, a learner's execution of interactive activities during collaboration may depend on whether the associated coordination and communication costs can be dealt with and whether doing so pays off (e.g., Janssen and Kirschner, 2020). Especially when individual preparation is complemented by group awareness support, this personal benefit-cost-ratio may be affected not only by one's own preceding constructive preparation activities (actor effect) but also by the constructive preparation activities performed of one's co-learner (partner effect). In this regard, both the actor's self-performed and the partner's enacted constructive preparation activities may each not only yield potential advantages but also disadvantages:

Adopting an *actor perspective*, research shows that the execution of constructive activities fosters deep comprehension outcomes (e.g., McNamara and Magliano, 2009; Ozuru et al., 2010; Chi and Wylie, 2014; Roscoe, 2014; Roelle et al., 2015).

Therefore, the number of constructive activities the actor executes when studying the instructional material during an individual preparation can be expected to foster the coherence and comprehensiveness of his or her initial understanding of the to be learned information prior to collaboration. Hence, in view of the subsequent collaboration, constructive preparation activities may positively affect (a) the learner's initial knowledge base upon which the additional information externalized by the co-learner could be integrated in terms of interactive activities and (b) the cognitive capacities available to deal with the associated coordination and communication costs (Schwartz et al., 2007; cf. Lam and Kapur, 2017; Tsovaltzi et al., 2017; Mende et al., 2021; Tan et al., 2021). Since in the same breath, however, the gaps between the actor's knowledge and the to-be-learned instructional material should be reduced through constructive preparation activities, the latter may also decrease the (experienced) potential benefits of subsequently using the co-learner's externalizations as additional learning resource (cf. Janssen and Kirschner, 2020). Therefore, it could also be that constructive preparation activities reduce the execution of interactive activities, possibly in favor of more individualistic learning processes (e.g., Tsovaltzi et al., 2015, 2017) such as the continued execution of constructive activities during collaboration which are not associated with communication and coordination costs and, thus, might yield a better benefit-cost ratio.

Considering the *partner perspective*, while own constructive activities correspond to own in-depth knowledge acquisition processes, the co-learner's constructive activities *per se* only represent additional information to oneself at first (e.g., Vogel et al., 2016). More concretely, the more constructive preparation activities are carried out by the partner, the more additional ideas, knowledge, and conclusions are externalized and presented to the actor in the course of group awareness support. Thus, on the one hand, the more constructive preparation activities executed by the partner, the more information not contained in the previously studied material are available to the actor right at the start of collaboration. Hence, the partner's constructive preparation activities increase the potential collaboration benefits for in-depth knowledge acquisition which the actor could use by performing interactive activities (Chi and Wylie, 2014; Chi et al., 2018). For example, the additional information provided by the partner can aid the actor in activating task relevant knowledge (cross cueing; e.g., Wegner, 1987; Moreland and Myaskovsky, 2000; Marion and Thorley, 2016) and induce conceptual cognitive conflicts (e.g., King, 1999; Cress and Kimmerle, 2008; Jorczak, 2011; Slavin, 2011; Webb, 2013) which in turn may assist, stimulate or provoke the actor to draw (further) inferences conducive to his or her own deep comprehension (cf. Dugosh et al., 2000; Noroozi et al., 2013; Erkens et al., 2016). On the other hand, however, this additional information also increases the overall complexity of the learning environment, putting additional burdens on the actor's cognitive resources (Dillenbourg and Betrancourt, 2006; Kolfschoten et al., 2014). In other words, the partners' constructive preparation activities increase the information processing costs the actor has to deal with and therefore may impede his or her execution of activities that correspond to deep information processing, such as interactive activities (Kirschner et al., 2018; Janssen and Kirschner, 2020; Mende et al., 2021).

1.4.2 Actor and partner effects of interactive collaboration activities on deep comprehension outcomes (b-paths)

As is the case with constructive activities, also self-performed and co-learner enacted interactive activities can be considered to relate differently to the individual learner's personal costs and benefits that are associated with collaboration (e.g., Chi and Wylie, 2014). Similar to self-performed constructive activities, also the actors own interactive activities can be expected to foster deep comprehension outcomes (King, 1999; Chi, 2009; Chi and Wylie, 2014; Deiglmayr and Schalk, 2015; Mende et al., 2017). Compared to constructive activities, only these interactive activities actively use the potential benefits of collaboration to this end (e.g., Chi et al., 2018).

In contrast, the results of the partner's interactive collaboration activities *per se* only provide additional information to the actor that is not contained in the instructional material—similar to the partner's constructive preparation or collaboration activities. Such additional information is important but not sufficient for the actor to benefit from collaboration in terms of deep comprehension outcomes. To this end, the externalizations resulting from the partners constructive or interactive activities must be subjected to the actor's interactive activities (Chi and Wylie, 2014; Chi et al., 2018). This view is supported by previous research suggesting that just receiving explanations from others does often not foster learning unless the explanations are elaborated or further applied by the receiver (Webb and Mastergeorge, 2003; Wittwer and Renkl, 2008; Vogel et al., 2016). Thus, when considered simultaneously, the actors but not necessarily the partner's interactive activities could be expected to foster the actor's deep comprehension outcomes. Moreover, since the partners interactive (and constructive) activities do not only represent additional resources (i.e., potential benefits) but at the same time increase the information processing demands (i.e., costs) for the actor, even the possibility of negative partner effects must be taken into account (cf. Dillenbourg and Betrancourt, 2006; Nokes-Malach et al., 2015; Janssen and Kirschner, 2020).

1.5 The potentially moderating role of prior knowledge

Prior knowledge could be understood as the amount of information related to the target instructional material already stored in a learner's long-term memory at the start of a learning phase (e.g., McCarthy and McNamara, 2021; Simonsmeier et al., 2022). Generally, learners already possessing high topic relevant prior knowledge are better able to activate relevant knowledge structures from their long-term memory in order to relate them to incoming information while low prior knowledge learners are less so. Accordingly, prior knowledge guides processing of novel information and fosters the construction and integration of knowledge from that information (e.g., Kintsch, 1998, 2004; Best et al., 2005; Kalyuga, 2009; McNamara and Magliano, 2009; Witherby and Carpenter, 2021). Hence, prior knowledge represents a crucial factor determining learners' capabilities to perform learning activities involving inferences, such as constructive or interactive activities (e.g., Webb, 1989; Chan et al., 1992; Kintsch, 1998; Ertl et al., 2004; McNamara, 2004; Best et al., 2005; Schwartz et al., 2007; Chi and Wylie, 2014). Consequently, prior knowledge could play a role for the effects investigated in this study in several respects.

Firstly, prior knowledge may play a role for whether and in which quantity learners indeed execute the constructive activities they are asked for by a generative preparation task. Prior research suggests that generative instructions and tasks are more effective for high than for low prior knowledge learners in terms of knowledge acquisition (Kirschner et al., 2006; Chen et al., 2017). Consequently, the effects of individual preparation task generativity on the execution of constructive preparation activities may increase with increasing prior knowledge of the learners.

Secondly, accumulating evidence highlights the critical role of learners' prior knowledge for the cost-benefit ratio of collaborative learning (e.g., Janssen and Kirschner, 2020). This raises the question of how prior knowledge may influence the effects of constructive preparation activities on the exploitation of the potential collaboration benefits for in-depth knowledge acquisition. Research suggests that prior knowledge should facilitate the uptake and integration of co-learners' externalized knowledge and ideas encountered during collaboration. Yet, collaboration may become redundant when learners possess sufficient knowledge to deal with the learning requirements associated with the instructional material on their own (e.g., Nokes-Malach et al., 2012; Sears and Reagin, 2013; Retnowati et al., 2018; Zambrano et al., 2019). Hence, prior knowledge could be, on the one hand, too low to deal with the information processing demands and coordination costs associated with enacting interactive activities during collaboration. On the other hand, it could also be too high such that the learning requirements could be dealt with on one's own and, thus, making interactive activities unnecessary or their performance ineffective for learning (Nokes-Malach et al., 2012, 2015; Kirschner et al., 2018; cf. Janssen and Kirschner, 2020). This notion also receives indirect support from research on multimedia-learning, frequently evidencing the expertise reversal effect as a special case of the redundancy effect: if external information is presented that is already contained in a learner's long term memory, interferences may occur if ignoring the redundant information is difficult, thus inducing higher extraneous load (e.g., Sweller et al., 1998; Kalyuga et al., 2003; Janssen and Kirschner, 2020).

Consequently, whether the potential advantages or disadvantages of constructive preparation activities for interactive collaboration activities prevail may depend on prior knowledge (a-path-moderation, Figure 1B): constructive preparation activities may facilitate the subsequent execution of interactive activities (actor effect) for low prior knowledge learner's while being ineffective or even counterproductive for higher prior knowledge learners in this regard. Meanwhile, for the co-learner's constructive preparation activities to foster one's own interactive activities (partner effect), a certain amount of own prior knowledge may be necessary to deal with the associated costs. However, doing so may not pay off if one already possesses a relatively large body of prior knowledge. Such potential moderation effects through actor prior knowledge may also have consequences for the partner's interactive activities, for which the externalizations resulting from one's own interactive activities are an important input source (e.g., Chi, 2021).

Alternatively, or in addition, prior knowledge may also influence the effectiveness of interactive activities in view of deep comprehension outcomes (b-path-moderation, Figure 1B): previous work has argued that using the partner's externalizations to draw the inferences necessary to acquire a sound understanding of the instructional material (i.e., enacting interactive activities) may become less effective if prior knowledge is already sufficient to generate the inferences on one's own (e.g., Nokes-Malach et al., 2012; Deiglmayr and Schalk, 2015). In line with this, Mende et al. (2017) showed the positive effects of interactive activities on deep comprehension outcomes to diminish with increasing prior knowledge.

1.6 The present study

The overall purpose of the present study is to investigate whether performing constructive activities during individual preparation can help the individual learner to subsequently exploit the potential benefits of digital collaboration (i.e. CSCL) in terms of using the co-learner's externalized knowledge as resource for own inferencing processes (interactive activities) in the service of in-depth knowledge acquisition (deep comprehension outcomes). Thereby, our goals are two-fold:

The first goal consists in investigating how preparation tasks differently designed in terms of their generativity affect the execution of constructive preparation activities as a prerequisite for such beneficial collaboration processes and outcomes coming into effect. More specifically, we first aim to obtain a general picture of (a) which task and prior knowledge conditions are more or less beneficial for encouraging learners to execute constructive preparation activities, and (b) whether conditions that are more conducive in this regard also lead to more interactive collaboration activities and better deep comprehension outcomes. As a control, we also consider how preparation task generativity affects (a) the execution of constructive *collaboration* activities and (b) take not only the learners own but also the dyad partners' prior knowledge into account as potential moderator. Accordingly, our first two research questions (RQ) are as follows (see Figure 1A):

RQ 1a: What are the effects of preparation task generativity (i.e., low, moderate, high) on (a) the number of constructive preparation activities, (b) the number of constructive and interactive collaboration activities, and (c) deep comprehension in terms of transfer posttest achievement?

RQ 1b: Are these effects moderated by the actors and/or the partners' prior knowledge?

The second goal consists in investigating how and under what conditions whose constructive preparation activities influence the learner's personal exploitation of the potential collaboration benefits for in-depth knowledge acquisition. Accordingly, the main interest is in the potential indirect effects of the actors and the partner's constructive preparation activities on the *actor's* deep comprehension outcomes that are mediated via the *actor's* interactive collaboration activities and in whether such indirect effects may depend on the *actor's* prior knowledge. To obtain a comprehensive picture of the possible advantages and disadvantages of constructive preparation activities as well as the processes and conditions involved, but also for control purposes, we consider some more variables and effects. Specifically, we consider (a) not only the indirect but also the direct effects of constructive preparation activities explicitly and (b) the influences of the collaboration activities (mediators) on deep comprehension outcomes (b-paths) not only in terms of actor but also in terms of partner effects. Further, we (c) control for constructive activities carried out during collaboration as potential alternative mediator, and (d) include not only the actor's but also the partner's prior knowledge as potential moderator to more exhaustively capture the conditions that may play a role in the reciprocal influence processes between the learners. Thus, our second two RQ's are as follows (see Figure 1B):

RQ 2a: Considering constructive and interactive collaboration activities as potential mediators, what are the direct and indirect actor and/or partner effects of constructive preparation activities on deep comprehension outcomes?

RQ 2b: Are these effects moderated by the actor's and/or the partner's prior knowledge?

Given the resulting moderated mediation model, four kinds of (moderated) indirect effects might occur per mediator when considering both the a-paths and the b-paths in terms of actor and partner effects (e.g., Sadler et al., 2011): actor-actor-effects, actor-partner-effects, partner-actor-effects, and partner-partner effects.

2 Materials and methods

2.1 Participants and setting

Due to the complexity associated with power calculations for CSCL experiments, there are no established guidelines to date (Janssen and Kollar, 2021). Therefore, we based our sample size on previous, comparable studies (e.g., Deiglmayr and Schalk, 2015; Jurkowski and Hänze, 2015; Vogel et al., 2016; Lam and Muldner, 2017; Tsovaltzi et al., 2017). Consequently, we conducted an experiment in which a total of 138 students (69 dyads) from a German university went through a CSCL scenario on the human circulatory system. Excluded from participation were students of medicine, biology, or similar fields, as well as non-native speakers. Some students were dyad-wise excluded *post hoc* because they did not follow the instructions in the learning phase (5 dyads), the data were incomplete (1 dyad), a dyad member turned out to be a non-native speaker (1 dyad) or due to technical problems (1 dyad). The final sample contained 61 dyads with a total of 122 undergraduate students (72.9 % female, mean age: 22.81 years, $SD = 3.95$) of psychology (49.2%) and educational sciences (50.8%).

2.2 Learning material

As learning material, we used an expository text on the human circulatory system translated and adapted from Chi et al. (2001). The text consisted of 1,090 words, approximately evenly distributed over 3 sections entitled as "The heart," "The vessels," and "The subsystems of the circulatory system." The text was presented on the monitor throughout the learning phase within the CSCL environment. A sound comprehension of the circulatory system requires not only knowledge of its single components and their properties, but also an understanding of the coordinated interaction between these components at different hierarchy levels and how these interactions provide the vital functions of the system as a whole. An expository text—such as the one used in this study—typically leaves out many of these features, relationships and interactions and, thus, leaves a lot of room for interpretation on the part of the learners. In other words, inferences are necessary to fill in these gaps and to build a proper mental model of the system that enables the flexible application of what has been studied (Chi et al., 1994).

2.3 Design and procedure

Participants arrived at the lab, were greeted and assigned to their computer desks. After an introduction to the CSCL environment, participants' demographic data and prior knowledge were obtained through an electronic pretest. All participants were informed that they would be learning about the human circulatory system with a text. They were instructed to develop an understanding of the circulatory system in terms of how it is composed, how it functions, and what its general purpose is (see Jeong and Chi, 2007).

Subsequently, the students were randomly grouped into stable dyads automatically by the CSCL system. All dyads followed a CSCL-script developed by the authors (READ-script; Mende et al., 2017) which prescribed the following learning phases (see Figure 2).

After reading the whole text (reading phase), each learner worked individually on a task and wrote their answer in a text box (externalization-phase). These task responses were subsequently delivered to the co-learners (i.e., dyad partners) by the CSCL system and both learners were explicitly requested to inspect each other's task responses (awareness induction phase). Finally, learners were asked to collaboratively discuss the text using the chat function that was now available (discussion phase). Here, they received the instruction to collaborate in order to help each other in improving understanding. The previously produced individual externalizations of both learners were still available to everyone during this phase.

The externalization, awareness induction, and discussion phases were repeated for each of the three text sections. In each of the externalization phases, participants were given a section-specific task and the text was

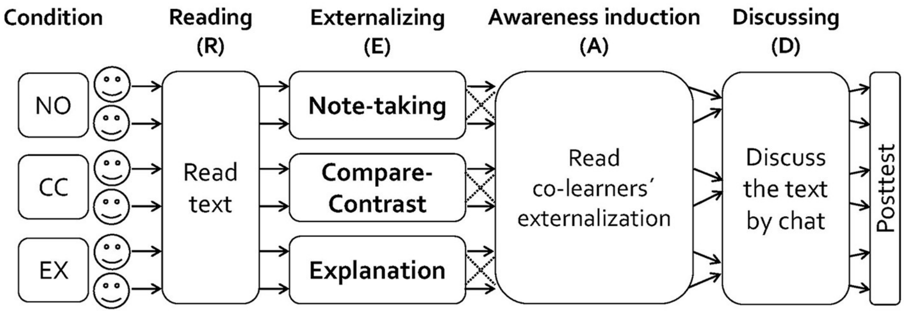


FIGURE 2
Experimental design and procedure. NO, CC, and EX refer to the note-taking, compare-contrast, and explanation task conditions, respectively.

automatically scrolled to the beginning of the relevant section. Depending on experimental condition, the dyads were randomly assigned to either one of three versions of the described script which differed only with respect to the type of preparation task applied in the individual externalization phases (see Appendix A in the Supplementary material).

Participants in the note-taking task condition were not specifically requested to perform constructive activities. Subjects in the compare-contrast task condition were required to compare-and-contrast central concepts addressed by the text. For example, subjects were asked to compare the different kinds of blood vessels of the circulatory system regarding their components and the processes they are involved in. Since many of these similarity and difference relations were not explicitly stated in the text, learners had to infer them, typically by connecting different information that are explicitly given in the text. In other words, learners had to perform constructive activities to complete this type of task. Participants in the explanation task condition were required to provide explanations related to the same central text concepts as in the compare-contrast task condition. For example, the learners were asked to find reasons why our circulatory system entails different types of blood vessels instead of only one type. To this end, the learners had not only to infer comparative relations, but also to connect these relations with each other in order to formulate explanations for the existence of the components addressed in the respective task. Besides of connecting different text information, this required to insert general or domain specific prior knowledge. In other words, compared to the compare-contrast tasks, learners had to perform even more constructive activities in order to complete the explanation tasks. Taken together, the extent and explicitness to which the described tasks ask for the execution of constructive activities (i.e., the task generativity) increases from note-taking (low) to compare-contrast (moderate) to explanation (high).

To keep learning time constant between experimental conditions, subjects were given a target time of 10 min each for the externalization and the discussion phases, being allowed to proceed to the next phase after 8 min at the earliest, and automatically forwarded after 12 min at the latest. One week after the treatment participants reentered the lab to answer a posttest capturing their text comprehension.

2.4 Measures

2.4.1 Pretest

We assessed the participants' prior knowledge with a test adapted from Jeong and Chi (2007). Students were requested to describe the blood path of the circulatory system in a textbox. They were asked to do this in as much detail as they could, while also including components and processes that play a role in the human circulatory system.

To code participants' prior knowledge, a predefined template was used that included topic-relevant idea units in terms of knowledge pieces about the circulatory system, for instance, "blood moves from the heart to the body" or "the heart is a pump." Participants received one point for each piece of knowledge expressed (Jeong and Chi, 2007). A second rater coded 17% of the data for inter-rater reliability ($\alpha_{\text{Krippendorf}} = 0.90$). The resulting prior knowledge score represents the sum of knowledge pieces contained in a participant's written response to the pretest. Please note that this score does not include information on the relationships among the idea units or learners' mental model about the circulatory system.

2.4.2 Coding of learners' individual externalizations

In order to assess the extent to which the learners enacted constructive preparation activities, the individual externalizations were subjected to a coding procedure. More concretely, the quality of participants' responses to the preparation tasks were coded using a scheme developed by the authors (Mende et al., 2017) based on previously published operationalizations of constructive activities (e.g., Chi and Wylie, 2014; De Backer et al., 2014; Roscoe, 2014). To this end, we assessed the occurrence of constructive activity indicators at the protocol level in terms of the number of sentences containing inferences, that is, topic-relevant information not already given in the learning text. This can have the form of, for instance, comparing the thickness of arteries and capillaries or generating a causal explanation such as "due to their thick walls, diffusion is not possible in the arteries" since these comparisons and explanations were not explicitly presented in the text. By contrast, mere repetitions of text information were not considered constructive activity.

By means of the described procedure, each of the three externalizations per participant were evaluated with respect to the number of constructive activities. A second rater coded 25% of the individual externalization protocols ($\alpha_{Krippendorf} = 0.91$). The resulting score represents the sum of constructive preparation activities a learner has performed during the individual externalization phases.

2.4.3 Coding of the collaborative discussion activities

In order to assess the extent to which the learners performed constructive and interactive activities during the collaborative discussion phases, the quality of the chat dialogues was subjected to a coding procedure. To this end, we applied a previously developed coding scheme (Mende et al., 2017) that has been adapted from previous work (e.g., Jeong and Chi, 2007; Berkowitz et al., 2008; Noroozi et al., 2013; Chi and Wylie, 2014; De Backer et al., 2014; Roscoe, 2014).

Participants' chat messages were first segmented according to punctuation and "connectives" (Strijbos and Stahl, 2007; Erkens and Janssen, 2008). In a second step, each segment was assessed for whether it contains topic-relevant information (i.e., information about the circulatory system; $\alpha_{Krippendorf} = 0.97$). This was done because computer-based learning dialogues typically comprise not only utterances directly related to processing the learning content but also utterances related to purely metacognitive, technical, coordinative or social concerns (e.g., Paulus, 2009; De Backer et al., 2014). Only segments containing topic-relevant information (e.g., "The heart is divided into four chambers, right?"; "I think that blood is oxygenated in the lungs") were considered for further coding. The remaining segments (e.g., "I understood the text passage well," "What should we talk about next?," "Which button do I need to press to continue?," and "What will we have for lunch?") were excluded from further analyses.

In a third step, two independent decisions were made for each topic-related segment: (a) does the segment contain an inference (see above)? (b) does the segment contain indications of referencing to a prior contribution of the co-learner in terms of taking up or incorporating information expressed in the dyad partner's individual externalization or previous chat messages? A second rater coded 25% of the discussion protocols ($\alpha_{Krippendorf} = 0.82$–$0.88$). Segments containing an inference without indications of referencing were counted as constructive activity and segments containing an inference with indications of referencing were counted as interactive activity. Segments containing no inference were not considered for further analyses. The resulting scores represent the sum of constructive or interactive activities a learner has performed during the collaborative discussion phases.

2.4.4 Posttest

One week after the treatment participants were administered with a computer-based posttest adapted from Chi et al. (2001) that assessed their knowledge about different aspects of the human circulatory system comprising the components, functioning and purposes of the heart, the vessels, and the different sub-circuits. The test consisted of 30 multiple choice questions covering shallow and deep text comprehension. Each question consisted of four answer options, with only one option being correct. Since retest effects can arise in pre-post-test designs, the multiple-choice format was only used in the posttest while the open response task format was used in the pretest.

The shallow comprehension subtest included twenty questions that could be answered by either restating an information explicitly provided in the learning material or by combining information which were explicitly given across several sentences of the learning material. The average item difficulty was 0.59 ($SD = 0.14$) and ranged from 0.40 to 0.90.

To correctly answer the 10 questions forming the deep comprehension subtest, learners had to transfer the text information to issues not directly addressed within the sentences contained in the learning material. That is, answering this kind of questions required that the learners had integrated their prior knowledge with the text information and formed a proper mental model of the circulatory system (Chi et al., 2001). The average item difficulty was 0.42 ($SD = 0.21$) and ranged from 0.16 to 0.75.

Examples of the items and answer options are provided in Appendix B in the Supplementary material. For each participant we computed percentages of correctly answered questions per subtest. Please note that the focus of this work is on learners' deep comprehension. Therefore, the results of the shallow comprehension test are only included in the descriptive statistics for overview purposes.

2.5 Data analysis

Since subjects were nested in dyads, we conducted linear mixed regression analyses for dyadic data (Kenny et al., 2006), using the restricted maximum likelihood method (REML) for effect estimations and the maximum likelihood method (ML) for assessment of model fit changes in terms of likelihood ratio tests (e.g., Campbell and Kashy, 2002).

As some of our research variables revealed deviations from a normal distribution, we performed bias-corrected and accelerated bootstrap analyses with 5,000 resamples to estimate the standard errors and confidence intervals for all regression coefficients (e.g., Puth et al., 2015; Scharkow, 2017). To be considered significant at the 5% significance level, an effect must not include zero in the 95% bootstrap interval. We centered all continuous predictors before analyses. Unstandardized regression coefficients are reported.

2.5.1 Research question 1

RQ1 investigated the effects of three individual preparation tasks differing in their generativity, as well as the moderating role of actor's and partner's prior knowledge in view of the number of constructive preparation activities, constructive and interactive collaboration activities as well as deep comprehension posttest achievement. Moderated mixed regressions were performed for each dependent variable applying a two-step approach: In a first step, experimental condition as well as the actor's and partner's prior knowledge were entered into the regression. Experimental condition was dummy-coded so that the compare-contrast task condition and the explanation task condition were each compared with the note-taking task condition as the reference group. In a second step, we entered the two-way interaction terms between condition and prior knowledge variables.

In order to also capture the effect of the explanation task condition in relation to the compare-contrast task condition, this two-step procedure was repeated using sequential coding. That is, this time the explanation task condition was compared with the compare-contrast task condition and the latter again with the note-taking task condition.

A moderator effect was assumed if the addition of the interaction terms in step 2 resulted in a significant improvement in model fit and the corresponding interaction term had a significant regression weight. In such a case, the simple slopes for the effects of task type were calculated at different values of prior knowledge as a follow-up analysis: at the 10th, 25th, 50th, 75th, and the 90th percentile of the sample distribution (e.g., Hayes, 2013), which correspond to prior knowledge scores of 4.00, 7.00, 11.50, 17.00, and 22.00.

2.5.2 Research question 2

Research question 2 was concerned with potential indirect actor and partner effects of constructive preparation activities (independent variables) on deep comprehension outcomes (dependent variable) through constructive and interactive collaboration activities (mediators) as well as the moderating role of prior knowledge for such indirect effects. In addition, we considered the direct actor and partner effects of constructive preparation activities on deep comprehension outcomes that were explicitly not transmitted through the mentioned mediators.

To investigate research question 2, moderated mediation analyses were conducted (e.g., Hayes, 2013; Song, 2018). Thereby we applied the procedure for estimating an Actor-Partner-Interdependence model for indistinguishable dyads (Kenny et al., 2006).

To assess the occurrence of indirect effects we followed the approach of Yzerbyt et al. (2018). The authors recommend testing three effects in sequence, all of which must be statistically significant to conclude that there is an indirect effect. These include a-path analysis, b-path analysis, and a*b-path analysis, with the latter being used to estimate the actual indirect effect (e.g., Hayes, 2013):

First, in the course of the a-path analyses we examined the actor and partner effects of constructive preparation activities (independent variables) on constructive and interactive collaboration activities (mediators) and whether these effects are moderated by the actor's and/or the partner's prior knowledge. Within the a-path analyses, moderation was assessed following the two-step procedure already described regarding the analyses for research question 1. If neither a significant (moderated) actor nor a partner effect was found in view of a mediator, the latter was not further subjected to the following b-path analyses.

Second, in the course of the b-path analysis, while controlling for actor and partner effects of constructive preparation activities (independent variables), we examined the actor and partner effects of the mediators not excluded during a-path analyses on deep comprehension posttest achievement (dependent variable) and whether these effects are moderated by the actor's and/or the partner's prior knowledge. If neither a significant (moderated) actor nor a partner effect of a mediator on a dependent variable was found, the mediator was not further subjected to the following a*b-path analyses. Within the b-path analysis model, also the direct actor and partner effects (c') can be obtained in terms of the effects of the constructive preparation activities controlled for the effects of the potential mediators.

Third, potential mediators not excluded during the previous steps were subjected to the a*b-path analyses. To this end, the respective a-path and the b-path coefficients as well as their bootstrapped standard errors were used to calculate the indirect effects (a*b-paths) along with 95% Monte Carlo confidence intervals based on 100,000 replications, using the SPSS macro MCMED (Hayes, 2013). If an indirect effect included an a-path and/or b-path coefficient for which the previous analyses indicated significant moderation, the respective a-path and/or b-path coefficients at different moderator values (10th, 25th, 50th, 75th, and 90th percentile) were used to calculate the indirect effect, resulting in a total of five estimates of the respective indirect effect (e.g., Hayes, 2013).

TABLE 1 Descriptives ($N = 122$).

Experimental condition (task generativity)	Low: note-taking ($n = 36$)	Moderate: compare-contrast ($n = 42$)	High: explanation ($n = 44$)
Age: *M* (*SD*)	22.19 (3.11)	22.52 (3.47)	23.59 (4.85)
Prior knowledge: *M* (*SD*)	13.08 (6.69)	11.50 (6.18)	13.05 (8.39)
Shallow comprehension post-test[a]: *M* (*SD*)	61.53 (16.60)	60.71 (18.10)	54.77 (13.47)
Sex: percentages			
Female	75%	66.7%	77.3%
Male	25%	33.3%	22.7%
Subject of study: percentages			
Psychology	58.3%	50.0%	40.9%
Educational Sciences	41.7%	50.0%	59.1%

[a] Percent of MC items answered correctly.

3 Results

3.1 Descriptive and preliminary analyses

Table 1 summarizes descriptive statistics for pretest variables. No significant pre-group differences regarding sex [$X^2_{(2,N=122)} = 1.33$, *n.s.*] subject of study [$X^2_{(2,N=122)} = 2.42$, *n.s*], age [$F_{(2,121)} = 1.42$, *n.s.*], or prior knowledge [$F_{(2,121)} = 0.65$, *n.s.*] occurred.

3.2 RQ1: effects of preparation task generativity and the potentially moderating role of prior knowledge

Statistical values are not presented in the text for better readability. The results of the analyses are provided in detail in Appendix C in the Supplementary material. An overview is given in Table 2. In the following, results are addressed separately for the different dependent variables.

3.2.1 Constructive preparation activities

Both, the compare-contrast and the explanation tasks led the learners to perform more constructive preparation activities than the note-taking tasks. The actor's prior knowledge moderated these positive main effects, though without qualifying them (see Table 2, first row & Figure 3). That is, the compare-contrast and the explanation tasks each had a significant positive effect on the constructive preparation activities of all learners, but these effects were stronger for learners with higher prior knowledge in both cases as indicated by the simple slope tests (see Figure 3).

In addition, findings revealed the explanation tasks to be superior to the compare-contrast tasks in terms of inducing constructive preparation activities. For this effect, the results showed no indications of a moderating role of the actor's or the partner's prior knowledge.

3.2.2 Constructive collaboration activities

The explanation task led learners to perform less constructive collaboration activities than the note-taking task (see Table 2, second row). No other main effects or any moderation effects were found.

3.2.3 Interactive collaboration activities

No main or moderated effects of task generativity were found in view of interactive collaboration activities (see Table 2, third row).

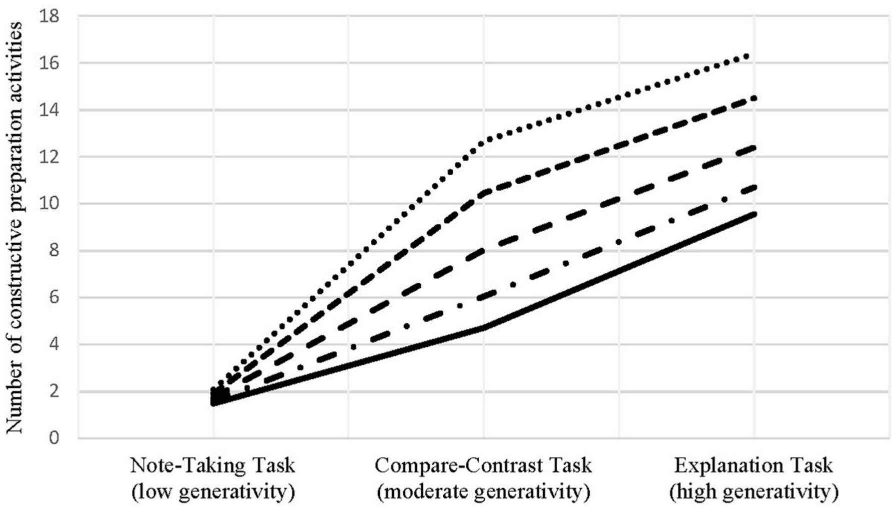
3.2.4 Deep comprehension achievement

In terms of deep comprehension posttest achievement, the compare-contrast task condition participants performed significantly worse than the subjects in the note-taking and explanation task conditions (see Table 2, fourth row). This effect was neither moderated by the actor's nor partner's prior knowledge. No further main or any moderation effects were found.

TABLE 2 Descriptives of dependent variables and overview of the results concerning RQ1 ($N = 122$).

Experimental condition (task generativity)	Low: note-taking ($n = 36$)		Moderate: compare-contrast ($n = 42$)		High: explanation ($n = 44$)		Effect: experimental comparison[b]
Dependent variable	*M*	*SD*	*M*	*SD*	*M*	*SD*	
Constructive preparation activities	1.83	1.81	7.88	4.82	13.00	5.33	Low vs. moderate: see Figure 3[c] Low vs. high: see Figure 3[c] Moderate vs. high: 4.59*
Constructive collaboration activities	2.11	1.94	1.74	1.96	1.34	1.38	Low vs. moderate: −0.38 Low vs. high: −0.77* Moderate vs. high: −0.39
Interactive collaboration activities	4.75	3.75	4.45	3.88	5.55	4.74	Low vs. moderate: −0.05 Low vs. high: 0.80 Moderate vs. high: 0.85
Deep comprehension posttest[a]	45.56	16.29	36.19	17.52	44.31	18.85	Low vs. moderate: −7.47* Low vs. high: −1.19 Moderate vs. high: 6.28*

[a]Percent of MC items answered correctly. [b]Unstandardized regression coefficients are reported as obtained from the results of the mixed moderated regression analyses; see Appendix C in the Supplementary material for details. [c] The effect is moderated by the actor's prior knowledge and therefore detailed in Figure 3. *$p < 0.05$ as determined by the 95% bias corrected and accelerated bootstrap confidence intervals.



Simple slopes at different percentiles of actor's prior knowledge:

Comparison		Low vs. moderate			Low vs. high		
Percentile		*B*	Boot SE	BCa *CI95%*	*B*	Boot SE	BCa *CI95%*
(solid line)	10th	3.22*	1.04	[1.14,4.96]	8.07*	1.00	[6.06,10.14]
(dash-dot line)	25th	4.46*	.79	[2.89,5.82]	9.11*	.81	[7.44,10.76]
(long-dash line)	50th	6.30*	.62	[5.07,7.58]	10.67*	.62	[9.42,11.94]
(short-dash line)	75th	8.55*	.92	[6.83,10.80]	12.59*	.69	[11.20,13.99]
(dotted line)	90th	10.60*	1.40	[7.95,14.31]	14.32*	.97	[12.40,16.15]

FIGURE 3
Follow-up-analyses of the significant interaction effects between task type and actor's prior knowledge on self-performed constructive preparation activities. The respective effects are visualized and reported in terms of simple slopes, consonant with the actor's prior knowledge at the 10th, 25th, 50th, 75th, and 90th percentile of the distribution. Unstandardized regression weights are reported. All continuous predictors were centered prior to the analyses. Asterisks indicate significance at the 5% level as determined by the 95% bias corrected and accelerated bootstrap confidence intervals.

3.3 RQ2: indirect and direct actor and partner effects of constructive preparation activities and the potentially moderating role of prior knowledge

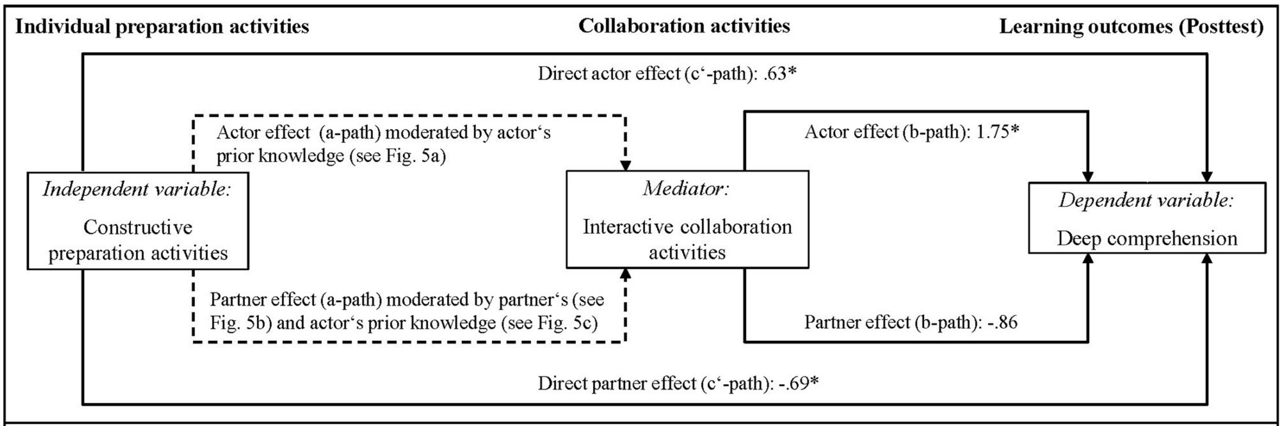
The results of the a-path and b-path analyses are provided in detail in Appendix D in the Supplementary material. An overview is given in Figure 4 together with the results of the final a*b-path tests for (moderated) indirect effects. In the following, results are addressed separately for the different mediators and the direct effects.

3.3.1 Constructive collaboration activities as potential mediator

Constructive collaboration activities were excluded as potential mediator already during a-path analyses since neither actor nor partner effects, whether unmoderated or moderated by the actor's or the partner's prior knowledge, were observed (see Appendix D in the Supplementary material).

3.3.2 Interactive collaboration activities as potential mediator

First, an indirect actor-actor effect moderated by the actor's prior knowledge was found: mediated via self-performed interactive collaboration activities, learners with relatively low prior knowledge (10th and 25th percentile) benefitted from performing constructive preparation activities in terms of deep comprehension outcomes while learners with relatively high prior knowledge (90th percentile) suffered losses from performing constructive preparation activities (see Figure 4 lower part). Consulting the results of the a-path and b-path analyses (Figure 4 upper part) helps interpreting this effect: self-performed constructive preparation activities fostered the learner's execution of interactive collaboration activities when their own prior knowledge was relatively low (10th and 25th percentile) but reduced the execution of interactive activities when prior knowledge was relatively high (90th percentile; see Figure 5A). The self-performed interactive activities in turn promoted own deep comprehension outcomes for all learners irrespective of prior knowledge (Figure 4 upper part). Hence, for learners with relatively high prior knowledge the execution of constructive preparation



Indirect effects (a*b-paths)

Prior knowledge at…	Actor-Actor effect as function of actor's prior knowledge		Partner-Actor effect as function of… …partner's prior knowledge		Partner-Actor effect as function of… …actor's prior knowledge	
	B	MC *CI95%*	B	MC *CI95%*	B	MC *CI95%*
…10th percentile	.53*	[.16, 1.01]	.79*	[.30, 1.41]	.04	[-.29,.38]
…25th percentile	.39*	[.11, .75]	.67*	[.26, 1.17]	.18	[-.06,.48]
…50th percentile	.18	[-.03, .44]	.46*	[.16, .85]	.37*	[.10,.73]
…75th percentile	-.09	[-.33, .12]	.21	[-.03, .52]	.61*	[.20,1.16]
…90th percentile	-.32*	[-.69, -.03]	.00	[-.33, .33]	.84*	[.27,1.60]

FIGURE 4
Summary of the moderated mediation analyses (RQ 2). Only interactive collaboration activities are presented as mediator and included in tests for indirect effects, as constructive collaboration activities have been excluded as potential mediator during the preceding a-path and b-path analyses; see Appendix D in the Supplementary material for details. Unmoderated paths are indicated by solid lines and labeled with the according main effect. Moderated paths are indicated by dotted lines with the respective effects being detailed in Figure 5. Since all to be estimated a*b-paths include an a-path coefficient which has been indicated to be moderated by the actor's and/or the partner's prior knowledge, each indirect effect is reported in terms of simple slopes consonant with prior knowledge at the 10th, 25th, 50th, 75th, and 90th percentile of the distribution. Unstandardized regression weights are reported. All continuous predictors were centered prior to the analyses. Asterisks indicate significance at the 5% level as determined by the 95% bias corrected and accelerated bootstrap confidence intervals or, in case of indirect effects, the 95% Monte Carlo confidence intervals.

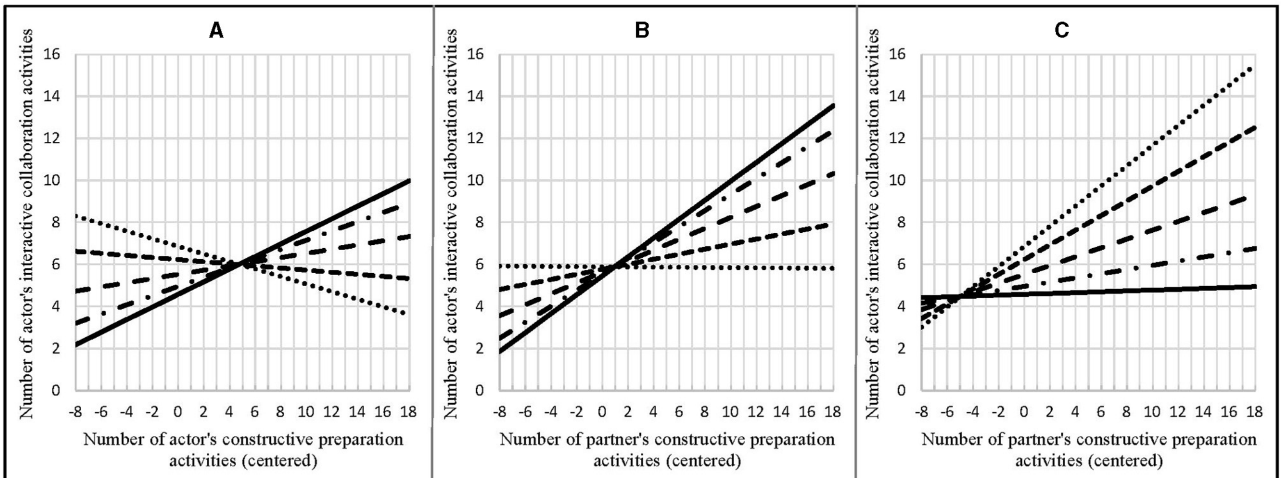
activities was detrimental to their deep comprehension outcomes as far as these activities prevented them from enacting interactive collaboration activities.

Second, we obtained an indirect partner-actor effect which was moderated by the partner's prior knowledge. Mediated via self-performed interactive collaboration activities, learners benefitted in terms of deep comprehension from the constructive preparation activities of their co-learners, but only if the latter's prior knowledge was relatively low to moderate (10th, 25th, and 50th percentile; Figure 4 lower part). Consulting the a-path and b-path analyses results shows relatively low to moderate (10th, 25th, and 50th percentile) but not higher prior knowledge co-learner's constructive preparation activities fostered one's own interactive collaboration activities (Figure 5B). The latter in turn promoted one's own deep comprehension outcomes regardless of prior knowledge (Figure 4 upper part). Put another way, the self-performed constructive preparation activities of learners with relatively low to moderate prior knowledge had a positive indirect effect on their co-learner's deep comprehension outcomes mediated by their co-learner's interactive activities.

Third, we found the indirect partner-actor-effect just described to be also moderated by the actor's prior knowledge. Mediated via their own interactive collaboration activities, learners with moderate to relatively high prior knowledge (50th, 75th, and 90th percentile) benefitted from their co-learners enacted constructive preparation activities in terms of deep comprehension (Figure 4 lower part). Consulting a-path and b-path analyses reveals moderate to relatively high (50th, 75th, and 90th percentile) but not relatively low prior knowledge learners' performance of interactive activities was positively affected by their co-learners previously executed constructive preparation activities (Figure 5C). Executing interactive activities in turn promoted own deep comprehension outcomes irrespective of prior knowledge (Figure 4 upper part).

3.3.3 Direct effect of constructive preparation activities

Constructive preparation activities were also found to have direct actor and partner effects on deep comprehension that are not mediated by interactive collaboration activities (Figure 4 upper part): The performance of constructive preparation activities had a positive direct influence on the learner's own deep comprehension in the sense of an actor effect. In contrast, co-learners' constructive preparation activities directly impaired



Effects at different percentiles of actor's prior knowledge (A)

Percentile	*B*	Boot SE	BCa *CI95%*
10th	.30*	.09	[.12, .49]
25th	.22*	.07	[.07,.39]
50th	.10	.06	[-.01,.23]
75th	-.05	.06	[-.16,.09]
90th	-.18*	.08	[-.32,-.01]

Effects at different percentiles of partner's prior knowledge (B)

Percentile	*B*	Boot SE	BCa *CI95%*
10th	.45*	.10	[.23, .61]
25th	.38*	.08	[.19,.52]
50th	.26*	.07	[.11,.39]
75th	.12	.07	[-.03,.27]
90th	-.00	.09	[-.18,.19]

Effects at different percentiles of actor's prior knowledge (C)

Percentile	*B*	Boot SE	BCa *CI95%*
10th	.02	.09	[-.16,.14]
25th	.10	.07	[-.04,.20]
50th	.21*	.07	[.07,.32]
75th	.35*	.10	[.13,.56]
90th	.48*	.14	[.16,.81]

FIGURE 5
Follow-up-analyses of the significant interaction effects between constructive preparation activities and prior knowledge on self-performed interactive collaboration activities. **(A)** Actor effect of constructive preparation activities on interactive collaboration activities as function of actor's prior knowledge. **(B)** Partner effect of constructive preparation activities on interactive collaboration activities as function of partner's prior knowledge. **(C)** Partner effect of constructive preparation activities on interactive collaboration activities as function of actor's prior knowledge. The respective effects are visualized and reported in terms of simple slopes, consonant with prior knowledge at the 10th, 25th, 50th, 75th, and 90th percentile of the distribution. Unstandardized regression weights are reported. All continuous predictors were centered prior to the analyses. Asterisks indicate significance at the 5% level as determined by the 95% bias corrected and accelerated bootstrap confidence intervals.

learner's deep comprehension in terms of a negative partner effect. No indications of moderation through prior knowledge were obtained in either case.

4 Discussion

The aim of this study was to investigate whether performing constructive activities during individual preparation can help learners to subsequently exploit the potential benefits of digital collaboration in terms of using co-learners externalized knowledge as resource for own inferencing processes (interactive activities) in the service of in-depth knowledge acquisition (deep comprehension outcomes). To address this aim, we firstly investigated on a more general level whether more rather than less generative tasks intended to induce constructive preparation activities are suited to increase the execution of interactive activities and deep comprehension achievement (RQ1). We secondly examined on a more detailed level the direct and indirect (via interactive activities) effects of the actor's and partner's constructive preparation activities on deep comprehension outcomes (RQ2). Prior knowledge was considered as potential moderator in both cases.

Overall, the results in response to RQ1 suggest increasing the preparation task generativity to be an effective way to raise the number of constructive preparation activities executed by the individual learning-dyad members prior to collaboration. However, the results further indicate that this *per se* is not sufficient to lead learners to better utilize subsequent collaboration in terms of in-depth knowledge acquisition. The analyses conducted in the course of addressing RQ2 provided some insights into the possible reasons for this pattern of results. These findings suggest that the execution of constructive activities during an individual preparation yields not only advantages but also disadvantages in view of subsequent collaborative learning: though self-performed constructive preparation activities had direct benefits for own deep comprehension outcomes, they promoted deep learning *from* subsequent collaboration only for learners with relatively low prior knowledge while they were ineffective or even detrimental in this regard for learners with relatively high prior knowledge. Co-learners' constructive preparation activities fostered one's own deep learning from collaboration under specific conditions of own and partner's prior knowledge, but negatively affected one's deep comprehension outcomes on the direct path. In other words, given the present findings, the answer to the question of whether constructive preparation activities can promote deep learning from subsequent collaboration seems to be an "it depends." In the following we discuss the results related to RQ1 and RQ2 in more detail.

4.1 The antecedents and consequences of constructive preparation activities

Concerning RQ1, our results revealed that more generative tasks led the learners to execute more constructive preparation activities during individual preparation: the number of constructive preparation activities significantly increased from the note-taking task (low generativity) over the compare-contrast task (moderate generativity) to the explanation task (high generativity). This is in line with previous generative learning research on the effectiveness of these different tasks in terms of inducing deep learning processes (e.g., Grabowski, 2004; Sidney et al., 2015; Chin et al., 2016; Ponce et al., 2020). Furthermore, in reference to the low generative task, the positive effects of the more generative tasks (i.e., compare-contrast and explanation) were the more pronounced, the higher the learners' prior knowledge which has been also expected in the face of previous research on text comprehension and cognitive load (e.g., Kintsch, 1998; Best et al., 2005; Chen et al., 2017). Taken together, a higher preparation task generativity consistently led all learners to enact more constructive preparation activities, although the effects were stronger for more knowledgeable learners.

This positive task generativity effects did, however, not transfer to the number of interactive (or constructive) collaboration activities and deep comprehension outcomes. We even observed participants in the compare-contrast task condition to perform significantly worse than the subjects in the note-taking and the explanation task conditions in terms of deep comprehension outcomes as indicated by the transfer posttest. As a possible explanation, the compare-contrast task may have focused the learners too much on single comparisons between the circulatory system components, thus preventing them from developing a more comprehensive understanding of how the system works as a whole, resulting in poorer transfer achievement (e.g., Chin et al., 2016). As a related explanation, the deep comprehension posttest primarily captured learners understanding of the functioning of the circulatory system in terms of cause-effect-relations. Thus, the fit between the preparatory compare-contrast task and the posttest was relatively low compared to the other conditions.

To summarize, in the present study, a higher preparation task generativity led learners to execute a greater number of constructive preparation activities. However, consistent with previous studies (e.g., Lam and Kapur, 2017; Lam and Muldner, 2017; Lam, 2019), we found no evidence that tasks of higher generativity are better suited than tasks of lower generativity to help learners take advantage of the potential benefits of subsequent collaboration for in-depth knowledge acquisition.

This invites a closer look into the mechanisms involved and the conditions relevant for the effects of constructive preparation activities enacted by oneself and one's co-learner (RQ2). To first give a general overview: both, one's own and one's partner's constructive preparation activities were found to have significant direct as well as moderated indirect effects on one's own deep comprehension outcomes. These indirect effects all included self-performed interactive collaboration activities as mediator. Specifically, learners own interactive activities positively affected their own deep comprehension outcomes irrespective of prior knowledge. *Moderated* indirect effects of one's own as well as the partner's constructive preparation activities occurred because each affected the execution of interactive activities differently in dependence of own and/or the partner's prior knowledge. In the following we discuss these indirect effects along with the direct effects.

To begin with, self-performed constructive preparation activities in themselves already fostered own deep comprehension outcomes directly, that is, not mediated by interactive (or constructive) collaboration activities. This could be expected in light of previous findings on the positive effects of constructive activities on deep learning (e.g., Chi and Wylie, 2014). Extending previous research, our results also show that executing constructive activities during an individual preparation can, in the sense of an indirect effect, promote but also hinder one's execution of interactive activities and, in turn, deep comprehension outcomes depending on own prior knowledge (actor-actor effect moderated by actor's prior knowledge). More specifically, our findings suggest that self-performed constructive preparation activities promote one's own subsequent execution of interactive collaboration activities at relatively low prior knowledge levels, have no effect at higher levels, and even lead to less interactive activities at the highest level considered (i.e., 90^{th} percentile). This is in line with the assumptions of benefit-cost approaches on the role of prior knowledge on collaborative learning (e.g., Nokes-Malach et al., 2012, 2015; Janssen and Kirschner, 2020): building relevant knowledge structures first through constructive preparation activities seems to have helped learners with little prior knowledge to deal with the costs associated with taking up and integrating externalized knowledge from co-learners (i.e., performing interactive activities) during collaboration while still leaving enough room to experience benefits from doing so, for instance, in terms of further developing or differentiating own initial conclusions and ideas together with the co-learner during discussion. Learners who already possessed a larger body of relevant prior knowledge were possibly more capable to deal with the costs of interactive activities from the outset, so that the execution of constructive preparation activities had no added value for them in this regard. Moreover, the higher the prior knowledge, the more likely the execution of constructive activities might have led learners to come to a comprehensive understanding of the instructional material already at the end of the preparation. This might have reduced the expected potential benefits of interactive activities and, thus, their execution. The results indicate, however, that self-performed interactive activities were conducive to deep comprehension outcomes irrespective of prior knowledge. That is, also high prior knowledge learners benefitted from enacting interactive activities in the present study.

The described prior knowledge dependency of the effects of one's own constructive preparation activities on one's own interactive activities seems to have consequences for the co-learner with respect to his or her usage of the potential collaboration benefits in terms of in-depth knowledge acquisition as well. More specifically, constructive preparation activities executed by learners at relatively lower levels of prior knowledge did not only had a positive indirect effect on their own deep comprehension outcomes via their own interactive activities (actor-actor effect moderated by the actor's prior knowledge) but also a positive indirect effect on their partner's deep comprehension via their partner's interactive activities (partner-actor effect moderated by the partner's prior knowledge). Both indirect effects became smaller with increasing prior knowledge. However, while the actor-actor effect became even significantly negative at relatively high prior knowledge, the partner-actor effect only decreased to a non-significant level (compare Figures 5A, B). This pattern of results seems reasonable when considering that the actor's constructive and interactive activities together form the input that goes beyond the instructional material and that the partner can use for his or her interactive activities during collaboration (e.g., Chi and Wylie, 2014). Thus, if the effect of one's own constructive preparation activities on one's own interactive collaboration activities is initially positive, then non-significant, and finally negative with increasing own prior knowledge, it seems plausible that this also applies in a weakened form to the interactive activities of the partner.

Our results further revealed the indirect effect of the co-learners' constructive preparation activities on one's own deep comprehension outcomes via own interactive activities to not only depend on the co-learner's but also one's own prior knowledge (partner-actor effect moderated by actor prior knowledge). This is because the partner's enacted constructive preparation activities fostered one's own execution of interactive activities only when own prior knowledge was at relatively higher levels (starting from the 50th percentile). This suggests that taking up and integrating the externalizations resulting from the co-learner's constructive preparation activities in the sense of own interactive activities requires at least some prior knowledge to deal with the associated costs (e.g., Kalyuga, 2009; Janssen and Kirschner, 2020). Since the co-learner's constructive preparation activities per definition contain conclusions, ideas, and perspectives not already presented in the instructional material, the benefits seem to have prevailed the costs thereby, despite an already advanced own knowledge about the instructional material.

While the partner's constructive preparation activities had a positive indirect effect on one's own deep comprehension outcomes under certain conditions of own and partner's prior knowledge as described, the direct effect was negative, which seems somewhat counterintuitive. Recall, however, that a direct effect is the influence that remains after taking into account the indirect effect: accordingly, the negative direct partner effect could be interpreted in terms of the impact of constructive activities externalized by the co-learner, which are not used as a learning resource in the course of one's own interactive activities in the service of deep comprehension. Thus, as a possible explanation, the negative direct partner effect could be understood as the impact of information that makes the learning situation more complex and increases the demands on one's own cognitive resources while not contributing to one's own learning (Kirschner et al., 2018; cf. Janssen and Kirschner, 2020).

To conclude, our results suggest that executing constructive activities during individual preparation seems to yield advantages as well as disadvantages in view of the learner's personal profit from subsequent collaboration in terms of in-depth knowledge acquisition. Whether the advantages or disadvantages prevail seems to depend on whose constructive activities we are asking about and who brings how much prior knowledge to the table. The outlined insights provide hints as to where approaches might be taken in order to optimize the design of the individual preparation and the subsequent collaboration phase so that learners could be better and more reliably supported in benefitting from their own and each other's executed constructive preparation activities in view of deep learning from subsequent collaboration. Among others, this is addressed in the next section.

4.2 Limitations and future directions

This work is subject to several limitations, pointing at the need for further developments and investigation in future studies. These concern (a) the instructional design choices, (b) the study variables considered, and (c) the design of the present study.

4.2.1 Instructional design choices

The findings of the present study must be seen in the light of the instructional design choices applied in the study. First, the preparation tasks were provided without any further support or guidance. Numerous practicable approaches are available in this regard, which can be implemented easily and flexibly thanks to digital technologies. For example, structuring scaffolds such as prompts pointing at important information or guidelines on how to decompose a complex problem may especially support learners with low prior knowledge in performing (more) constructive activities in response to highly generative tasks (e.g., Reiser, 2004; Kalyuga, 2009). Future studies should therefore investigate whether the interaction between prior knowledge and the generativity of preparation tasks demonstrated here still holds when the latter are provided with additional support. However, it is an open issue for further research whether such support for learners with higher prior knowledge would be redundant and, thus, ineffective or even detrimental to their learning process (e.g., Kalyuga et al., 2003; Chen et al., 2017). Hence, it deserves further attention how the interplay between task generativity, prior knowledge, and supporting scaffolds might affect learners' execution of constructive preparation activities. Respective insights could inform adaptive support strategies which help to streamline generative preparation task effectiveness.

Second, within the individual preparation phases, after completing the individual externalization task, learners received each other's individual task responses (awareness induction), with these responses being presented exactly as written by the co-learner and without specific instructions on how to process the response in order to further prepare for collaboration or using them during collaboration. In addition, a relatively general instruction was intentionally used for the subsequent collaboration phase: to work together to help each other improve their understanding about the instructional material. Future work could examine how the awareness induction and collaboration phases could be optimized so that the benefits of constructive preparation activities can be enhanced and the disadvantages mitigated. For instance, data mining techniques could be applied to filter and (graphically) organize the co-learner's task responses received during awareness induction, which could facilitate their processing and comparison with one's own response (e.g., Erkens et al., 2016; Bodemer et al., 2018). This might reduce the costs imposed on oneself through the externalized constructive preparation activities of co-learners, so that their negative direct effect on one's own deep comprehension outcomes could be reduced in favor of a greater positive indirect effect via one's own interactive activities (cf. Janssen and Bodemer, 2013). In addition, this could also allow learners with little prior knowledge to use and benefit from their partner's externalized constructive preparation activities. As another example, learners could be scripted to go through their preparation products with each other step by step during collaboration, with the task of reaching explicit consensus at each step (e.g., Kollar et al., 2014; Lam and Muldner, 2017). Among other things, this could stimulate also learners with high prior knowledge to progress from their previously externalized constructive preparation activities to more (rather than less) interactive activities because they have to explicitly discuss their individually prepared thoughts and conclusions with their co-learner.

Third, considering the ubiquitous use of digital technologies in all areas of human life, the relevance and ecological validity of this work is very high. Computer use yields many advantages over analog solutions, especially in synchronous learning (e.g., Jeong and Hmelo-Silver, 2016): digital technologies facilitate the collection, distribution, presentation, and graphical organization of group awareness information such as individual task solutions or dialogue protocols (e.g., chat histories). Further, learners can be presented with virtual environments or interfaces tailored to the collaborative task at hand as well as their individual prerequisites and, thus, allow for the ergonomic and effective implementation of collaboration scripts. In addition, realizing synchronous learning via chat rooms allows many groups to interact in the same physical room without disturbing each other. Last but not least, computer techniques facilitate researcher's data collection since the results of learners' activities can be logged automatically. An interesting question for future research would be, whether the present results could be replicated in an asynchronous digital learning setting.

4.2.2 Study variables

As a first issue, in contrast to the (potential) benefits, we considered the costs of collaboration not explicitly in the form of process measures. This is also indicated in the results: Regarding the effects of actor's and partner's constructive preparation activities on deep comprehension outcomes, we found not only indirect effects via the interactive activities, but also direct effects. In the literature on mediation analysis (e.g., Zhao et al., 2010), this is typically seen as a reason to search for hitherto unaccounted mediators in future studies. In our view, this applies less to the direct positive actor effect, since the latter can be interpreted reasonably as the learning effect of performing constructive activities, so that the question of mediating variables does not necessarily arise here. With regard to the negative direct partner effect, on the other hand, the search for previously omitted mediators seems more advisable. One candidate would be, for example, the mental effort invested by the learners during the collaboration (e.g., Janssen et al., 2010; Zambrano et al., 2019). Future studies should include also such or similar mediators to not only capture processes associated with the benefits (such as interactive collaboration activities) but also with the costs of collaboration more explicitly. This could add to the picture of the mechanisms underlying the advantages and disadvantages of constructive preparation activities in view of deep learning from subsequent collaboration.

Secondly, the coding of the preparation and collaboration activities according to ICAP could be further differentiated according to other available coding schemes. Though the ICAP framework provides clear criteria concerning the quality an activity must have to be coded, for example, as a constructive activity (i.e., must contain an inference), these classes are quite broad and domain general. In future studies constructive and interactive activities could, for instance, each be assessed with respect to whether they have the structure of more or less complete arguments or explanations.

Thirdly, this study considered the effects of constructive preparation activities on subsequent deep learning from collaboration exclusively through a cognitive lens. Future studies could expand the picture by also taking into account metacognitive and motivational variables as mediators and/or learning outcomes. For example, confidence judgments measured between preparation and collaboration phases (e.g., Schnaubert and Bodemer, 2019) could be examined as a possible mediator of the effect of one's own constructive preparation activities on one's own interactive collaboration activities, thus providing more insight into the possible reasons for the effect's dependence on own prior knowledge. Alternatively, or in addition, experienced curiosity could be a motivational mediator candidate here (cf. Glogger-Frey et al., 2015).

4.2.3 Design

As a first issue, we excluded students of medicine, biology etc. Though this decision was made to avoid ceiling effects, it limits the generalizability of the results to learners with low prior knowledge with regard to the learning domain. At the same time, when interpreting the present results, it should be taken into account that the learning topic (i.e., circulatory system) did not play a role in the education program of the subjects studied, which may have limited their learning motivation.

Secondly, it is possible that the effects of constructive preparation activities (also) depend on prior-knowledge related dyad composition (i.e., homogeneous or heterogeneous; cf. Janssen and Kirschner, 2020). However, the analyses we conducted in response to RQ 2 did only allow for conclusions about the effects of constructive preparation activities in dependence of the actor's *or* the partner's prior knowledge. A proper investigation of this issue would require the analysis of higher-order interactions (e.g., actor constructive activities x actor prior knowledge x partner prior knowledge). To this end, future studies should employ a larger sample size and/or a priori grouping by prior knowledge to ensure that a wide range of value combinations of own and partner prior knowledge are each present in sufficiently large numbers of cases (i.e., dyads).

Thirdly, the findings concerning the deep comprehension results must be seen in the light of the delay of 1 week at which the posttest was administered. More concretely, the missing benefits of the explanation and compare-contrast as compared to the note-taking conditions might be (in part) a result of the noise caused by the delay. Thus, it is an open question for further research if potential benefits of more rather than less generative tasks would be more apparent in an immediate posttest.

5 Conclusion

This study contributes in several ways to our understanding of how more or less generative preparation tasks can influence learners' individual execution of constructive preparation activities and later collaborative learning. It also highlights aspects which should be taken into consideration in future investigations and in the instructional design of CSCL arrangements.

First, our findings suggest that is not so much the preparation task itself but rather what learners actually do with it that is critical to the subsequent collaboration quality and deep comprehension outcomes. This indicates that researchers should not only manipulate learning conditions involving different preparation tasks and then capture the desired collaborative learning activities and outcomes. They should also consider the activities learners actually execute in response to the tasks during individual preparation (cf. Chi and Wylie, 2014).

Second, this study highlights that data analyses should not only include deep comprehension as a collaboration outcome but also interactive activities as a mediating process in order to obtain information about whether constructive preparation activities indeed foster deep learning from rather than irrespective of subsequent collaboration. We argue that this analytical procedure should be generally applied in investigations concerned with assessing whether a certain intervention qualifies as effective means in fostering deep *collaborative* learning.

Third, considering prior knowledge as a moderator in conjunction with the distinction between actor and partner effects provided new insights into how the learner's personal benefit-cost ratio of performing interactive collaboration activities may be affected by previous constructive preparation activities. More specifically the present findings suggest that one's own and one's co-learner's constructive preparation activities (a) related differently to these personal benefits and costs, (b) both yield potential advantages and disadvantages in this regard with, and (c) prior knowledge being critical to what prevails.

Taken together, this study indicates that increasing the generativity of individual preparation tasks fosters the learner's execution of constructive preparation activities. However, it also shows that this alone is not sufficient to subsequently promote deep learning from collaboration. To this end, the results of our detailed analyses provide concrete starting points for future research that should investigate how instructional design around generative preparation tasks can be optimized for whom, so that the disadvantages of own and co-learner's constructive preparation activities are mitigated and the advantages can unfold.

Data availability statement

The quantitative raw data including the SPSS analysis syntax and an Excel spreadsheet that we created for the analysis are available at: https://osf.io/wq83c/.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. For low-risk studies like the one described in this manuscript, there is no ethics approval required in Germany. 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

SM: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Conceptualization. AP: Writing – review & editing, Visualization, Supervision, Software, Methodology, Conceptualization. SN: Writing – review & editing, Visualization, 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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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2024.1335682/full#supplementary-material

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Enhancing doctoral learning through virtual communities of practice: an autoethnographic perspective

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This article explores the role of virtual communities of practice in enhancing the doctoral experience, particularly in the contemporary digital era. The author emphasizes the multifaceted benefits, including elevating academic networking, optimizing knowledge management, and supporting the mental well-being of remote learners. The establishment of clear shared objectives, dynamic leadership, and a conducive environment for collaborative innovation are identified as key prerequisites for building successful virtual communities of practice. As remote doctoral education becomes more prevalent, virtual communities of practice not only facilitate academic engagement but also foster mutual support and advocacy among doctoral students. The researcher, as a final year PhD student employed autoethnography as a research method to offer an intimate and reflective exploration of her personal experiences within virtual communities of practice. This unique insider perspective adds depth to the discussion on elevating academic networking, optimizing knowledge management, and supporting the mental well-being of remote learners. Furthermore, her ongoing doctoral research focuses on the socialization process and the development of a sense of belonging among doctoral students. Motivated by her research topics, she commenced her doctoral studies during the epidemic and cultivated the practice of consistently maintaining a researcher's reflection diary. This perspective article examines her diary, elucidating her experiences, opinions, and feelings. The researcher utilized a thematic approach to thoroughly analyze the author's research diaries covering the period from December 2020 to August 2023. The article concludes by calling for further research into the professional identity development of doctoral students within virtual learning communities, exploring potential challenges and effective coping mechanisms to achieve inclusive practices in the complex and diverse digital era of academia.

KEYWORDS

doctoral experience, virtual communities of practice, networking, knowledge management, mental well-being, remote learning

1 Introduction

We all belong to some communities of practice as they are an integral part of our daily lives. A community of practice defines itself along three dimensions: its joint enterprise as understood and continually renegotiated by its members; the relationships of mutual engagement that bind members together into a social entity; and the shared repertoire of communal resources that members have developed over time (Wenger, 1998a, b). Concerning doctoral learning, communities of practice may enhance the experiences of doctoral students (Lahenius, 2012; Coffman et al., 2016; Cai et al., 2019). In this study, doctoral experience refers to the journey and process of obtaining a doctoral degree, and it encompasses various aspects, including academic study, research, teaching, professional development, and personal growth. Doctoral learning experience is a trajectory of becoming a researcher, negotiating new identities and reconceptualizing themselves both as people and professionals (Mantai, 2017).

In the digital era, virtual communities of practice use the Internet and technology to facilitate their construction, applying contemporary media and platforms to create attractive and conducive online environments. Not all website spaces are considered virtual communities of practice. They must conform to the original definition of offline communities of practice, which consist of three basic elements: domain, community, and practice. The social learning space has moved online, but it still emphasizes that a group of people with common enthusiasm and interests gather voluntarily and regularly to discuss a specific knowledge or technical field, thereby achieving dual growth of individuals and organizations (Hanisch, 2006; Sibbald et al., 2022).

Despite the existence of the community of practice concept for over two decades, there remains a dearth of holistic investigations into their role within doctoral education contexts in the contemporary digital era. Presently, doctoral students, positioned as emerging researchers, engage in research activities utilizing a distinct approach, wherein their educational experiences are intricately interwoven with technological advancements, leading to a profound immersion in online academic environments. This article commences by elucidating the advantageous implications of virtual communities of practice for doctoral students. Following this, the author articulates her viewpoint on the key attributes that contribute to the effectiveness of a virtual doctoral community of practice. Ultimately, the article concludes with a synthesis of conclusions and proposes avenues for prospective research endeavors in this domain.

2 Literature review

2.1 Virtual communities of practice for doctoral candidates/studies

The cultivation of virtual communities of practice holds substantial promise in enriching the doctoral experience through multifaceted advantages. Firstly, the establishment of such communities augments the professional networks available to doctoral candidates, fostering an environment conducive to meaningful collaborations, information exchange, and interdisciplinary discourse. Secondly, the optimization of knowledge management processes within these virtual communities facilitates the seamless dissemination and acquisition of scholarly insights, thereby contributing to the intellectual enrichment of participating doctoral candidates. Moreover, the supportive and collaborative nature of these communities plays a pivotal role in promoting the mental well-being of doctoral candidates, offering a platform for shared experiences, encouragement, and the mitigation of the isolation often associated with the doctoral journey. In essence, the integration of virtual communities of practice serves as a holistic enhancement to the doctoral experience by addressing not only academic aspects but also the social and emotional dimensions of doctoral candidates' endeavors.

2.2 Elevating academic networking and optimizing knowledge management

The advent of the internet and digital technology affords doctoral students expanded opportunities to engage with academically akin peers and to establish enduring collaborative relationships with them. The inherent worth of any body of knowledge or specific domain is underscored by the recognition that individuals possessing requisite knowledge and skills can be considered social capital. The concept of social capital proves valuable when contemplating collaborative virtual learning environments and dispersed communities of practice. Facilitated by technological interventions, the processes of knowledge exchange, dissemination, and evolution have accelerated, thereby refining the overarching landscape of knowledge management within the context of doctoral education (Daniel et al., 2003; Chiu et al., 2006; McLoughlin et al., 2018). Accordingly, doctoral students must accrue this form of social capital as a strategic imperative for the advancement of their professional development and subsequent level of career preparedness upon the attainment of their degrees. In practical applications, there are many types of doctoral virtual communities of practice. Platforms that can be used include the school's Black Board platform, Microsoft Teams and Zoom meetings organized by students themselves, as well as various practice groups privately established by students based on their majors, cultural and linguistic backgrounds, etc. Groups typically use application software on portable technologies, such as WhatsApp, Telegram, etc. These practice groups can effectively extend and supplement what they learn in formal classes and seminars. Further, online space such as Google documents, for example, provides a convenient place for doctoral students to write together, allowing co-journaling to become an online collaboration among researchers.

2.3 Support for the psychological well-being of remote learners

Numerous doctoral students grapple with feelings of alienation and an inadequate sense of belonging. Consequently, they encounter heightened challenges and impediments that exert adverse effects on their socialization processes and the formation of their identities (Schmidt and Hansson, 2018; Waight and Giordano, 2018; Jackman et al., 2022). Nevertheless, various technologies can help solve these issues. Technology can aid doctoral students in overcoming alienation and enhance members' inclusion by providing avenues for communication and collaboration through online platforms and virtual meetings (Carroll and Mallon, 2021; Hammond et al., 2021). For example, access to digital libraries, online courses, and workshops enables flexible learning, while social media and virtual communities offer peer support. Collaborative tools facilitate remote research collaboration, and technology provides mental well-being support such as regular consulting through telehealth services. Flexible learning environments, virtual conferences, and global collaboration opportunities break down geographical barriers. Apparently, as remote doctoral education has gained prevalence in the aftermath of the pandemic, virtual communities of practice emerged as valuable platforms for fostering mutual psychological support among remote learners.

The pressures placed on doctoral students are unique since the work and leisure boundaries of doctoral students are blurry. Compared to the structured curriculum-based undergraduate or Master's, doctoral experience is an intensive research practice and it is characterized by a 'plurality of practices' and 'lack of structure'(Elliot, 2023). In addition, many of them were formerly professionals who suddenly found themselves back to being students, often with added pressures such as family financial and caregiving responsibilities at the same time. These stressful doctoral experiences might cause well-being issues and increase attrition rate (Laufer and Gorup, 2019; McCray and Joseph-Richard, 2020). For relatively young doctoral students, they also face various psychological pressures and burnout. These pressures may come from developing independent research, publishing, and future employment considerations. In addition, unlike a master's program, a doctorate takes several years to earn, which is a great test for remote learners' physical and mental health. Online practice communities can relieve the inner tension of doctoral students, allowing them to regularly share the difficulties encountered along the way, by providing opportunities to study with their peers and other scholars, solve problems together, and share the joy of success.

3 Research questions and research method

3.1 Research rationale, aim, and research question

Considering the transformative impact of virtual communities of practice on doctoral education, there exists a research gap that warrants investigation. The current body of literature acknowledges the importance of in doctoral learning experiences. However, there is a noticeable lack of in-depth exploration regarding doctoral learning within the context of post-pandemic academia. As the landscape of academic learning undergoes dynamic changes in the wake of global events, understanding and documenting these strategies become imperative. Therefore, this research aims to fill this gap by systematically examining the strategies to optimize doctoral learning experiences in the post-pandemic era. The research seeks to provide valuable insights into effective practices for building and sustaining communities of practice online, thereby contributing to the enhancement of doctoral education in contemporary digital academic environments. The research question in this study is: What are the key strategies employed by virtual communities of practice in enhancing doctoral students' learning experiences in the digital era?

3.2 Autoethnography

This autoethnographic study was conducted by the researcher, a current doctoral student immersed in the digital era of academia, who delves into the transformative role of virtual communities of practice in enhancing the doctoral experience. Autoethnography emerges as a robust qualitative research approach, particularly when applied to scrutinizing a reflective diary. This method facilitates a thorough exploration of personal experiences, embracing subjectivity and emotions, and offering valuable insights often overlooked by conventional research methods. By accentuating the cultural context in which these experiences unfold, autoethnography enables researchers to position their reflections within broader societal patterns and historical influences. This contextualization enhances the understanding of the studied phenomenon, fostering a nuanced examination of the researcher's positionality and biases through reflexivity. Furthermore, this approach acknowledges the importance of emotions and embodiment in the research process. Examining a reflective diary through autoethnography allows for a deeper investigation into the emotional dimensions of personal experiences and how these emotions are embodied within the cultural context. In addition, as a form of advocacy, autoethnography empowers researchers to assert their voices, challenging dominant narratives and contributing to a more inclusive comprehension of the studied phenomenon. In essence, employing autoethnography to analyze a reflective diary offers a distinctive pathway for researchers to authentically engage with their own experiences, establishing a profound connection with the subject matter while simultaneously enriching the broader academic discourse (Russell, 1999; Cunningham and Jones, 2005; Marak, 2015; Chang, 2016).

The researcher possessed fluid and dynamic narrative voices during her doctoral trajectory. To deconstruct the competing tensions within the personal self and the social context, the researcher adopted 'multivocality'(Tilley-Lubbs, 2016) that reflects on her subjectivity. The evocative mode was used, and the focus was evoking emotional experiences. The researcher wrote in a descriptive and detailed manner about her experiences in virtual doctoral communities of practice, paying attention to how these experiences shape her learning and identity. The focus was exploring the connections between these experiences and her doctoral learning journey. Some prompts or questions were used for her reflective journals on a weekly or monthly basis: (1) What were the key activities I have engaged within virtual communities of practice recently? (2) How did these interactions or activities contribute to my understanding of doctoral research and learning? (3) What obstacles did I encounter in participating in virtual communities of practice, and how did I navigate them? (4) How did my participation in virtual communities of practice influence my perspectives, beliefs, or practices related to doctoral research and learning?

3.3 Analysis techniques

Going beyond the surface-level content is essential in autoethnographic research. In this study, thematic analysis was chosen to interpret the data, aligning with the narrative review's goal of synthesizing information from various studies. The researcher followed six phases: getting acquainted with the data, creating initial codes, identifying themes, reviewing themes, defining themes, and documenting the findings (Braun and Clarke, 2006). This method is particularly effective in identifying recurring themes or ideas across different studies, aiding the researcher in discerning patterns, trends, and commonalities within the literature. The thematic analysis allows for a more nuanced exploration of broader themes and meanings emerging across studies, going beyond a simple summarization of individual research findings. To align with the reflective diary prompts, the author began by thoroughly reviewing each entry to identify recurring themes specific to each question. After that, key themes were summarized with supporting excerpts.

Moreover, the flexibility and adaptability inherent in thematic analysis are especially valuable in the context of narrative review. This open-minded approach lets themes emerge organically from the data, avoiding the imposition of preconceived categories and contributing to a comprehensive understanding of diverse perspectives within the literature. By applying the thematic method to her research diaries, the author systematically identifies recurring themes, patterns, and insights related to academic networking, knowledge management, and mental well-being. The thematic analysis serves as a robust framework, offering a nuanced understanding of the multifaceted benefits derived from virtual communities of practice. This method allows for a deeper exploration of the transformative role of these communities in the author's doctoral journey, emphasizing the significance of academic engagement, mutual support, and advocacy. The utilization of thematic analysis enriches the article's discussion by delving into the specific dynamics and evolving nature of the virtual communities over the specified time. Through this introspective approach, the author enhances the scholarly discourse on elevating academic networking, optimizing knowledge management, and supporting the mental well-being of remote learners within the context of doctoral education in the digital era.

4 Findings and discussions

After analyzing monthly research journals, the researcher identified certain useful strategies to create, maintain, and develop a sustainable virtual doctoral community of practice. The strategies resonate with the essence of 'competence, autonomy, and relatedness' in self-determination theory (Ryan and Deci, 2020, p. 5), which are closely aligned to advanced scholarly experience such as in the doctoral and post-doctoral contexts (Elliot, 2023, pp. 39–40). Establishing a thriving virtual doctoral community of practice necessitates several key prerequisites. Foremost among these is the imperative for members to collectively embrace a shared and well-defined objective, acting as a unifying force and guiding beacon for the community's cohesion and efficacy. Dynamic leadership is crucial, not just in appointing leaders but in cultivating a culture where leadership roles can be assumed by various members, thus fostering a fluid exchange of ideas and collaborative spirit. Active contribution by each member is pivotal for the community's vitality, extending beyond participation to a commitment to sharing expertise, experiences, and resources to which doctoral students can obtain equal access.

4.1 Define shared objective goals

The researcher noted that her involvement in self-organized online research conferences, seminars, and workshops, particularly those facilitated by small, informal student practice groups, posed challenges in sustaining community longevity due to a lack of shared objectives. She and her fellow researchers frequently encountered numerous WhatsApp and Zoom discussion groups that lacked clear distinctions between academic and social purposes. Devoid of explicitly defined shared objectives and enterprises, the utilization of advanced technologies alone would not suffice to establish a meaningful and productive virtual community of practice (Wenger, 1998b; Ardichvili, 2008; Barnett et al., 2012). Accordingly, without explicitly defined shared objectives and common undertakings, relying solely on advanced technologies would fall short of establishing a meaningful and productive virtual community of practice for doctoral students. The efficacy of technological tools hinges on a foundation of collective purpose and well-defined goals. It is the harmonization of these shared objectives that gives purpose to the utilization of advanced technologies within the virtual community, transforming them from mere tools into enablers of collaborative scholarship. In the absence of a clear and shared direction, even the most sophisticated technological platforms would struggle to foster the depth of engagement and intellectual exchange necessary for a thriving doctoral community.

Therefore, the synergy between technological infrastructure and a collectively embraced mission becomes integral, forming the essential groundwork for a virtual space where doctoral students can collaborate meaningfully, share insights, and collectively advance their scholarly pursuits. For example, if an online dissertation writing community is established specifically for students of the Faculty of Education, it is first necessary to stipulate who can participate (such as final year students of the same faculty), the platform used for each online meeting, and the gathering time. More importantly, the organizers should also set plans and goals at the outset, so that members can understand which aspects of academic writing can be explored and discussed at each gathering, exchange online journals and specific books, as well as conduct research with their links that can be shared with group members. Over time, this online writing community will form a rich and substantial reservoir of shared knowledge, transcending the barriers of time and geography.

4.2 Implement distributed leadership

In 2021, the researcher, along with four to six other doctoral students, initiated the establishment of an online reading club. The group consistently exchanged journal articles, organized progress panels, shared ongoing research, and delved into each other's methodologies. Within these virtual communities, there is not a designated leader; instead, everyone takes turns serving as the meeting chair. This shared purpose and recognition foster a supportive environment, encouraging mutual support among peers and contributing to the student's professional development. Ultimately, the engagement in shared goals and collaborative initiatives creates a sense of belonging, especially during the pandemic and fully online programs in post-pandemic.

Cyberspace offers the potential for dynamic leadership in virtual doctoral communities of practice, where participants are categorized as core or partial members. Doctoral students, with varying levels of engagement, include individuals who assume leadership roles by actively contributing to events, planning, discussions, and decision-making processes. Leaders enhance the cognitive progress of the community of practice by offering members a steady and unified vision of its goals. Yet, depending solely on the leader to guarantee the success of a virtual community of practice can be precarious. Leaders may lack experience in their roles, and even the most enthusiastic ones may benefit from seeking advice. Engaging in a model of distributed leadership plays a significant role in building strong communities of practice, and this type of effective leadership could play a crucial role in the success of online doctoral learning (Bourhis and Duba, 2005; Muller, 2006; Clarkin-Phillips, 2011). For example, when doctoral students from various research societies and practice groups, they can invite prestigious scholars in the field to participate, or school institutions can support students with financial and human resources. However, the long-term operation within the community must achieve the spirit of centralization, social responsibility, and collective learning, rather than being controlled by a few top faculty or specific senior students, who are likely to move on once they graduate leaving a void that needs to be filled. That may, in turn, lead to the collapse of the community.

4.3 Building a conductive collaborative environment

In 2023, the author commenced her contributions to her research center's blog at her university, employing an informal writing style to disseminate research insights to the school's faculty and peers. Furthermore, she established a collaborative Google Document file space for co-editing and writing, engaging in online co-authoring endeavors with fellow doctoral students. Finally, she found that: to build, maintain, and develop a successful virtual community of practice, doctoral students must be provided with a conducive environment to collaboratively cultivate innovative approaches that foster a high level of engagement. These virtual platforms ensure equal opportunities for all participants to articulate their perspectives, promoting an inclusive and participatory atmosphere. This learning model offers doctoral students an unconventional approach to innovation by diverging from traditional top-down methods, creating a supportive environment that accommodates uncertainty and fosters constructive partnerships, and mitigating the impact of power imbalances (Brandon and Charlton, 2011; Botha and Kourkoutas, 2016; Mortier, 2020). The overarching objective is to empower doctoral students to take proactive initiatives in shaping their own learning journeys, concurrently fostering a sense of passion and advocacy within their respective academic institutions.

5 Limitations and future suggestions

5.1 Limitations

The temporal scope of the research diaries, covering a specific period from December 2020 to August 2023, could potentially miss evolving trends and changes in virtual communities of practice. A more extended and continuous observation period is suggested to provide a more comprehensive understanding of the dynamics at play.

Additionally, autoethnography itself is an ethical practice (Ellis, 2007). The main limitation of the autoethnographic study is its individualized and introspective nature. The use of autoethnography may introduce subjectivity and potential bias into the findings, posing a challenge to the study's overall validity. Future research could address this limitation by combining the autoethnographic approach with other research methodologies or triangulation methods to strengthen the credibility of the study. Furthermore, the absence of a comparison group or alternative research approach makes it challenging to assess the unique impact of virtual communities of practice on the doctoral experience compared to traditional methods.

The article predominantly highlights the positive aspects of virtual communities of practice, potentially overlooking challenges or negative experiences that some participants might face. A more balanced exploration of both positive and negative dimensions is recommended to provide a comprehensive view of the intricacies involved.

5.2 Future suggestions

Future research should consider including a more diverse range of participants, representing different disciplines, demographics, and stages of doctoral studies. This would not only enhance the generalizability of findings but also ensure that the benefits and challenges of virtual communities of practice are understood across a broader doctoral student population. Further, conducting longitudinal studies that span the entire duration of doctoral programs is suggested to offer a more in-depth understanding of how virtual communities of practice evolve and impact the overall doctoral experience over time.

Additionally, comparative studies between virtual and traditional communities of practice are recommended to enable a clearer assessment of the unique advantages and disadvantages of virtual platforms in fostering academic networking, knowledge management, and mental well-being. Lastly, the call for further exploration into the professional identity development of doctoral students within virtual learning communities provides an avenue for valuable insights into the long-term impacts on participants' careers and academic trajectories.

6 Conclusion

To encapsulate the main points, three key strategies are identified to enhance doctoral learning by virtual/online communities of practice. To begin with, establishing explicit and shared objectives and common undertakings is crucial for the success of virtual communities of practice. This involves clearly defining the purpose, goals, and direction of the community, particularly in the context of doctoral studies. The synergy between technological infrastructure and a collectively embraced mission is essential for transforming advanced technologies into enablers of collaborative scholarship.

Moreover, dynamic leadership in virtual doctoral communities of practice plays a vital role, with participants categorized as core or partial members. Leaders contribute to events, planning, discussions, and decision-making processes. Depending solely on a single leader may be precarious, so a model of distributed leadership is advocated. This involves engaging individuals with varying levels of experience and expertise to contribute to the success of the community. Distributed leadership can involve inviting scholars to participate, obtaining support from institutions, and ensuring a balance between centralized guidance and collective responsibility to avoid dependence on a few individuals.

Lastly, providing a conducive environment for collaborative learning is essential for building, maintaining, and developing successful virtual communities of practice. Virtual platforms should ensure equal opportunities for all participants to express their perspectives, creating an inclusive and participatory atmosphere. This approach diverges from traditional top-down methods, promoting innovative approaches, accommodating uncertainty, fostering constructive partnerships, and mitigating power imbalances. The goal is to empower doctoral students to take proactive initiatives in shaping their learning journeys. These three strategies collectively emphasize the importance of clear objectives, distributed leadership, and a supportive collaborative environment in enhancing the effectiveness of virtual communities of practice for doctoral learning.

In essence, this article sheds light on the crucial role of virtual communities of practice in enhancing the doctoral experience, particularly in the contemporary digital era where technology intertwines with academic pursuits. The exploration underscores the multifaceted benefits of such communities, ranging from elevating academic networking and optimizing knowledge management to supporting the psychological well-being of remote learners. It emphasizes the importance of clear shared objectives, dynamic leadership, and a conducive environment for collaborative innovation in building successful virtual communities of practice. As remote doctoral education gains prominence, these virtual platforms emerge as valuable tools not only for academic engagement but also for fostering mutual support and advocacy among doctoral students.

Moreover, with an increasing number of doctoral students embracing an academic nomadic lifestyle, the significance of the social situational learning model within virtual communities of practice becomes noteworthy. The author contends that further investigation into this subject is warranted, particularly concerning the professional identity development of doctoral students within virtual learning communities. There is a need to delve into the potential challenges such scholars might encounter during this process and explore effective coping mechanisms. The aspiration is to gain a deeper insight into achieving inclusive practices for doctoral students who are both complex and diverse in this digital era.

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

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Beyond words: investigating non-verbal indicators of collaborative engagement in a virtual synchronous CSCL environment

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In the future of higher education, student learning will become more virtual and group-oriented, and this new reality of academic learning comes with challenges. Positive social interactions in virtual synchronous student learning groups are not self-evident but need extra support. To successfully support positive social interactions, the underlying group processes, such as collaborative group engagement, need to be understood in detail, and the important question arises: How can collaborative group engagement be assessed in virtual group learning settings? A promising methodological approach is the observation of students' non-verbal behavior, for example, in videoconferences. In an exploratory field study, we observed the non-verbal behavior of psychology students in small virtual synchronous learning groups solving a complex problem via videoconferencing. The groups were videorecorded to analyze possible relations between their non-verbal behaviors and to rate the quality of collaborative group engagement (QCGE). A rating scheme consisting of four QCGE dimensions (Behavioral, Social, Cognitive, and Conceptual-to-consequential QCGE) was applied, and non-verbal behaviors during the task were coded based on related research literature. We quantitatively and qualitatively analyzed non-verbal behaviors as indicators of QCGE. The results show that groups use a wide range of non-verbal behaviors. Furthermore, certain non-verbal behaviors are significantly related to specific dimensions of QCGE. These results help to identify relevant indicators of QCGE in virtual synchronous learning settings and thus promote the development of advanced methods for assessing QCGE. Furthermore, the indicators can be discussed as possible anchors for supporting collaborative learning in virtual synchronous groups.

KEYWORDS

CSCL, non-verbal behavior, virtual synchronous learning, quality of collaborative group engagement, virtual learning groups, higher education

Introduction

The future of learning in higher education will have to meet the new demands of future workplaces and changes in society as well as the new corresponding demands of students (Pelletier et al., 2023). Universities must evolve as organizations alongside current global trends and challenges in a complex world (Pelletier et al., 2023). In the time since the COVID-19 pandemic, trends in higher education include hybrid and remote learning settings as an emerging new normal or mainstream, with some universities now even offering purely remote programs (Pelletier et al., 2022). Furthermore, as collaboration is one of the key future skills in the workplace and therefore in higher education (Dishon and Gilead, 2021), group learning is becoming increasingly important. As a result of these current trends, students' future learning will be more virtual (i.e., supported by digital tools) and group-oriented, and thus, computer-supported learning groups are becoming increasingly important in today's higher education. Previous research on computer-supported collaborative learning (CSCL) has shown, on the one hand, that CSCL is a tool for improved learning of content and learner attitudes (Chen et al., 2018) and, on the other hand, a goal in its own right regarding the twenty-first-century skills of the future (Dishon and Gilead, 2021). This new reality of academic learning poses challenges. Although virtual group learning environments can sometimes be inspiring and stimulating, they may also be tedious. Solving study problems or writing or preparing for examinations together in groups can be socially challenging. Wilson et al. (2018) report, for instance, that students collaborating in groups may experience stress, interpersonal conflict, and unequal distributions of effort. Ferri et al. (2020) identified the challenge in virtual synchronous CSCL groups that the settings may reduce the social presence and the quality of social interactions between students. This is partly due to the reduced social cues in computer-mediated communication (e.g., Kiesler et al., 1984), resulting in uncertainties on the socio-emotional level. Adding to the problem is a certain neglect of social interaction quality at the higher education level in the sense that positive and productive social student interactions are often mistakenly taken for granted (Kreijns et al., 2003) and thus underrepresented in academic teaching concepts or lesson planning. Yet, positive social interactions in student learning groups are not self-evident as many failures in daily practice suggest. Or, to put it in other words, group dynamics need to be considered explicitly and supported actively in academic learning. This includes both socio-cognitive and socio-emotional process regulation (Järvelä and Hadwin, 2013), and success depends on complex regulatory processes, as was found in CSCL research (cf. Järvelä et al., 2019). In sum, there is a need and an opportunity to explore CSCL-relevant group processes in virtual synchronous environments. One important group process is the students' collaborative engagement. This collaborative engagement is related to the group's shared regulation (Lee et al., 2015) and based on their collaboration and social interaction (Sinha et al., 2015). More precisely, collaborative group engagement is a key element for CSCL, as it is central to the regulation process (Järvelä and Hadwin, 2013) and plays an important role in academic success (Liu et al., 2022). In consequence, to successfully support positive social interactions, the underlying group processes, such as group engagement, need to be understood in detail. From this, an important question arises: How can group engagement be assessed and supported in virtual synchronous group learning settings? One approach to assessing this multidimensional latent construct could be to explore different indicators on the behavioral level (e.g., non-verbal behavior and verbal communication). Within CSCL, the research concerning the multidimensionality of this construct has been limited (Sinha et al., 2015; Rogat et al., 2022; Xing et al., 2022), while to our knowledge approaches to using behavioral markers like non-verbal behavior are scarce.

Sinha et al. (2015) first introduced an approach to assess the construct of quality of collaborative group engagement (QCGE). The researchers defined collaborative group engagement as a multifaceted, shared, and dynamic core group process mediating group-level relationships between motivation, effort, and learning success (Sinha et al., 2015). They assessed QCGE using an observational approach, in which learning groups were rated at multiple time points during a collaborative learning task. Sinha et al. (2015) present a theoretical and methodological framework that distinguishes four dimensions: (1) Behavioral QCGE is conceptualized as the level of the group's participation and effort invested in the ongoing task. Behavioral QCGE is necessary, but by itself, it does not ensure overall engagement, as students may complete activities without being engaged at the social and cognitive levels. Free riders (Salomon and Globerson, 1989) can reduce the quality of behavioral engagement by failing to cooperate and disengaging other group members. Thus, low Behavioral QCGE would be indicated by being disengaged from the task. (2) Social QCGE is conceptualized as the quality of the socio-emotional interactions, which can be observed by indicators of respectful and inclusive conversation as well as group cohesion and their degree of collaboration. High-quality Social QCGE, which frames tasks as joint efforts, enhances group cohesion, and facilitates task coordination, thereby increasing other dimensions of engagement (Sinha et al., 2015). High-quality Social QCGE also promotes shared understanding within the group (e.g., Dillenbourg et al., 2009). Low-quality Social QCGE, however, can lead to conflict and inequality (Salomon and Globerson, 1989). (3) Sinha et al. (2015) derived Cognitive QCGE from earlier frameworks on multidimensional school engagement (Fredricks et al., 2004). However, there is ambiguity in the naming convention for this dimension in previous research. The term "Cognitive engagement" in this framework could also be referred to as "Meta-cognitive engagement" as it consists of meta-cognitive processes such as task monitoring and socially shared regulation of cognition. More recent approaches to collaborative group engagement use dimensions such as "Meta-cognitive" rather than "Cognitive engagement (Rogat et al., 2022) or "Meta-cognitive engagement" as an additional dimension (Xing et al., 2022). In this study, we based our methodology on Sinha et al.'s (2015) QCGE framework, which is nuanced and theoretically sound. Therefore, we adopted the terms of the dimensions accordingly, which was useful for our purposes. Sinha et al. (2015) conceptualized Cognitive QCGE as the regulation of cognition and tasks in a collaborative group task. Reflecting the collaborative aspect of Cognitive QCGE, the active use of socially shared regulatory strategies (Järvelä and Hadwin, 2013) is central to this dimension. Thus, high Cognitive QCGE is evident in groups jointly regulating their task (i.e., planning and monitoring), whereas low Cognitive QCGE may show a focus on superficial aspects of the shared task. (4) Conceptual-to-consequential (CC) QCGE defines the groups' indication of progressing toward the overarching task goal and how they achieve their learning goals by using evidence or sharing knowledge. As conceptualized by Sinha et al. (2015), CC QCGE is described as student groups that use subject-matter content to solve meaningful problems. High-quality CC is evidenced by groups that provide justifications for their solutions after critically considering alternatives and that connect their ideas to prior knowledge and the larger context of the problem. This can contribute to the development of conceptual understanding in computer-supported collaborative learning (CSCL) situations. The quality of these different dimensions determines the success of the group (Sinha et al., 2015). It is further emphasized that collaborative group engagement is dynamic within groups; hence, there are no "successful vs. failing learning groups" but rather high or low QCGE phases within groups' collaborative processes that can (and must) be regulated (Isohätälä et al., 2020).

Although Sinha et al. (2015) originally applied their construct to a face-to-face setting, it was applied to a setting with virtual collaboration in higher education as well (Altebarmakian and Alterman, 2017). In their article, Altebarmakian and Alterman (2017) report that the virtual learning groups they observed over the course of a semester indicated a fluctuation of collaborative engagement during the stages of their group work, namely, that students showed higher content-based and individual engagement by the end of the semester. The authors argue that this rather individual engagement pattern may be related to the virtual nature of collaboration, which can be "difficult, unnatural, and awkward" (Altebarmakian and Alterman, 2017, p. 8). A possible explanation for this shift from collaborative to individual engagement may be reduced social presence. Social presence can be defined as the "feeling of togetherness" in computer-mediated communication (Hauber et al., 2005, p. 2). Even though modern computer-mediated communication offers high-quality audio-visual remote communication for virtual learning groups, the social presence of peers is still reduced (Hauber et al., 2005), and important social cues are missing concerning non-verbal behaviors (Mottet, 2000). For example, group members can only see their upper body or even only the face, fewer hand gestures, or whole-body movements.

In this context, research on non-verbal behavior has been considered important in both human–computer interaction (e.g., Turan et al., 2022) and CSCL research (e.g., Zahn et al., 2010; Rogat et al., 2022). This research often focuses on kinesics—the non-verbal language of the body, such as head movements, facial expressions, and posture (Burgoon and Dunbar, 2018)—as well as coverbal behavior, which is defined as gestures (e.g., hand gestures or eye contact) that follow speech (Kendon, 2000; Kong et al., 2017). To date, research has also focused on facial expressions (e.g., smiling or gaze direction) as a specific classification of non-verbal behavior that has served as the basis for many of the studies of non-verbal behavior (cf. Ekman, 2017). Systems have been developed that theoretically and empirically assign facial expressions to different affective states of people (e.g., FACS, Ekman and Rosenberg, 1997) as well as systems that link facial expressions to cognitive processes (FEC, Turan et al., 2022). In this paper, we refer to non-verbal behavior to include both coverbal behavior and facial expressions. Non-verbal behavior is important in collaborative group processes because it has several socio-cognitive and affective functions. It is part of a dynamic system of interactions within a social setting, and it underlies social processes such as social evaluations (Patterson, 2019). In addition, members of social groups, including learning groups, have a need to feel verbally and non-verbally validated by others (as conceptualized in social presence theory; Short et al., 1976). Furthermore, non-verbal actions such as head nodding, eye contact, and gestures can be used to communicate group engagement, participation, interest, and mutual reinforcement (e.g., Dunbar and Burgoon, 2005). Technological improvements have allowed researchers to successfully collect and analyze non-verbal behaviors, such as gestures and body posture, thereby increasing knowledge about group processes and collaborative behaviors (Schneider et al., 2021). For example, recent research has found that affirmative non-verbal behaviors associated with technology interactions, such as avatar nodding, have been shown to improve learning motivation and communication processes (Allmendinger et al., 2003), while eye-tracking technology has demonstrated the benefits of joint visual attention (i.e., mutual gaze at specific information on the screen in computer-mediated collaboration) on collaborative problem solving (Schneider and Pea, 2014). In particular, research has also shown that some non-verbal activities, such as hand gestures, smiling, eye contact, and nodding, are positively associated with learning outcomes as well as student and group engagement (e.g., Behoora and Tucker, 2015; Schneider et al., 2021; Paneth et al., 2024).

In other words, non-verbal behaviors provide important information about the emotions of the learners and the quality of their social relationships (e.g., Burgoon and Dunbar, 2018) and can therefore be valid indicators of important group processes such as the quality of collaborative group engagement (QCGE), as recent research suggests (Paneth et al., 2024). It is still open whether future virtual scenarios could be improved by automatic coding of such indicators during collaborative learning, e.g., for tailoring interventions to current processes. Therefore, the construct of QCGE, especially in virtual learning contexts where social cues are not so easy to discover (Ishii et al., 2019), and in relation to non-verbal indicators of it, needs more explanation and clarity from a theoretical viewpoint and new original empirical research. The goal of the study presented in this contribution is to provide new, original results to close this research gap. Precisely, the following two research questions are investigated: (1) How do student groups communicate non-verbally in a virtual synchronous learning setting? (2) Which non-verbal behaviors are indicative of which dimension of QCGE?

Methods

Sample and pilot study

The sample consisted of seven groups of three to four undergraduate students, resulting in $N = 23$ students. The participants, all psychology students, indicated a mean age of $M = 27.36$ and consisted of a majority of female participants ($N = 19$). Half of the participants indicated that they already knew all of the other group members. Twenty seven percent indicated that they knew one other group member, while 27% did not know anyone beforehand. Before conducting the main study, we carried out a pilot study to pre-test the instructions and the technical setup. Therefore, we invited two groups consisting of three members each. The pilot study was satisfying, and we proceeded with the main study.

Context

The study took place in a realistic field setting during an online undergraduate course in applied psychology at a Swiss university. Adhering to common ethical standards (approved by the university ethics committee), students were free to participate in the study without any consequences related to their course performance (like course credits) or to any other factors when they decided not to. Participation in the study did not directly influence course success, and the teacher did not know who participated because the study was conducted independently by research staff (the teacher was not present at any time during the study). The students were recruited as part of the online course. In this online course, which was titled "Cooperation and New Media," the students would learn about the hidden-profile task. Thus, students who signed up for the study could learn about the hidden-profile task by experiencing it themselves. For this study, we used a hidden-profile task that consisted of a "murder mystery."

Murder mystery task

The murder mystery task can be classified as a complex problem and hidden-profile paradigm. Problem-solving and the hidden-profile paradigm are popular methods in CSCL and group research. In such a task, groups are presented with general information (shared information), while each member of the group is provided with additional information (unshared information), that the other group members are not provided with. Thus, the groups need to share their knowledge to optimize their decision-making (Sohrab et al., 2015). The learning objectives of the task consisted of two aspects: First, students could learn about success factors and barriers to virtual cooperation, which contribute to their professional competencies in work and organizational psychology. Precisely because they had to gather individual and group-related experiences in exchanging information and making decisions in virtual groups, then they could reflect on their experiences and integrate this new experiential knowledge with aspects of psychological theory. Second, they learned about the core statements of the theoretical model behind the hidden profile through a practical application, which makes the theoretical and practical implications easier to understand.

Procedure

Participants who signed up for the main study were first informed about the study, its contents, and its objectives by the lecturer. They were informed that they would have the choice to participate in a study on virtual cooperation in the upcoming course. As the task was related to the course content ("learning by doing"), participation in the study was a voluntary learning opportunity. Students who chose to participate in the study (i.e., $N=23$ out of a total of 85 students) had 2 h of the following regular course available to them; students who chose not to participate could use these 2 h for themselves or for studying. Study participants then received further instruction from academic staff. They first received an informed consent form with all relevant information about the study, the voluntary nature of participation in accordance with current ethical guidelines (see above approved ethics vote), and the fact that participation was independent of performance assessment in the module. Because the study was conducted online using a videoconferencing tool, students provided consent via a secure online form. After completing the consent form, they were given detailed instructions on how to proceed with the study. To this end, students were first given extensive instructions on how to proceed in the study and were given the opportunity to ask questions. In addition, group members were assigned different roles during the task: breakout room manager (i.e., securing the gallery view within the breakout session and video recording the online collaboration), whiteboard manager (i.e., ensure the functioning and order within the digital whiteboard), and discussion leader (i.e., keeping track of time and leading the discussion if it gets stuck). As part of the individual preparation phase within the breakout sessions, the students were given detailed instructions on how to carry out their specific roles. The purpose of these roles was to meet the technological requirements of collaborating with the digital whiteboard and video conferencing tool, to ensure time management, and to avoid diffusion of responsibility (Tosuntaş, 2020). We did not explicitly include collaborative roles for the purpose of scripting and scaffolding (Fischer et al., 2013; Vogel et al., 2017), as this was not the main scope of our study. Students were then divided into random breakout groups and asked to solve the "murder mystery" task. Within the breakout rooms, groups were provided with shared and non-shared information about a fictitious murder case and were given 20 min to individually set up their workstations and read the instructions as well as the (partially non-shared) information about the "murder mystery." Then, the group task and the actual information exchange in the virtual group started, and they were given 30 min to reach a consensus and find the "murderer." This part of the study was video recorded, as it was the focus of our observation. As they worked on a solution, they used a digital whiteboard to take notes and document their progress. Finally, the groups were instructed to decide who the murderer was, based on the evidence they had gathered. After completing the task, student groups were instructed to finish and save the video recording independently. They were then given a short online questionnaire to complete individually, asking for demographic information, acquaintance with group members, previous experience with virtual collaboration, and other variables such as enjoyment and interest (IMI, Ryan, 1982), subjective satisfaction with group outcome and learning success, and self-rated collaborative group engagement (QCGE, Paneth et al., 2023). Subsequently, the groups reconvened in plenary, and the study guides solved the "murder mystery." As part of the regular post-study course, students were then debriefed and given the opportunity to reflect on their learning gains from the hidden-profile tasks.

Instruments and materials

The units of interest in this study were the 1-min sequences of collaboration that resulted in $N=197$ sequences that were observed, rated (QCGE), and coded (non-verbal behaviors). We used a *coding* scheme for coding the non-verbal behaviors of the study participants in the learning groups and a *rating* scheme to rate the QCGE in the groups. The schemes will be described in the following sections.

Non-verbal behavior coding scheme

To collect non-verbal behavior data like students' gestures and facial expressions during video conferences, a non-verbal behavior coding scheme was developed and applied. We developed the coding scheme based on an iterative method consisting of a deductive and an inductive approach. In the initial deductive approach, we inferred non-verbal indicators of engagement based on literature about non-verbal communication and social interaction (e.g., Husebø et al., 2011; Mahmoud and Robinson, 2011; Schneider and Pea, 2014;

Behoora and Tucker, 2015; Burgoon and Dunbar, 2018; Rack et al., 2018; Noroozi et al., 2021). For instance, Behoora and Tucker (2015) found that propping the head can signal boredom and therefore presumably disengagement. Subsequently, we scanned the video data for additional frequently occurring non-verbal behaviors of participants completing the study to inductively enhance the coding scheme. The coding scheme was then tested by two trained raters, applying it to a video recording of one learning group from our study. To yield interrater reliability, we calculated *intraclass correlation coefficients* (ICC) for each non-verbal behavior in the coding scheme following the instructions from Koo and Li (2016). The ICC estimates and 95% confidence intervals were calculated by applying the R package irr (Gamer et al., 2019) based on a single-rating ($k = 2$), absolute-agreement, two-way fixed-effects model ICC (2, 1). The ICC was calculated for each code in the coding scheme, and the results are presented in Table 1. The two raters indicated moderate-to-excellent ICC for all but one code. We excluded that code (i.e., scratching of the head or neck area), as that specific ICC indicated poor interrater reliability (ICC = 0.433). The final coding scheme consisted of seven codes (see Table 1). As the QCGE rating scheme was divided into 1-min sequences (see below), we aligned the coding of non-verbal behaviors by also creating 1-min sequences and then asking the trained coders to provide their behavior codes following the instructions. The frequencies of the codes were then counted for each person in each group. This resulted in a dataset with N = 636 rows, consisting of aggregated frequencies of non-verbal behavior for each person within each 1-min sequence, as well as the group ratings of QCGE for each dimension within each 1-min sequence.

Quality of collaborative group engagement rating scheme

To measure QCGE, an observation-based rating scheme was used, originally developed by Sinha et al. (2015), based on their definitions of the four dimensions of collaborative group engagement (Behavioral, Social, Cognitive, and CC). As demonstrated by Sinha et al. (2015) in their study, this rating scheme distinguishes between three levels of QCGE (low, moderate, and high) on each dimension. The rating procedure consists of segmenting transcribed student group conversations into short sequences (time-based) and then asking trained raters to rate QCGE in each of these sequences as low, moderate, or high for each QCGE dimension (see Table 2). In our study, the transcript was segmented into 1-min sequences, resulting in a total of $N = 193$ sequences over all groups. Our rating scheme thus adheres to the original QCGE definitions by Sinha et al. (2015), on the one hand, and, on the other hand, was adapted to the task the students were working on. The rating instructions are presented in Table 2. The rating scheme was tested by two raters applying it to the transcripts of one group. For interrater reliability, we followed the same approach as described above concerning the non-verbal coding scheme. The ICC was calculated for all four QCGE dimensions and is presented in Table 3. The two raters indicated good to excellent ICC for all four dimensions.

Quantitative and qualitative data analysis

In order to answer the research questions, we analyzed our data according to the following mixed-method approach: To get a general insight into our data and answer the first research question, we visualized the variation of the data for the frequencies of non-verbal behavior (see Figure 1). To answer the second research question, we visualized the QCGE ratings and compared the frequencies of non-verbal behavior with the fluctuations of QCGE by visualization (see Figure 2) and statistical modeling. Since the data was based on repeated measures of frequencies of observed non-verbal behavior and hierarchical (i.e., participants were nested in groups), we calculated mixed-effects models with the ratings of each QCGE dimension for each minute as the dependent variable. As the QCGE rating scheme produced an ordinal structure, we ran cumulative-link mixed models with the R package ordinal (Christensen, 2019). We fitted the data with four models, one for each dimension of QCGE. For each model, we defined all the non-verbal behavior frequencies as fixed effects. Since we repeatedly assessed the frequencies over each 1-min sequence and aimed at controlling for sequence effects, we added the sequence as a random intercept. We also modeled the participants and groups with random intercepts and nested the participants in each group to control for individual- and group-level random effects. To counter convergence problems, the approach recommended by Bates et al. (2015) was followed by calculating the

TABLE 1 Coding scheme of non-verbal behavior, mean frequencies and standard deviation per sequence, intraclass correlation coefficients, and confidence intervals.

				95% CI	
Code	Description	*M* (SD)	ICC	Lower	Upper
Propped-up head	Face or chin must be propped on hand	2.02 (1.34)	0.937	0.903	0.959
Hand in front of face	Hand in front of face but no propping	1.70 (1.36)	0.856	0.784	0.905
Head nodding	Vertical nod, no horizontal shake	4.54 (3.28)	0.661	0.515	0.769
Leaning forward	Moving the upper body toward the screen	1.84 (1.26)	0.550	0.375	0.686
Gesturing	All movements with hands, including pointing	0.82 (1.02)	0.855	0.783	0.905
Laughing	Smiling and laughing with and without sound	2.00 (2.34)	0.902	0.852	0.936
Changing of the seating position	Moving the seating position in any direction	2.23 (1.59)	0.619	0.445	0.744

most complex model first and iteratively simplifying and comparing the models. For each dimension, we initially calculated the full model, namely with each frequency of non-verbal behavior per sequence as a fixed effect. From there on, to simplify the model, we removed insignificant (α-level = 0.05) non-verbal behavior fixed effects. We then compared the initial model with the simplified one and continued with the better fit. From there on, we tested the random effects for each model and removed random effects with no variance.

To highlight and further explore the relationships between QCGE and non-verbal behaviors, we conducted a qualitative analysis based on video analysis methods (Zahn et al., 2021) and case analysis methods (Koschmann and Schwarz, 2021). For this purpose, we scanned qualitative data (i.e., transcripts, QCGE ratings, and non-verbal behavior codes) for illustrative sequences (i.e., cases) in which the relationships found between non-verbal behaviors and QCGE dimensions were significant for the purpose of case illustration. More specifically, we selected 10 sequences with the most frequent correlated non-verbal behaviors and 10 sequences with the least frequent correlated non-verbal behaviors. For example, for the positive correlation between high CC QCGE and head nodding (see Results section), we selected 10 sequences in which CC QCGE was of high quality and in which head nodding occurred most frequently. Conversely, for this dimension, we selected 10 sequences in which CC QCGE was low quality and head nodding occurred least frequently. We then carefully reviewed these selected sequences within the recorded video material and made notes on them. This allowed us to fully describe and analyze the narrative within the sequence in terms of the relationships between the QCGE dimensions and the corresponding non-verbal behaviors. Finally, we prepared them as case illustrations, highlighting and describing the interplay between the non-verbal behaviors and the quality of the QCGE dimensions to enhance the results found by our quantitative analysis. Exemplary sequences were then selected for each QCGE dimension to be illustrated in the results section.

TABLE 2 Definition and rating instruction by QCGE dimension, adapted from Sinha et al. (2015).

Dimension	Rating instruction
Behavioral	**High**: No off-task behavior **Moderate**: One member is off-task **Low**: More than one member is off-task
Social	**High**: Equal contribution, respectful tone **Moderate**: One or two members dominate the discourse, respectful tone **Low**: One member dominates discourse, disrespectful tone
Cognitive	**High**: Group indicates a thorough plan which represents the solution to the task (i.e., how to find the murderer) and task monitoring (i.e., timekeeping) **Moderate**: Group indicates an incomplete plan or only task monitoring (i.e., timekeeping) **Low**: Group indicates no structure in their task approach and no task monitoring
Conceptual-to-consequential (CC)	**High**: Evidence is used in discourse; knowledge is shared; discourse is on finding the murderer **Moderate**: Discourse is about connecting knowledge; use of evidence is inconsistent **Low**: Discourse is based on declarative knowledge (facts, no interpretation and sharing of knowledge); use of evidence is inconsistent

Results

The following analyses were conducted with version 4.2.1 of R (R Core Team, 2023) in the R Studio environment (RStudio Team, 2023).

Non-verbal communication

We counted the total frequencies across all non-verbal behaviors (cf. Table 1) and plotted the mean frequencies per non-verbal behavior and QCGE as well as the QCGE rating level (1 = low, 2 = moderate, 3 = high) in Figure 1. We also present the mean frequencies and standard deviation per 1-min sequence in Table 1. Figure 1 shows the differences in mean frequencies between the non-verbal behaviors, the four QCGE dimensions, and the rated QCGE levels. Results show, on a descriptive level, that head nodding occurs more frequently than gesturing. All other non-verbal behaviors occurred in a similar quantity per sequence.

Non-verbal behavior as indicators of QCGE

Figure 2 illustrates the distribution of the QCGE ratings for each group and QCGE dimension. The results suggest that the groups received similar ratings of QCGE for the dimensions of Behavioral and Social QCGE. Across groups, the mean ratings (low = 1,

TABLE 3 Quality of collaborative group engagement (QCGE) rating scheme, mean rating and standard deviation per sequence, intraclass correlation coefficients, and confidence intervals.

				95% CI	
Code	Description	*M* (SD)	ICC	Lower	Upper
Behavioral	On-task/off-task behavior	2.91 (0.29)	1	NA	NA
Social	Inclusion, respectful interaction, collaboration	2.84 (0.37)	0.792	0.591	0.900
Cognitive	Planning, structuring, task monitoring	1.37 (0.52)	0.853	0.701	0.931
CC	Use of evidence, connection of shared knowledge, working on task goal	2.00 (0.79)	0.751	0.520	0.880

For Behavioral QCGE, the agreement between the two raters was perfect; therefore, the confidence intervals and *F*-test results indicate not applicable (NA).

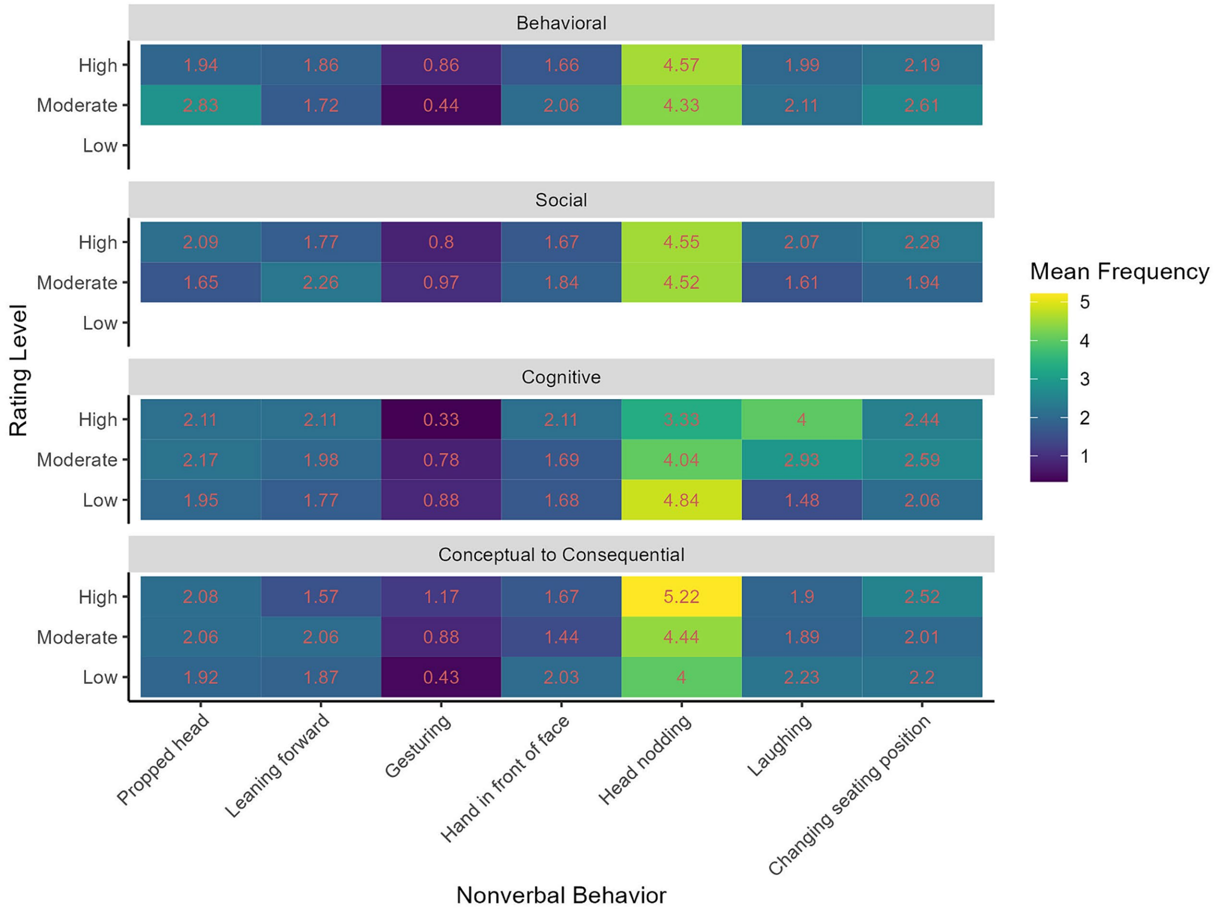

FIGURE 1
Mean frequencies per 1-min sequence for each QCGE dimension level and non-verbal behavior.

moderate = 2, and high = 3) for Behavioral and Social QCGE are higher than Cognitive and CC QCGE (see Table 3). Furthermore, the standard deviations over all groups for Behavioral and Social QCGE are smaller than Cognitive and CC QCGE (see Table 3). The lower standard deviations in the ratings are apparent in Figure 2 for Behavioral and Social QCGE, where it is indicated that for both dimensions there were no low ratings, and in general, low variance with a skew to high ratings.

The results of the descriptive statistics and statistical modeling answered our question about whether the coded non-verbal behavior is indicative of QCGE. In Figure 1, the changes in mean frequencies per rating level show the direction of the relationship between non-verbal behavior and the QCGE rating. For instance, the mean frequency of head nodding increases with higher ratings for CC QCGE. On the other hand, the mean frequencies of the hand in front of the face do not follow a linear relationship with CC QCGE ratings, as the frequency for the sequences with a moderate rating ($M = 1.44$) was lower than for the high ($M = 1.67$) and low ($M = 2.03$) ratings. Further findings are described below in the sections regarding indicators of QCGE.

The results of the cumulative-link mixed model for each of the four dimensions suggest that both random effects of the group and sequence level turned out to enhance the fit of the model. For all four QCGE dimensions, the random intercept term of the individual participant that was nested in the group indicated no variance, and we therefore removed it.

Indicators of behavioral QCGE

The results of the cumulative-link mixed model for Behavioral QCGE (cf. Table 4) suggest that groups where participants were more likely to prop their heads indicated lower Behavioral QCGE than groups with less head propping. The odds ratios indicate a 36% increase in the odds of being rated lower on Behavioral QCGE for each one-unit increase in head propping. Moreover, the random effects seem to explain parts of the variability of the model, supporting the inclusion of random intercepts of the group and the sequence.

A qualitative exemplification of the negative relationship between Behavioral QCGE and a propped-up head is presented in Table 5. In the sequence at minute 17 of Group 4, members indicate higher frequencies of propped-up heads and only a moderate rating of Behavioral QCGE. This sequence was rated moderate on Behavioral QCGE quality, as evidenced by the fact that only two of three group members are on-task and that longer pauses occur during which group members do not appear to be on-task. At the beginning of this sequence, only Group Member 1 participates actively in the

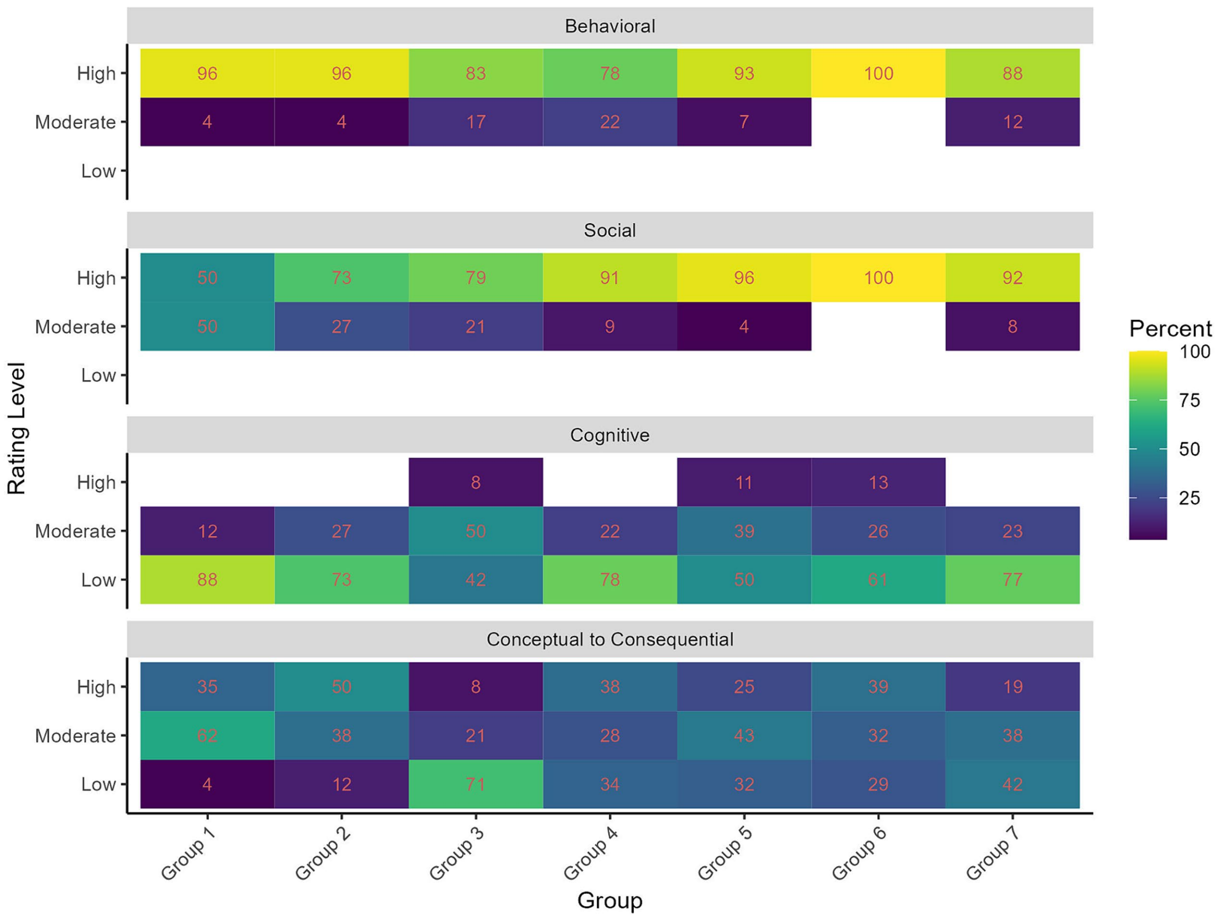

FIGURE 2
QCGE rating distribution categorized by group and QCGE dimension.

TABLE 4 Cumulative-link mixed model for behavioral QCGE.

Predictors	Odds ratios	CI	*p*
Propped-up head	0.64	0.45–0.91	0.013
Random effects			
σ^2	3.29		
$\tau_{00\ \mathrm{Sequence}}$	2.91		
$\tau_{00\ \mathrm{Group}}$	1.51		
ICC	0.57		

CI, confidence interval; σ^2, overall random effect estimated variability; τ_{00}, random intercept variability for group and sequence; ICC, intraclass correlation coefficient.

conversation and thus seems to be on-task, sharing information about the murder case. Only after a break and in the second half of the sequence, Group Member 2 joins the conversation by adding information about the murder case. All three group members propped up their heads, appearing either bored or overwhelmed by the task, which seems to highlight the moderate-quality Behavioral QCGE.

Indicators of social QCGE

The results of the cumulative-link mixed model (cf. Table 6) suggest that no non-verbal behavior relates significantly to Social QCGE. However, from all non-verbal behavior, head nodding indicates a similarly high odds ratio compared to other models we present. Moreover, the qualitative analysis indicates face validity of the relationship between head nodding and Social QCGE. Thus, we included this model in the results. The odds ratios indicate a 20% increase in the odds of being rated higher on Social QCGE for each one-unit increase in head nodding. Moreover, the random effects seem to explain parts of the variability of the model, supporting the inclusion of random intercepts of the group and the sequence.

For example, during a sequence of Group 2 (cf. Table 7), Social QCGE was high, and the group indicated high frequencies of head nodding. As can be seen in the conversation among group members, the group gathers information about the murder case, each reinforcing the other verbally (i.e., “mhm,” “yes,” “correct”) as well as non-verbally (i.e., head nodding). What is further noticeable in this sequence is that group members tend to complete the sentences started by other group members (see the sequence from min. 02:19.0). This shows responsiveness and thus a high-quality Social QCGE (Sinha et al., 2015). This responsiveness is subsequently supported by frequent nodding. Moreover, a nod from one group member is often followed by nods from the other group members (see min. 02:27.2; 02:43.0; 02:49.6). This also seems to have a reinforcing effect, and the nod is often automatically perceived as a “yes” and thus as confirmation of one’s own statement, whereupon conversation continues.

TABLE 5 Section of action transcript of Group 4.

Time	Group Member 1	Group Member 2	Group Member 3
17:13.8	[propped-up head] and then… so that would be a motive somehow, and also that they always have arguments… and with Mr… Hölscher, the money would simply be the motive, or rather he probably did not want to kill him, maybe he just wanted to steal his wallet, but… it then degenerated to an extent….		
17:23.1	[propped-up head]		
	PAUSE	PAUSE	PAUSE
17:26.5			[propped-up head]
17.38.1		I still have the statement of Marion Schmidt	
17:38.4		[propped-up head]	
17:40.3	mhm…		
17:41.2		She said she heard noise at 6.40 a.m.	

TABLE 6 Cumulative-link mixed model for Social QCGE.

Predictors	Odds ratios	CI	*p*
Head nodding	1.20	0.99–1.46	0.070
Random effects			
σ^2	3.29		
$\tau_{00\ Sequence}$	1.07		
$\tau_{00\ Group}$	3.31		
ICC	0.57		

CI, Confidence Interval; σ^2, overall random effect estimated variability; τ_{00}, random intercept variability for group and sequence; ICC, intraclass correlation coefficient.

Indicators of cognitive QCGE

The results of the cumulative-link mixed model for Cognitive QCGE (cf. Table 8) suggest that groups where participants were more likely to laugh or lean forward received significantly higher ratings on the Cognitive QCGE dimension, than groups with less laughing or leaning forward (cf. Figure 1). The odds ratios indicate a 64% increase in the odds of being rated higher on Cognitive QCGE for each one-unit increase in laughing and a 42% increase in the odds of being rated higher on Cognitive QCGE for each one-unit increase in leaning forward. Concerning head nodding, the results suggest that there is a negative relationship to Cognitive QCGE (cf. Figure 1). The odds ratios indicate a 16% increase in the odds of being rated lower on Cognitive QCGE for each one-unit increase in head nodding. Moreover, the random effects seem to explain parts of the variability of the model, supporting the inclusion of random intercepts of the group and the sequence.

The relationship between laughing and Cognitive QCGE is exemplified in Table 9. In this sequence of Group 6, we found high frequencies of laughing as well as a high Cognitive QCGE. It is evident here that the four group members are consistently engaged in task monitoring and planning. When Group Member 1 checks whether the group have gathered all relevant information at the beginning, Group Member 4 reacts by reading her information again, Group Member 3 reminds the group about the remaining time, and Group Member 2 proposes a plan of action, all of which can be characterized as task monitoring activities. In addition, they seem to get along well with each other, as evidenced by multiple laughing from all group members. Here, laughing seems to have a trust-building and loosening function in the sense of an icebreaker. This trust-building seems to motivate all group members to make suggestions for the further planning of the solution of the task and also to critically question the previous task monitoring and to adapt it (see sequence from minute 23:21.2). Group Member 2 expresses that she finds it difficult to collect information because of its arrangement and Group Member 4 responds with a self-critical and reflective statement that she could have done a better job of writing down the information on the shared whiteboard.

Furthermore, the relaxed atmosphere in this sequence of Group 6 allows for jokes about working together, which in turn builds trust. The relationship between laughing and Cognitive QCGE could be explained here by the fact that task monitoring is usually a rather serious matter, and, depending on the group constellation, group members do not always courageously integrate this element into group work. One does not always make oneself popular if one strictly monitors and corrects the processing of tasks. However, if there is a lot of laughing and thus a development of trust and compassion, this can encourage the group members to also include somewhat more serious and perhaps more unpleasant elements, such as task monitoring.

Indicators of CC QCGE

The results of the cumulative-link mixed model for CC QCGE (cf. Table 10) suggest that groups where participants were more likely to nod their heads received significantly higher ratings on the CC Engagement dimension than groups with less head nodding. For head nodding, Figure 1 corroborates this linear relationship. The odds ratios indicate a 14% increase in the odds of being rated higher on CC QCGE for each one-unit increase in head nodding.

Concerning laughing or leaning forward, the results suggest that there is a negative relationship to CC QCGE. The odds ratios indicate a 20% increase in the odds of being rated lower on CC QCGE for each

TABLE 7 Section of action transcript of Group 2.

Time	Group Member 1	Group Member 2	Group Member 3
02:19.0	mhm… And then it's also about the tire tracks….		
02:27.2		[head nodding]	
02:27.3	[head nodding]		
02:28.1		mhm…	
			… that were found.
02:29.9		mhm…	
02:30.0			… which were not yet there on Friday because it was raining….
02:33.4	correct		
02:36.3		right	
02:39.4	and he left after informing Mrs. Schmidt…		
02:43.0			[head nodding]
02:44.4		[head nodding]	
02:47.2			mhm…
02:47.3	… about and um he left then, where the emergency doctor came		
02:49.6			[head nodding]
02:50.1		[head nodding]	
02:54.0	[head nodding]		

TABLE 8 Cumulative-link mixed model for cognitive QCGE.

Predictors	Odds ratios	CI	*p*
Head nodding	0.84	0.72–0.99	0.033
Leaning forward	1.42	1.08–1.88	0.013
Laughing	1.64	1.31–2.05	<0.001
Random effects			
σ^2	3.29		
$\tau_{00\ \text{Sequence}}$	1.59		
$\tau_{00\ \text{Group}}$	1.09		
ICC	0.45		

CI, confidence interval; σ^2, overall random effect estimated variability; τ_{00}, random intercept variability for group and sequence; ICC, intraclass correlation coefficient.

one-unit increase in laughing. Concerning leaning forward, the odds ratios indicate a 24% increase in the odds of being rated lower on CC QCGE for each one-unit increase in leaning forward. Moreover, the random effects seem to explain parts of the variability of the model, supporting the inclusion of random intercepts of the group and the sequence.

The relationship between nodding and CC QCGE is exemplified in Table 11. In the activity transcript, there were high frequencies of nodding. For this group, the initial phase seems to have been successful in terms of high Social QCGE, and trust has been built, which can foster Cognitive and CC QCGE, as stressed by Sinha et al. (2015) and described above (section Indicators of Social QCGE). The group conversation shows a high-quality CC QCGE: group members link individual pieces of information together in such a way that an overall picture emerges. In this way, an attempt is made by the group to find an answer to the overarching question, namely, who the murderer was (see the sequence from min. 07:24.5). Group Members 1 and 2 gather and link pieces of information, and Group Member 3 helps them by asking questions and confirming their statements. These confirmation activities of Group Member 3 occur verbally ("mhm") as well as non-verbally (head nodding).

Discussion

In this study, the non-verbal behaviors of virtual synchronous student groups completing a complex problem-solving task in a CSCL setting were analyzed based on video recordings. Moreover, the quality of collaborative group engagement (QCGE) in these virtual groups was sequentially rated. Using a mixed-methods approach, we investigated two research questions: First, how do the student groups communicate non-verbally in the virtual synchronous learning setting? Second, which non-verbal behaviors are indicative of which dimension of QCGE?

Concerning the first research question, we found that a variety of non-verbal behaviors were displayed with different frequencies (see Table 1; Figure 1): In sum, the non-verbal behavior coded most frequently was group members` head nodding. The non-verbal behavior coded least frequently was gesturing. Other non-verbal behaviors include laughing, head propping, leaning forward, gesturing, putting one's hand in front of the face, and changing seating positions. These were coded at similar frequencies across the behavior categories. Results thus indicate that nodding is a non-verbal behavior that occurs more often in the online-videoconference situation than other non-verbal behaviors, which reflects the synchronous CSCL setting at hand with group members sitting in front of their PCs and cameras and talking about the problem they want to solve while only their upper body parts are shown. Yet, results show, too, that despite the limitations of the camera setting not only head nodding but also other behaviors did occur. This indicates that the groups interacted non-verbally in complex ways besides talking. On this empirical basis with the variety of non-verbal behaviors at different frequencies we found, it is possible to search for non-verbal behaviors that could differentiate regarding QCGE.

Concerning the second research question, we searched for non-verbal behaviors that indicate QCGE, focusing on all the non-verbal behaviors that were found in our study, including nodding, laughing, head propping, leaning forward, gesturing, hands in front of the face, and changing seating positions. To model the relationship between non-verbal behaviors and QCGE, we first descriptively explored QCGE. We found that the groups show different variances in their levels of QCGE. Moreover, dimensions such as Behavioral and Social QCGE indicate a skew toward higher levels, whereas Cognitive

TABLE 9 Section of action transcript of Group 6.

Time	Group Member 1	Group Member 2	Group Member 3	Group Member 4
23:10.5				[laughing]
23:14.1		[laughing]		
23:14.8			[laughing]	
23:15.2			We have exactly 3 min left…	
23:15.2			[laughing]	
23:17.8			[Confused chatter]	
23:18.3		Come on now just say something		
23:18.3		[laughing]		
23:14.8	[laughing]			
23:19.1				I did not write down that much either…
23:21.2				[laughing]
23:25.8		It's just difficult now, because everything is so scattered, you know, it would be more practical if you could put it down and…		
23:32.6	mhm…			
23:34.2		but this way it's slide by slide…		
23:38.3				umm I could have written it down a little bit better, yeah….
23:40.6				[laughing]

TABLE 10 Cumulative-link mixed model for CC QCGE.

Predictors	Odds ratios	CI	*p*
Head nodding	1.14	1.00–1.29	0.048
Leaning forward	0.76	0.60–0.96	0.021
Laughing	0.80	0.64–0.99	0.042
Random effects			
σ^2	3.29		
$\tau_{00\ Sequence}$	2.59		
$\tau_{00\ Group}$	1.06		
ICC	0.53		

CI, confidence interval; σ^2, overall random effect estimated variability; τ_{00}, random intercept variability for group and sequence; ICC, intraclass correlation coefficient.

and CC QCGE indicate a more uniform distribution. We then applied statistical modeling to explore the relationship between the non-verbal behaviors and QCGE. The cumulative-link mixed models suggest that certain non-verbal behaviors significantly relate to QCGE:

(1) For Behavioral QCGE, results show that more frequent instances of head propping indicate a lower quality. This can be interpreted by the assumption that head propping may signal boredom and thus a greater tendency to be distracted or off-task. This is consistent with literature that associates head propping with boredom (Behoora and Tucker, 2015). However, in our virtual synchronous CSCL setting, head propping on the table in front of the webcam may also indicate that an individual is focused on the screen. The group members may be reading something, and in combination with leaning forward, head propping could be misinterpreted as off-task behavior. Nevertheless, the results of our analysis suggest that head propping is associated with lower-quality Behavioral QCGE. However, as the Behavioral QCGE ratings indicate a large ceiling effect, this finding should be taken with caution. Head propping may indicate moderate Behavioral QCGE ratings. However, it is not clear what non-verbal behavior may indicate higher levels of Behavioral QCGE other than lower frequencies of head propping.

(2) Regarding Social QCGE, we found that no non-verbal behaviors relate significantly to this dimension. However, the odds ratio for head nodding at least suggests that more frequent instances of head nodding relate to higher quality. Moreover, the qualitative analysis suggests a certain face validity of this relationship as illustrated in the activity transcript (see Table 7). Therein, the group members ended each other's sentences accompanied by frequent head nodding. Nevertheless, compared to a parallel study we ran investigating CSCL groups in a face-to-face setting (Paneth et al., 2024), the missing significance of the results in this study here is surprising. In the face-to-face setting of the other study, we found that head nodding relates significantly and positively to Social QCGE. Therefore, it is relevant to discuss what could be the reason for the lack of significance in our present study here. First, the low variance in Social QCGE and rather limited data could explain why the analysis does not suggest a relationship here. Second, the results may be due to reduced social cues in the virtual CSCL setting, similar to virtual synchronous communications described by Kiesler et al. (1984) in the theory of reduced social cues. This theory postulates that social cues like head nodding would be less easily perceived under virtual conditions than in face-to-face settings. In theory, one could argue that nodding relates to responsiveness, which is a criterion for high Social QCGE. As a consequence, in our study, group members might have felt less mutual reinforcement and responsiveness even though there was a verbal confirmation (e.g., "mhm," "yes," "ok"). According to recent literature (Hardwig and Boos, 2023), trust in groups

TABLE 11 Section of action transcript of Group 2.

Time	Group Member 1	Group Member 2	Group Member 3
07:24.5		So, they have confirmed that he was at the tennis court at 7 a.m.	
07:30.1		[head nodding]	
07:31.2			Did they confirm that, or did he just say that?
07:32.4		No, they confirmed that, but it's the cause of death, or the time of death could have been already at half past six, that means he could have killed him before he went to the tennis court…	
07:37.0			[head nodding]
07:40.4			[head nodding]
07:47.7	mhm… I read that Schmidt and Mr. Meier live only 10 min away from each other, by car…		
07:47.7			[head nodding]
07:51.6		[head nodding]	

decreases with increasing virtuality. In this respect, it may be particularly important in virtual synchronous learning group settings to build trust, which, in turn, can be supported by head nodding, especially regarding the reduced social presence that students experience in virtual synchronous settings (Ferri et al., 2020). Once "virtual trust" is established, group members can reach their full potential (Kazemitabar et al., 2022), and learning groups are more successful (Gerdes, 2010). This, in turn, is a good basis for the high quality of the other facets of engagement (i.e., cognitive and CC QCGE), which is in line with Sinha et al. (2015), who state that high-quality social QCGE at the outset of a group learning task can support other engagement facets as the task progresses. Even though there may be a lag between utterances, non-verbal behavior such as nodding still accompanies verbal communication, as used in a face-to-face setting. However, there is no evidence that the participants were looking at the videoconference or, therefore, at the non-verbal information the other participants would be signaling. Hence, the question is whether nodding is only a habit from face-to-face interaction and is still used even though the nodding may not be received by the other group members who do not observe the videoconference window. This aspect would be interesting to further investigate in future research.

(3) Concerning Cognitive QCGE, results show that groups that exhibited more frequent laughing or leaning forward have significantly higher levels of QCGE. However, more frequent head nodding indicates lower Cognitive QCGE. Laughing as an indicator of Cognitive QCGE seems counter-intuitive. However, it seems that laughing can function as a facilitator to enhance joint regulation and monitoring. According to the action transcripts, during a task, when a group experiences a comical situation that triggers laughing, afterward the group jointly regulates the emotional outburst. This joint regulation may lead to a "restart" of the group processes and reorientation in the task progress. Therefore, an instance of frequent laughing may be indicative of subsequent higher-quality cognitive QCGE. In addition, as humor helps CSCL groups to lighten serious learning topics and thus make them more manageable (Hovelynck and Peeters, 2003), laughing can serve as a facilitator for the use of regulatory strategies such as planning and monitoring and thus for high-quality cognitive QCGE. Laughing could also be a form of social QCGE. As Sinha et al. (2015) also point out, good group cohesion or a high-quality social QCGE, which can be facilitated by laughing, is an important premise for high QCGE as it is also related to positive socio-emotional processes (Hu et al., 2021). However, laughing could also just be an indicator of off-task communication. Therefore, the subsequent regulation may just be the consequence of the disengagement from the task, which is identified by the laughing of the group members and not facilitated by it. In general, the direction of this laughing-to-joint relationship effect must be further explored and confirmed. In contrast to this result, the positive relationship between leaning forward and Cognitive QCGE is more intuitive. Leaning forward could be understood as a general form of engagement and interest in virtual synchronous settings, as is pointed out by related literature (Behoora and Tucker, 2015). Be it, to spend more focus on what is happening on the computer screen or, in a fashion, to be more rooted in a face-to-face setting, where the signalization of leaning forward could imply the direction of focus for a person in a group, or in this case the video conference window. Finally, head nodding relates negatively to Cognitive QCGE. This result is rather surprising, as one could argue that the nodding behavior could be indicative of co-constructive processes in relation to the regulation effort that is Cognitive QCGE. Thus, nodding would appear to be a function of socially shared regulation (Hadwin et al., 2017; Järvelä et al., 2018). Moreover, in a face-to-face setting, the relationship seems to be indeed positive (Paneth et al., 2024). Therefore, the nodding behavior seems to have a different function in a virtual synchronous environment. Furthermore, it could be argued that during instances of joint regulation and task monitoring, there is more need for verbal discussion than for non-verbal agreement through nodding. Moreover, participants may also engage in task-related behaviors such as overlooking current progress, monitoring the

time left to accomplish the task, or making notes of the discussion. Especially in this virtual synchronous setting, a sequence of higher focus may lead to a higher focus on the task at hand and therefore away from the video conference, leading to less head nodding.

(4) Finally, for CC QCGE, more frequent head nodding goes along with significantly higher ratings. The positive relationship between head nodding and CC QCGE may stem from the higher intensity of discussion during instances of high CC QCGE, which is consistent with related literature suggesting that head nodding fosters a smooth communication process (Allmendinger et al., 2003). The group is attempting to connect and share information to find the answer to the overarching question. In this case, the discussion leads to the formation of a thesis, which is confirmed by the other group members through verbal (e.g., “mhm,” “ok”) and non-verbal (i.e., nodding) statements. It seems that the head nodding has a reinforcing effect on CC QCGE in the sense that the group members feel confirmed and encouraged in their statements and thus have enough trust built to further elaborate their collaboration and deepen the conversation about the murder case. Finally, leaning forward and laughing negatively relate to CC QCGE. One could argue that high CC QCGE occurs more frequently closer to the finalization of the task, where information is shared and a conclusion will be made, which requires a lot of concentration. At the same time, there may be little time left for funny situations, and therefore, less laughing occurs. Over all four QCGE dimensions, the results suggest that different types of non-verbal behaviors have different indications of the four dimensions of QCGE. Most prominently, the non-verbal indicators for Cognitive and CC QCGE are the same, but with opposite directions of the relationship. Specifically, laughing is an indicator of higher cognitive QCGE and lower CC QCGE. Furthermore, leaning forward and head nodding indicate higher CC QCGE and lower Cognitive QCGE. Thus, the combination of these three non-verbal behaviors may distinguish between CC and Cognitive QCGE. Moreover, head nodding can indicate higher Social QCGE but may also indicate lower Cognitive QCGE. From there, different combinations of non-verbal indicators could be used to more reliably indicate the different dimensions of QCGE.

Limitations

This study has its limitations. The sample size would be low for the investigation of group-level differences. However, the use of repeated measurements for both QCGE and non-verbal behavior facilitates that limitation. Nonetheless, the results of this exploratory study should be confirmed, optimally with a larger sample size. Moreover, our correlational analysis restricts us from interpreting the causality of the relationships we have found between non-verbal behavior and QCGE dimensions. Future research could apply a more experimental approach to investigate causality. Based on this research, directed hypotheses could be formulated and tested to confirm the relationships we found exploratively.

Regarding Behavioral QCGE, the rating of the on-task behavior was additionally challenged because the raters were not able to fully deduce from the transcripts whether the participants were on- or off-task. Presumably, some participants were just reading something on the screen while still being on-task. This limits the validity of the Behavioral QCGE rating and may also explain the low variance and skew toward higher ratings. Moreover, for Social QCGE, the study setting may incentivize pro-social behavior and social desirability effects and therefore fewer instances of low or moderate Social QCGE scores, which could also impede the study of this variable. Concerning the QCGE framework, in other research we report issues with the QCGE rating scale, which can lead to skewed Behavioral and Social QCGE (Paneth et al., 2023). We assume that the rating scale may not be optimal for standardized study settings where groups are incentivized to consistently be engaged during the task. This resulted in a lower variance for Behavioral and Social QCGE, making it difficult to model this variable.

Implications

In general, the results of this study show how student groups communicate non-verbally in a virtual CSCL setting through a set of complex non-verbal behaviors, and they show that certain non-verbal behaviors are related to different dimensions of QCGE. Similar findings were reported in a prior study by our research group, conducted in a face-to-face setting (Paneth et al., 2023, 2024). What are the implications of the results?

Regarding theory building, the results on the non-verbal behavior of CSCL groups in videoconferencing add to our understanding of QCGE as a complex construct in need of further theory development (see also Rogat et al., 2022). The results from our study show that QCGE “in the field” and even in a virtual setting is not only located in the thinking and verbal communication of learners but manifests itself in their bodily communication (non-verbal behaviors, e.g., differentiating between Cognitive and CC), and this extends and substantiates the construct of QCGE in line with both theories of social interaction (e.g., Burgoon and Dunbar, 2018) and embodied cognition (Varela et al., 2017; Gallagher, 2018). This, in turn, is important for further theory building, future research on QCGE, and, generally, investigations aiming at better understanding and assessing group processes.

Regarding methodology, we present potential new measures for QCGE (i.e., non-verbal indicators) in line with our prior multimethod approach (Paneth et al., 2023). Moreover, based on our findings, we can suggest that certain non-verbal indicators for QCGE could be potentially automatically measured to assess collaborative engagement more accurately. Head nodding has already been established as a non-verbal behavior that can automatically be classified (Nguyen et al., 2012). The authors successfully applied a multimodal approach based on a combination of visual and auditory signals. In addition, leaning forward and laughing would presumably also be feasible to automatically detect in video recordings. With modern open-source frameworks like MediaPipe (Lugaresi et al., 2019), models can be trained to identify smiling faces and body poses from video recordings. With the combination of laughing, leaning forward, and head nodding, an automatic differentiation between Cognitive and CC is promising. Regarding Social and Behavioral

QCGE, more research should be conducted to generate more data and variance to explore the intricacies of these two dimensions. Then, non-verbal behavior could be identified that would differentiate between the QCGE dimensions and the levels within. Combined with automatic transcription of verbal communication, verbal indicators of QCGE (Jeitziner et al., 2023, In preparation)[1] (Zheng et al., 2023) could add more information to build a holistic measure of QCGE.

This leads to practical implications of our findings for educational use. This granular multimethod measurement and possibly automated measurement processes would increase the chances of applying targeted and effective interventions for virtual synchronous CSCL groups. While we are careful not to overgeneralize and overinterpret our findings (see section Limitations), we do suggest supporting the design of virtual learning environments in line with related research. As suggested by CSCL researchers (e.g., Järvelä and Hadwin, 2013), students need regulation in CSCL, either through teacher or lecturer feedback to groups to support socially shared regulation of learning or "from the outside" through CSCL tools, e.g., in the form of scripting or scaffolding (Vogel et al., 2017). A detailed knowledge of QCGE and how it is expressed in non-verbal behaviors could support this, e.g., through real-time analysis and feedback systems (Deeva et al., 2021; Zheng et al., 2023) that automatically analyze and mirror groups' QCGE and allow students and teachers to become more aware of group processes and thus regulate them (Hmelo-Silver and Jeong, 2023). Our results could lead to important original insights for the design of such feedback systems. Some initial, more far-reaching implications include that practitioners who use virtual group learning settings are aware of the QCGE dimensions (Behavioral, Social, Cognitive, and CC) and the importance of non-verbal indicators. If practitioners knew more about the complexities of collaborative group engagement, for example, through teacher education or training, they could differentiate what student collaborative engagement is and how it manifests and develops their own interventions.

In conclusion, this study contributes to the development of the assessment of QCGE in virtual synchronous CSCL groups and could serve as a basis for real-time feedback to promote QCGE during virtual synchronous courses at universities. The analysis suggests that the non-verbal behavior of CSCL groups in videoconferencing may be a promising aspect for further investigation to understand and assess group processes.

Data availability statement

The anonymized data and analysis scripts supporting the findings of this study are available at the Open Science Framework (OSF) repository via the following link: https://osf.io/kngdx/.

Ethics statement

The studies involving humans were approved by Ethics committee, School of Applied Psychology, University of Applied Sciences and Arts Northwestern Switzerland. 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

LJ: Data curation, Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing, Investigation, Software. LP: Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Investigation, Project administration, Resources, Visualization. OR: Conceptualization, Funding acquisition, Supervision, Writing – original draft, Writing – review & editing, Resources. CZ: Conceptualization, Funding acquisition, Project administration, Supervision, Writing – original draft, Writing – review & editing, Resources.

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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

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How do different goals affect students' internal collaboration script configurations? Results of an epistemic network analysis study

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Introduction: Research has suggested that how learners act in CSCL environments is considerably influenced by their internal collaboration scripts. These scripts are knowledge structures that reside in an individual's memory and consist of play, scene, scriptlet, and role components. In its "internal script configuration principle," the Script Theory of Guidance suggests that as learners work in a CSCL environment, these components are dynamically (re-) configured, and that this (re-)configuration is influenced by the goals of the individual learner. However, this principle has not yet been tested empirically.

Methods: In this study, upon entering a CSCL environment, we therefore experimentally manipulated the goals that students pursued while learning. In one condition, we induced learning goals while in the other condition, no goals were induced. A total of 233 pre-service teachers collaborated in dyads on the task to analyze an authentic, problematic classroom situation by aid of educational evidence. We measured their internal scripts both at pre-test (i.e., before collaboration and before goal induction) and post-test (i.e., after collaboration and goal induction), focusing on the scriptlet level.

Results: Results show that goal induction had no effects on the kinds of scriptlets participants selected during collaboration. However, results from Epistemic Network Analysis show that learning goal induction led to significantly different combinations of scriptlets (especially to more relations between scriptlets that are indicative of pursuing learning goals) than no goal induction. Furthermore, participants from the learning goal induction acquired significantly more knowledge about educational theories and evidence than students from the control condition.

Conclusion: This study is among the first to provide direct evidence for the internal script configuration principle and demonstrates the effectiveness of inducing learning goals as a scaffold to support students' knowledge acquisition processes in CSCL.

KEYWORDS

computer-supported collaborative learning, script theory of guidance, achievement goals, epistemic network analysis, higher education

1 Introduction

A vast amount of research over the past 30 years has demonstrated that computer-supported collaborative learning (CSCL) can be a powerful method to facilitate learning in different educational contexts (Chen et al., 2018; Radkowitsch et al., 2020; Stahl and Hakkarainen, 2021; Vogel et al., 2017; Yang, 2023). During CSCL, learners are encouraged to actively participate in the learning process through negotiating and discussing ideas with peers (Roberts, 2005). That this really is the case is corroborated by meta-analytic findings that demonstrate the effectiveness of CSCL across a broad range of disciplines (e.g., Jeong et al., 2019; Xu et al., 2023) and digital technologies (e.g., Sung et al., 2017), yielding positive effects of CSCL both on domain-specific knowledge and cross-domain competences (for an overview, see Kollar et al., 2024).

The way learners actually learn and collaborate in CSCL environments can be considered as being influenced by two factors that mutually interact with each other: (a) the design of the learning environment and (b) the individual group members' learning prerequisites. With respect to (a), research on CSCL has accumulated a considerable number of insights (Miller and Hadwin, 2015; Vogel et al., 2017), for example on the effects of different kinds of scaffolds on the quality of learning processes and outcomes. Yet, with respect to (b), empirical research seems to be scarce (Hsu et al., 2008; Prinsen et al., 2007). In this article, we therefore focus especially on this latter topic.

One prerequisite that has received attention in CSCL research is the learners' internal collaboration script (Kollar et al., 2006). Internal collaboration scripts are cognitive structures of individuals that guide them in the way they understand and act in collaborative learning situations (Fischer et al., 2013). They are assumed to consist of different knowledge components (play, scenes, roles, and scriptlets) that are dynamically configured in learners' memory. This assumption has been formulated in the Script Theory of Guidance (SToG) by Fischer et al. (2013), which also is concerned with how external scripts (scaffolds that structure a group's collaboration process through specifying, sequencing, and distributing learning activities and roles among its members) affect collaboration and learning. In total, the SToG proposes a total of seven principles that describe the roles of internal and external scripts during CSCL. With respect to learners' internal scripts, one central principle of the SToG refers to the assumption that the configuration of internal script components that learners (typically unconsciously) select to make sense of a given CSCL situation is influenced by the current goals of the learners (internal script configuration principle).

Surprisingly though, this principle has hardly been tested empirically so far. In fact, learners can have very different goals when collaborating, and it is not clear how exactly these different goals affect the configuration of their internal collaboration scripts and subsequent knowledge acquisition (Pintrich, 2000a). Following a well-known distinction from Achievement Goal Theory (Dweck and Leggett, 1988; Elliot, 2005), some learners may engage in learning and studying with the goal to arrive at a deep understanding of the learning material (learning goal). Other learners, in contrast, may rather engage in learning and studying because they pursue the goal to demonstrate how competent they are (performance goal). For this reason, in this paper, we investigate how different goals, respectively their induction, are related to learners' internal script configuration and knowledge acquisition in the context of CSCL.

2 Literature review

2.1 Components of learners' internal collaboration scripts in CSCL according to the script theory of guidance

The term CSCL covers many different instructional methods, all of which have in common that "peers interact […] with each other for the purpose of learning and with the support of information and communication technologies" (Suthers and Seel, 2012, p. 1). Based on recent meta-analyses, CSCL offers a vast potential to support learners' academic achievement, for example, because it promotes students' knowledge acquisition or skill development (Chen et al., 2018). From a theoretical point of view, there are many potential benefits of collaborative learning, even without the support of digital technologies, which include academic (e.g., fostering knowledge acquisition and critical thinking), social (e.g., developing social skills) or affective-motivational aspects (e.g., reducing anxiety; see Johnson and Johnson, 1989; Laal and Ghodsi, 2012).

However, there may also occur problems during collaborative learning, such as individual learners contributing little to collaboration or learners not actually working together but rather splitting the tasks among themselves (Roberts, 2005; Salomon, 1992). Especially under such circumstances, the collaborative learning process may be supported by the use of digital technologies, for example by providing tools to organize learners' ideas and contributions, to provide resources, or guidance to structure the collaboration process (Stahl et al., 2006; Suthers and Seel, 2012).

A theoretical approach that conceptualizes such guidance is the Script Theory of Guidance (SToG; Fischer et al., 2013), which focuses on one particular kind of guidance that has received very much attention in CSCL research: so-called "external collaboration scripts." External collaboration scripts provide group learners with guidance on the kinds and sequence of activities and roles they are supposed to take over during collaboration, often supporting their execution via prompts or sentence starters. SToG, however, assumes that what actually happens during collaboration is not only influenced by such external collaboration scripts, but also by the learners' internal collaboration scripts.

According to the SToG, internal collaboration scripts are configurations of knowledge components in the learner's cognitive system that determine their understanding and acting in a given collaborative situation. Based on Schank's (1999) dynamic memory approach, a basic tenet of the SToG is that internal scripts consist of configurations of four different kinds of script components (see Figure 1): (a) The "play" component includes knowledge about the kind of the situation an individual experiences, e.g., a discussion held in a chat forum or the joint writing of a blog post. Once a learner has (consciously or unconsciously) selected a specific "play," this "play" then connects a set of (b) "scenes." Scenes refer to the person's knowledge about the different situations that typically make up the play. In a discussion, for example, a learner's "discussion play" might include a scene in which the group collects information to develop

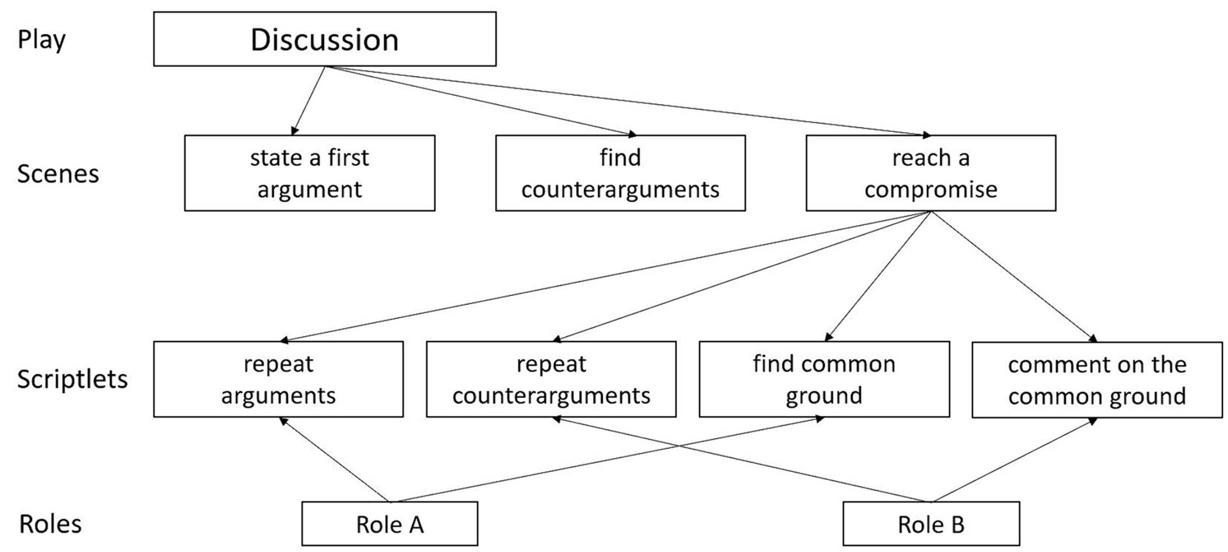

FIGURE 1
Example of an internal collaboration script of a learner during a discussion. Only a few examples of possible scriptlets are shown. Theoretically, every scene is connected to a specific set of scriptlets.

arguments, while another scene might be to exchange arguments. Once a certain scene is activated, the person also has expectations on what kinds of activities are typically part of that scene. Knowledge about the kinds and sequence of the activities that are likely to occur during that scene, are then represented in so-called (c) "scriptlets." Therefore, scriptlet components describe the learners' knowledge about sequences of activities within particular scenes (Schank, 1999). In the scene "reaching a compromise," for an exemplary learner, the first scriptlet might refer to the activity "summarize the most important arguments," while for another learner whose internal script might include the same scene, the first scriptlet in that scene might refer to the activity "define what would count as compromise." Finally, learners hold knowledge about different kinds of (d) "roles," i.e., about the question what kinds of activities are likely to be taken over by what person in the given collaborative situation. Similar to a theatre play, roles may extend over several scenes and include several activities.

2.2 The internal script configuration principle within the script theory of guidance

A central assumption of the SToG is that through experience, learners acquire a range of different plays, scenes, scriptlets, and roles, and that these knowledge components are dynamically combined in each new situation, depending on the individual's perception of the current situation, and on the goals they pursue in that situation. This idea lays the foundation of the so-called configuration principle of the theory. Literally, this principle states that "How an internal collaboration script is dynamically configured by a learner from the available components to guide the processing of a given situation, is influenced by the learner's set of goals and by perceived situational characteristics" (Fischer et al., 2013, pp. 57–58).

As described, the internal collaboration script consists of different knowledge components that refer to collaborative learning situations that are considered. These components are assumed to be very flexible in the way they are combined with each other. This means that in any situation, a learner may select different plays, scenes, scriptlets, and roles available in memory that – from their subjective perspective – are promising to make sense of the current situation. Even small changes in the situation and changing requirements can result in a quick (and very often subconscious) adaptation and reconfiguration of the internal collaboration script components. For example, certain tool features such as a flashing cursor might indicate an opportunity to enter a text, making learners' selection of a scriptlet "enter text" more likely than if there was no such flashing cursor (Fischer et al., 2013; Kirschner et al., 2008; Schank, 1999).

Yet, not only situational characteristics (i.e., external factors) may influence a learner's internal script configuration, but also personal characteristics may do so (i.e., internal factors). As formulated in the internal script configuration principle, this refers in particular to learners' goals. Thus, learners' current set of goals can, on the one hand, influence the *selection* of script components, i.e., plays, scenes, scriptlets, and roles. This means that the learner is likely to choose or act out those script components that appear as most useful to pursue their current goals, resulting in an engagement in activities that are conducive to reaching those goals. Simultaneously, scriptlets that refer to activities that are not in line with the current goals are inhibited. For example, if a learner notices that their learning partner does not seem to exert effort during collaboration, and if they have the goal to get the task done anyway, they may de-activate scriptlets that would guide them to ask their learning partner for input and replace this scriptlet by a scriptlet "solve the task alone." On the other hand, goals may also influence the order of the scriptlets of a learner's internal script (i.e., how these different activities are *sequenced*). For example, if a learner's dominant goal is to do well on a subsequent multiple-choice exam, they might first select a scriptlet "solve items of the test exam," and only later select scriptlets that might help them reach a deeper understanding of the learning material (e.g., "discuss how the different concepts relate to each other" or "jointly develop examples for the application of the information." In contrast, a learner who is in the same situation, but whose primary goal is to arrive at a deep understanding of the learning material might select the reverse order of scriptlets and start with more deep-level learning activities and use the scriptlet "solve items of the test exam" only afterwards.

As Fischer et al. (2013) point out, a study by Pfister and Oehl (2009) provides (indirect) evidence for the influence of goals on the configuration of learners' internal collaboration scripts. This study investigated how goal focus, task type, and group size influence synchronous net-based collaborative learning discussions. For this purpose, they varied the goal focus of the learners: in one condition, participants should take on an individual focus (i.e., they received rewards based on their individual performance), while in a second condition, they should take on a group focus (i.e., they received rewards based on their group's performance). Results indicated that learners with the group focus used more supporting functionalities of the tool (e.g., the possibility to mark what previous chat message one's own message refers to) than learners with the individual focus. Fischer et al. (2013) interpret this finding in a way that the different foci of the learners led to a (re-)configuration in their internal scripts, as represented in learners' use of different tool functions.

However, a couple of limitations of this study and of Fischer et al.'s (2013) interpretation need to be noted here. First, the (re-) configuration of the internal script is only inferred indirectly (from the use of a certain feature by the learners), rather than measured directly. To do that, it would be necessary to apply methods that indicate the kinds of internal script components and provide insight into their sequential nature. Second, the authors of the study did not examine how the internal script of the learners was structured. Therefore, it is also not possible to assess to what extent this script and its components actually reconfigured during collaboration. Third, "goal focus" was experimentally manipulated by providing rewards either for individual or for collaborative performance. In addition, the SToG does not offer an in-depth conceptualization of the concept of learners' goals (Stegmann et al., 2016). While a "goal focus" is certainly one way to think about goals, research on Achievement Goal Theory (e.g., Elliot and Fryer, 2008) has focused on goals that have been shown to have even tighter relations to learning processes and outcomes. This research will be discussed in more detail in the next section.

2.3 Learners' goals during CSCL

Goals influence students' learning processes. From a theoretical perspective, they describe a standard by which learners can assess their learning progress and initiate regulatory processes accordingly (Pintrich, 2000b). Goals that a learner pursues in learning and performance contexts are referred to as achievement goals. They describe the reasons why learners engage in competence-related behavior (Elliot, 2005; Elliot and Fryer, 2008). Even though more nuanced goal typologies have developed over the years (e.g., Bardach et al., 2022), at a global level, achievement goal theory distinguishes between two types of goals. Firstly, in a given situation, learners may pursue so-called *learning goals*, which means that learners engage in learning because they are motivated to improve their competence. Secondly, they may also have *performance goals*; for learners with these goals, it is particularly important to engage in learning in order to demonstrate their performance or to outperform others (Heyman and Dweck, 1992). With respect to the dichotomy of learning goals and performance goals, empirical research has often shown positive relations between learning goals with various favorable learning processes and outcomes (Hulleman et al., 2010; Payne et al., 2007). For example, students who pursue learning goals have been reported to be likely to persist on difficult tasks, to use deep level instead of surface level learning strategies, and (though not consistently, see Darnon et al., 2007) reach high levels of achievement (Meece et al., 2006). When learners pursue performance goals, in contrast, they typically rather use surface-level learning strategies (Payne et al., 2007), which in turn can be helpful to solve easy academic tasks but can be detrimental when more difficult tasks are posed (Utman, 1997). These findings indicate that different achievement goals may lead to different learning processes and outcomes.

In terms of CSCL, research also investigated strategies specifically using social interaction as means to learning. It found that the more students have mastery goals, the more they tend to seek help (Karabenick and Gonida, 2018; Ryan and Pintrich, 1997) and ask for feedback (Cellar et al., 2011; Payne et al., 2007; VandeWalle and Cummings, 1997). Students with strong mastery goals also prefer other students with mastery goals as teammates (Barrera and Schuster, 2018). Therefore, we can expect students to engage the more in regulating collaborative learning, the more they pursue mastery goals. And indeed, Greisel et al. (2023) found that students intended to execute more different strategies directed at the self-, co-, and socially shared level during collaborative learning, the more mastery goals they had. In contrast, performance goals were not related to help-seeking and asking for feedback (Cellar et al., 2011; Payne et al., 2007; Senko and Dawson, 2017). Instead, students with high performance goals engage more in self-handicapping (Senko and Dawson, 2017), and feedback seems to diminish their performance (VandeWalle et al., 2001). Thus, they seem to be more concerned with their impression than their learning in social circumstances. However, in small collaborative learning groups at least, they do intend to engage in socially shared regulation but not co-regulation (Greisel et al., 2023). Furthermore, a study by Giel et al. (2021) also suggests that the compatibility of learners' achievement goals affects collaborative learning outcomes. For example, the results indicate that the degree of compatibility of group members' mastery goals is linked to engagement, whereas the degree of incompatibility is related to performance, highlighting the importance of examining students' achievement goals in collaborative learning processes (Giel et al., 2021). From these findings, we conclude that different achievement goals prepare students for different behaviors during collaborative learning.

At a cognitive level and in the context of the SToG, these differences should be represented by differences in the configuration of learners' internal collaboration script, i.e., the knowledge they activate regarding the kinds and sequences of activities that are likely to occur during collaboration. While hypothetically, learners have different internal script components (in this case, scriptlets) available in their dynamic memory that would enable them to engage in the collaboration process, they (consciously or unconsciously) select those scriptlets that fit their personal goals the best and disregard those that do not (Stegmann et al., 2016). For example, a pronounced learning goal might encourage learners in a collaborative situation to select scriptlets that lead them to ask more questions or ask for feedback from their peers. Thus, these learners could select scriptlets leading them to engage more actively in the collaboration process in order to acquire more knowledge, and omit or postpone others, for example, the scriptlet "agree with learning partner." In contrast, learners with pronounced performance goals might be more likely to select scriptlets that are related to impression management techniques as they might want to only appear competent, for example by using subject-specific language very deliberately (Greisel et al., 2023). In turn, they might, for instance, omit the scriptlet "ask for feedback," in order to avoid being perceived as incompetent. This, in turn, might also imply that (the induction of) different achievement goals within CSCL could influence students' knowledge acquisition. Yet, empirical evidence on these issues seems to be missing so far.

2.4 Research questions and hypotheses

In sum, evidence from the field of CSCL, but also from research on achievement goals, indicates that different goals of learners may influence how learners act in collaborative learning. On this basis, the SToG argues that learners' goals in CSCL lead to specific configurations of different script components (plays, scenes, scriptlets, roles) in the learners' cognitive systems, both with respect to the kinds of scriptlets that are selected, and with respect to the sequential organization in which they are combined with each other. However, so far there has been little research investigating this configuration and the actual change in the internal script as a function of the presence or absence of different achievement goals. Moreover, to date, there is a scarcity of research examining the impact of such goals on knowledge acquisition within the context of computer-supported collaborative learning. Therefore, in the present study, we actively manipulated learners' goals either in the direction of an actualization of learning goals or of performance goals or no goal induction and investigated the effects of this manipulation on their internal collaboration scripts (more precisely, the scriptlets) when working on a CSCL task.

Our first research question was: Does the induction of different kinds of achievement goals (no induction vs. learning goals induction vs. performance goals induction) influence the configuration of the internal collaboration script? We hypothesized (H1) that learners from the three conditions would select different scriptlets to guide their collaboration. Furthermore, we assumed that not only the selection, but also the sequential organization of scriptlets would differ depending on whether or what kind of an achievement goal is induced (H2).

Additionally, to date, there is only limited research on how prompting specific achievement goals during collaborative learning within the tool influences students' knowledge acquisition. Thus, we wondered whether the induction of different goals would affect the knowledge students would acquire as an outcome of their collaboration. For this reason, our second research question was: Does the induction of learning vs. performance goals vs. no goals affect students' knowledge acquisition in a collaborative task? Based on research on achievement goals (e.g., Hulleman et al., 2010; Meece et al., 2006; Payne et al., 2007), we hypothesized that the induction of learning goals would lead to a higher knowledge acquisition than when no goals would be induced (H3). Since previous research on performance goals indicates a relatively mixed picture, we only anticipated that the performance goal condition would differ from the control condition (H4) regarding students' knowledge acquisition.

3 Method

3.1 Participants and design

A total of $N = 233$ pre-service teachers participated in the study. They were on average 22 years old ($M_{Age} = 22.3$, $SD_{Age} = 2.3$), mostly female (72%) and in their fifth semester ($M_{Sem} = 5.0$, $SD_{Sem} = 1.1$). They were enrolled in a teacher education program for elementary school teachers, middle school teachers, high school teachers, and secondary school teachers of various subjects. The study was embedded as a compulsory part of a course in educational psychology for pre-service teachers. Their task was to analyze an authentic, written case that described a problematic classroom situation and a teacher's efforts to solve those problems. All students within these courses were invited to participate in the additional scientific data collection. However, the students were free to decide whether they wanted to participate and suffered no disadvantages if they decided against it. Students who decided to participate received no reward for their participation. The potentially available sample was therefore determined by the sizes of the courses that were available for data collection.

We conducted a sensitivity analysis with G*Power [3.1.9.7] to assess the effect size that was realistically detectable with our sample size. Since one group was later excluded (see Section 4.1) only two groups remained with 71 and 72 students, respectively. We calculated the sensitivity analysis with an α-error probability set to 0.05 and desired power set to 0.80. For an ANOVA with one between-subject factor with two levels and one repeated measurement with two time points, the analysis revealed that an interaction effect with Cohen's $f = 0.12$ could be detected, indicating a sufficient likelihood to detect small to moderate interaction effects. For a t-test comparing two independent groups, the analysis indicated that an effect size of Cohen's $d = 0.47$ could be detected, indicating a sufficient likelihood to detect moderate effects.

Students worked on the task in the learning management system Stud.IP. To support their collaboration, they used a collaboration tool "coLearn!." This tool serves to structure collaborative learning with external collaboration scripts by giving instructors the opportunity to assign, sequence, and distribute learning activities and roles, to specify prompts, and to provide tasks and learning materials. To investigate how different achievement goals impacted their internal collaboration script configuration, we established a 1 × 3 between-subjects design with the conditions "induction of learning goal," "induction of performance goal," and a control group (no goal induction). The conditions differed in that the instructions within coLearn! included prompts that highlighted the respective goal. More specifically, for example, participants in the learning goal conditions were told that completing the learning task would be very important in order to expand their skills. In contrast, participants in the performance goal condition were told that their performance would be evaluated by their instructor (see Table A1). Lastly, participants in the control condition did not receive any such information about the goals that were to be pursued. Participants were randomly assigned to dyads and to one of the three conditions mentioned before.

3.2 Procedure

During pretest, we measured students' initial internal collaboration scripts and knowledge of the theoretical concepts that would be addressed during case analysis (i.e., the Cognitive Load Theory by Sweller, 2011, and the ICAP framework by Chi and Wylie, 2014). For three weeks, the students then worked in pairs using "coLearn!." In week 1, they were instructed to individually analyze a case vignette that described several problematic teacher actions (e.g., prompting students to only watch other students recording a video without any other further instruction; prompting students to integrate items in their videos that are not conducive to the learning goals) during her lesson, using one of two scientific educational theories: Cognitive Load Theory (Sweller, 2011) or the ICAP framework (Chi and Wylie, 2014). The case vignette was 421 words long and did not contain any information on the lesson's content (see Figure 2). The educational theories were presented as texts explaining central elements of the theories, supported by examples. The length of the texts was comparable (Cognitive Load Theory: 806 words, ICAP framework: 800 words). In week 2, these analyses were swapped between the students within a dyad, and the students were instructed to evaluate the analysis of their respective partner and to expand on it with the help of the respective other theory. In week 3, the students received the evaluation and elaboration from their peer and were asked to use it to revise their original analysis. After this three-week collaboration phase, we conducted a manipulation check by asking the participants whether, during the use of the tool, (1) it was particularly important to develop their competencies (learning goal), or (2) to achieve a high performance (performance goal). Moreover, the students' internal collaboration scripts and knowledge about the theories were measured again.

3.3 Goal induction

As described, the two goal conditions differed from each other with respect to the presentation of statements in coLearn!. Each week, a new page with instructions and text fields was displayed in the tool. In addition to specific instructions regarding the case analysis that were identically presented in the control group, the prompts highlighted a specific goal. In the *learning goal* condition, after instruction, the task was labeled as "important in order to improve one's own competencies and to successfully cope with problems in later professional life." In addition, working with the tool was explicitly framed as a learning opportunity in this condition. In contrast, in the *performance goal condition*, it was stated that the task was "important in order to achieve good grades." In addition, working with the tool was framed as an "important opportunity to prepare for exams," and it was stated that tutors would check the assignments later (see Table A1).

3.4 Dependent variables

3.4.1 Internal collaboration scripts

In order to assess the learners' internal collaboration scripts, prior to using the collaboration tool, in the pretest participants described how they would generally carry out a collaborative analysis of a problematic classroom situation. Based on a synopsis of typical

FIGURE 2
User interface of the tool "coLearn!". In the right area, the case vignette, educational theories, and instructions were displayed. Depending on the specific role of each student, the tool provided either a text about the Cognitive Load Theory (Sweller, 2011) or the ICAP framework (Chi and Wylie, 2014).

collaborative activities (Csanadi et al., 2018), they were given a list of 40 activities (e.g., "asking questions," "reflecting on the theory" etc.) to choose from, representing different scriptlets that could be carried out as part of such a collaboration (see Table A2). The participants were instructed to drag and drop the activities they would perform from the list and put them in the order in which they would perform them. In this way, we captured their internal collaboration scripts regarding a collaborative case analysis considering the kinds of scriptlets and their specific sequence. In the posttest, participants were instructed to select and arrange activities from the same set of activities, again using drag-and-drop and arrange them according to how they actually carried them out during collaboration. Afterwards, we conducted an expert survey to categorize the activities that the students could select. For this purpose, nine experts from the field of educational psychology who are well-versed in the area of collaborative argumentation and, on average, had been working in related research for 4 years (*Mdn* = 3.5) were asked to categorize the activities. To do this, they should assess whether they would associate them with a learning goal orientation, performance goal orientation, both, or neither of them, in the context of conducting a collaborative case analysis. If over 50% of the experts indicated that a specific activity could clearly be assigned to one of the two goal orientations, that activity was categorized accordingly. In this way, 16 out of the total of 40 activities were classified as typically related to learning goals and 8 as typically related to performance goals (see Table A2). For the remaining activities, no clear consensus was reached, or the researchers assigned the activity either equally to both or none of the goals. Subsequently, for the pre- and the post-test separately, we calculated a total score for each participant by coding whether the students selected a specific activity (1) or not (0).

3.4.2 Achievement goals

To ensure that there were no pre-existing differences in goal orientations between the groups, students were surveyed their goal orientations prior to the intervention (Daumiller et al., 2019). They were required to answer four items each to assess their learning goal orientation (e.g., "When using the plug-in, developing my competencies is particularly important to me," Cronbach's $\alpha = 0.92$), and performance goal orientation (e.g., "When using the plug-in, achieving a good performance is particularly important to me," Cronbach's $\alpha = 0.80$).

3.4.3 Knowledge

During pre- and post-test, students were required to answer a total of 48 items in the form of multiple-choice questions to assess their content-specific knowledge about the theories that they were supposed to apply to the cases. They had to decide whether they agreed with each of the four options based on a preceding question and received a point for each correctly selected answer. The items were formulated based on the theoretical texts that the students were given to use during their case analysis, thus addressing aspects of the ICAP framework (Chi and Wylie, 2014; 20 items) and the Cognitive Load Theory (Sweller, 2011; 28 items). For instance, a question concerning the Cognitive Load Theory was, "What are potential sources of extraneous load during the processing of multimedia representations?." The options for answers below included, for example, "Background music in animations" (correct) and "Prompts to self-explain the learning material" (incorrect). Based on the correctly answered questions, a percentage was calculated, allowing the students to achieve a total score between 0 and 1 in the pre- or posttest, respectively.

3.5 Statistical analyses

To test whether the configurations of participants' internal collaboration scripts differed between the selected scriptlet categories (H1), we conducted a mixed ANOVA for the sum of scriptlets in each category as dependent variable. The condition represented the between-subjects factor (learning vs. performance vs. control), whereas time was used as within-subjects factor (pre- vs. posttest).

Regarding the potential difference in the sequential organization of scriptlets (H2), we conducted an Epistemic Network Analysis (ENA; Shaffer et al., 2016). ENA is an innovative approach for measuring, illustrating and understanding co-occurrences of activities in sequential data. It describes a body of techniques to detect and quantify relations between elements of coded data and visualizes them in network graphs, which display the structure and strength of connections between codes. For each student, the co-occurrences of their selected activities were accumulated by using a moving window that goes through the indicated activity sequences and determines, which activities in the sequence were occurring in the same temporal context and are consequently positioned at a close distance in the data (Shaffer et al., 2016). In the present analysis this window was set to 4 activities, meaning that the algorithm looked for co-occurrences between an activity and the three activities that preceded it. Since, overall, participants reported an average of 16 activities ($M = 15.85$, $SD = 5.20$) in the post-test, we chose a window size as small as possible which still allowed for meaningful co-occurrences of learning activities. As we aimed to compare students in different experimental groups, the analysis further accumulated co-occurrences of activities for students per experimental group as the unit of analysis. The resulting cumulative adjacency matrices are converted into adjacency vectors and normalized to transform frequencies of co-occurrences into relative frequencies. Using a dimensionality reduction approach (singular value decomposition), the original high-dimensional vector space is rotated to identify those dimensions that explain most variance in the data. The result is a multidimensional network model that can be depicted as two-dimensional network graphs.

In the two-dimensional network graphs, the activities are represented as gray nodes, with the relative size of the nodes indicating the relative frequencies of activities. The nodes are connected by colored lines (also referred to as edges), with the thickness of the lines representing the relative frequencies of co-occurrences of activities (i.e., relative strength of their sequential connection). Accordingly, instead of interpreting the absolute thickness of lines, it is relevant to compare the thickness of lines in comparison to the other lines. To facilitate comparisons between the different experimental groups, ENA can subtract one group's network from the other group's network, allowing for the identification of the most significant differences between two networks. The resulting difference in the two networks' edges are then visualized as a comparison graph, which we will mainly focus on in our interpretation for the purpose of the group comparison. In the comparison graph, thicker lines signify larger disparities in the intensity of a connection, while thinner lines reveal smaller differences in connection strength. The color of each line designates which of the two group's network possesses the stronger connection.

Additionally, ENA maps what is called a centroid of a network. It represents the network as a single point in the projection space. Similar to a center of mass of an object, the centroid of the network graph is constituted by the arithmetic mean of the edge weights of the network model that are allocated according to the network projection in space. Hence, the centroid position can be interpreted similar to a group mean: closer located centroids indicate similar networks of the two groups, whereas centroids that are located more distant represent rather different networks of the two groups.

The calculation of centroids also allows for the statistical comparison of multiple networks. For this purpose, the network model is rotated such that systematic variance in the groups' differences is shifted to the one dimension in the network space, which is why the two group's centroids are then aligned with the x-axis. This enables performing a t-test to evaluate whether there are significant differences between the two groups' networks. Subsequently, in the case of significant differences, researchers can visually inspect the subtraction network (see above) to identify which connections differ between the two networks (Shaffer et al., 2016). Before the analysis, we dropped the four least frequent activities ($n < 10$ in pre- or posttest). Two further activities were dropped after the first analysis which were not connected to the rest of the network and represented outliers.

To assess whether students in different experimental conditions gained a different amount of knowledge between pre- and posttest, we conducted a mixed ANOVA (H3 and H4). Analogously to the first hypothesis, the condition (learning vs. performance vs. control) represented the between-subjects factor and time (pre- vs. posttest) represented the within-subjects factor.

4 Results

4.1 Preliminary analyses

In order to perform a manipulation check, we conducted an ANOVA to determine whether there were differences between the groups concerning the perception whether it was particularly important to develop their competencies or to achieve a high performance while using the collaboration tool. The manipulation check revealed that there were only significant differences as expected between the learning goal condition and the control group regarding the perception that it was particularly important to develop competencies when using the tool, $F(2, 230) = 5.03$, $p < 0.001$, $\eta^2 = 0.04$. Thus, there were no significant differences between learning goal condition and performance goal condition or performance goal condition and control group. Also, there were no significant differences regarding the perception that it was important to achieve a high performance between the performance goal condition and control group or learning goal condition and performance goal condition, $F(2, 230) = 1.27$, $p = 0.28$. Therefore, in the following analysis, only the learning goal condition and the control condition will be compared.

To ensure that these differences do not reflect *a priori* differences in students' achievement goals, we investigated their general goal orientations prior to the intervention. A *t*-test demonstrated that there were no significant differences in terms of learning goal orientation ($t(152) = 0.68$, $p = 0.50$) or performance goal orientation ($t(152) = -0.60$, $p = 0.55$) between the learning goal condition and the control condition.

4.2 RQ1: effects on goal induction on students' internal script configuration

4.2.1 H1: effects of goal induction on scriptlet selection

To test H1 regarding the selection of the scriptlets in the pre- and posttest, we conducted two mixed ANOVAs, one for each category of activities we had identified based on the expert ratings described above. There was no significant interaction between time of measurement and condition with regard to learning goal associated activities, $F(1, 143) = 0.17$, $p = 0.68$; $\eta^2 = 0.001$, or performance goal associated activities, $F(1, 143) = 0.32$, $p = 0.57$; $\eta^2 = 0.002$. Thus, there were no significant effects of condition on the kinds of activities (scriptlets) participants mentioned to have used during collaboration from pre- to posttest. However, there was a significant main effect of time regarding the learning goal associated activities, $F(1, 143) = 122.51$, $p < 0.001$, $\eta^2 = 0.46$, indicating a significant decrease of the sum of reported learning goal associated activities between pre- and posttest, but not in terms of the performance goal associated activities, $F(1, 143) = 0.000$, $p = 0.99$, $\eta^2 < 0.01$. There was no significant main effect of group, meaning that both groups did not differ significantly regarding the learning goal associated activities, $F(1, 143) = 0.01$, $p = 93$, $\eta^2 < 0.01$, or performance goal associated activities, $F(1, 143) = 0.006$, $p = 94$, $\eta^2 < 0.01$.

4.2.2 H2: effects of goal induction on scriptlet configurations

To evaluate H2, we conducted an ENA to compare the networks of scriptlets in each condition in the posttest (learning vs. no goal induced). The mean centroid value for scriptlets in the epistemic network of the learning goal condition was significantly different from the mean centroid value in the network of the control condition, $t(131.53) = 9.56$, $p < 0.001$, Cohen's $d = 1.67$, indicating that the true difference in means is not equal to 0. Consequently, the results indicate that there were significant differences with respect to the sequential organization of the scriptlets selected between participants from the learning goal induction condition and the control condition.

Subtracting the networks (Figure 3) revealed that the network of the control condition (red), in comparison to the learning goal condition (blue), displayed stronger connections between the scriptlets "read theory," "read case," "identify problem" and "relate theory and case" as well as "summarize." In addition, there were comparatively stronger connections between the scriptlets "set goal" and "explain case" as well as "read case" and "read instructions." In contrast, the learning goal condition showed a much stronger connection particularly between the "explain case" and "link knowledge" scriptlets. There were also comparatively stronger connections between the scriptlets "describe case" and "link knowledge." Overall, it thus appears that in the control condition, a variety of different activities were more strongly interconnected, whereas the learning goal condition showed stronger connections between a smaller number of activities.

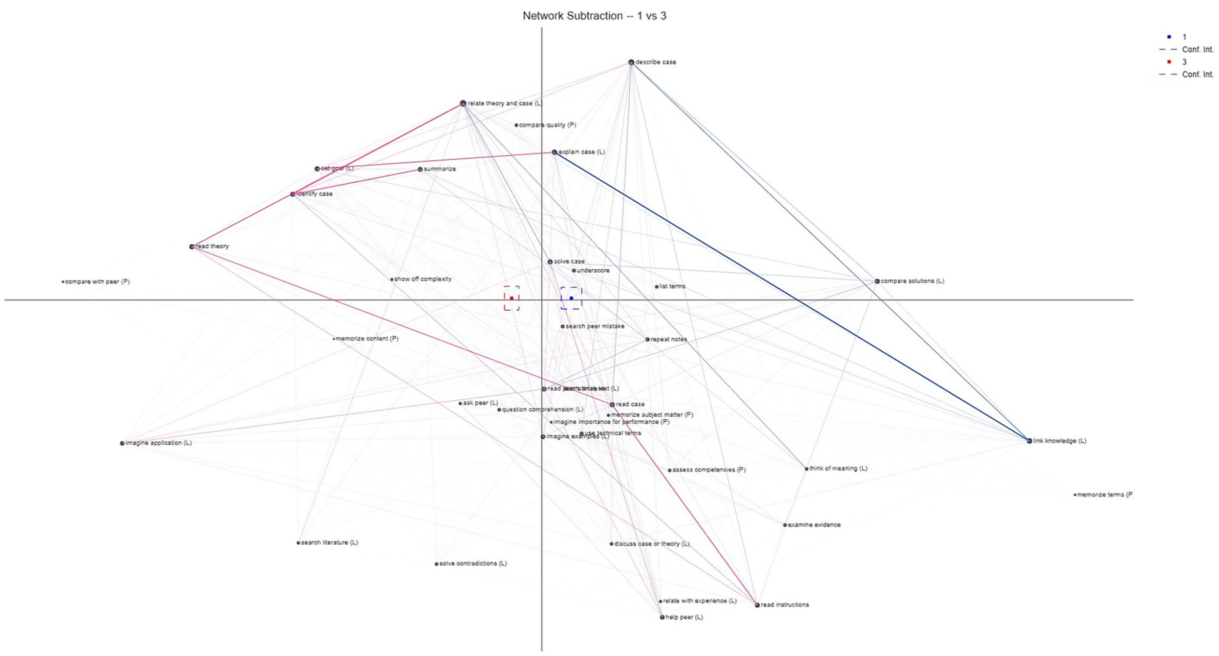

FIGURE 3
Epistemic network analysis of the difference between the networks of scriptlets in learning goal condition (1/blue) and control condition (2/red). Abbreviations following some activities represent their expert ratings (L = activities associated with learning goals, P = activities associated with performance goals).

To gain an exploratory understanding of how the activities could be evaluated in terms of the induced goals, we combined this analysis with the expert ratings by adding the abbreviation "(L)" for activities that, according to the expert ratings, are typically associated with learning goals, or "(P)" for activities that are typically associated with performance goals. First, it is important to note that the control condition did not involve any form of goal induction, meaning that no particular goal orientation was expected to emerge in this condition. Consequently, in theory, students can be expected to more or less equally engage in activities related to learning and performance goals. Furthermore, as described earlier, some activities could not be clearly attributed to either or any of the mentioned goals, which is why these activities were not annotated at all (see Figure 3). Additionally, overall, more activities were identified by the experts as associated with learning goals than with performance goals. However, it can be noted that, despite the overall lower number of strong connections in the learning goal condition, at least with regard to the link between the scriptlets "explain case" and "link knowledge," two scriptlets associated with learning goals were strongly interconnected in this condition. In contrast, the scriptlets "read theory," "read case," "read instructions," "identify case" and "summarize," for which the results of the ENA show stronger connections in the control condition, could not be clearly associated with a specific goal by the experts. Yet, in the control condition, there also appeared strong connections between the scriptlets "set goal," "relate theory and case," and "explain case," which are likewise associated with learning goals. Therefore, it could be summarized that in the control condition, numerous associations were observed, involving both learning and performance goal-related scriptlets, as well as scriptlets that could not be clearly categorized. In contrast, the learning goal condition appears to feature fewer associations, yet these seem to be predominantly linked to learning goal-related scriptlets.

4.3 RQ2: effects of goal induction on knowledge acquisition

With respect to RQ3 and H3, respectively, Figure 4 illustrates the development of students' knowledge acquisition between pre- and posttest for the learning goal and control condition. Descriptively, students in both conditions displayed a slightly higher test score in the posttest than in the pretest. Moreover, the control group already exhibited a higher score in the pretest compared to the learning goal condition.

Regarding H3, a mixed ANOVA revealed that there was a significant interaction effect between time and condition, $F(1, 143) = 5.28$, $p = 0.02$, $\eta^2 = 0.04$, indicating a small to medium effect (Cohen, 1988). However, there was no simple main effect of condition in the pretest ($\eta^2 = 0.014$, $p = 0.15$) or posttest ($\eta^2 = 0.004$, $p = 0.46$), which probably can be attributed to the crossover interaction (Sawilowsky and Sawilowsky, 2007). For this reason, we additionally conducted a t-Test with the difference in test scores between pre- and posttest as the dependent variable to compare the knowledge acquisition between the two groups. This yielded a significant difference with respect to the knowledge acquisition between the groups, with the difference in the test score being approximately 3,52% higher in the learning goal condition (95%CI [0.005, 0.065]), $t(143) = 2.30$, $p = 0.01$, Cohen's $d = 0.38$. The simple main effect of time was significant in the learning goal condition, $F(1, 71) = 23.76$, $p < 0.001$, $\eta^2 = 0.25$, but not in the control condition, $F(1, 72) = 1.08$, $p = 0.30$, $\eta^2 = 0.02$.

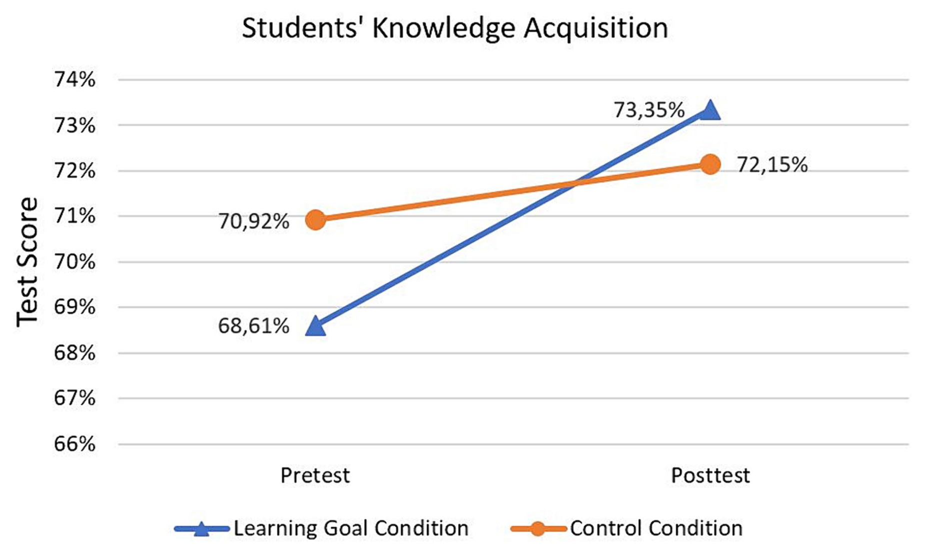

FIGURE 4
Means of students' test score in pre- and posttest for the learning goal and control condition. The test score is calculated based on the percentage of correct answers out of 48 items. Therefore, the theoretical minimum and maximum is 0 and 100%, respectively.

5 Discussion

The StoG (Fischer et al., 2013) assumes that learners' goals affect the configuration of learners' internal collaboration scripts. However, to the best of our knowledge, this principle has not yet been tested directly empirically. Therefore, we investigated whether the induction of different achievement goals (Dweck and Leggett, 1988) affects the selection/change (H1) and sequential organization (H2) of the scriptlets that pre-service teachers select regarding a specific collaborative task and their subsequent knowledge acquisition (H3).

Regarding H1, we assumed that the induction of different kinds of achievement goals would affect the kinds of scriptlets learners select during collaboration. By means of the expert rating, the activities could be categorized as to whether they are typically associated with a learning goal orientation or performance goal orientation. Subsequently, for each of these two kinds of activities, we calculated a sum score for both pre- and posttest. Using these scores as dependent variable, we examined whether there were differences between the conditions. Based on the manipulation check, which only showed significant differences between the learning goal condition and the control condition, we narrowed down the analyses to just these two conditions and dropped the performance goal induction condition from the analyses. Our analyses did not indicate significant differences with respect to the change in the selected activities between the learning goal and control condition from pre- to posttest. However, the significant main effect of time indicates an influence of the collaborative case analysis regardless of a specific condition and might therefore be attributed to the task and the actual collaboration itself. Consequently, the hypothesis that the induction of a learning goal (as compared to no goal induction) would have an impact on the selection of scriptlets must be rejected, at least on the basis of the evidence regarding H1. In contrast, previous studies have suggested that learners engage in different activities (e.g., Pfister and Oehl, 2009) or strategies depending on their goals (e.g., Greisel et al., 2023). However, it is important to note that these studies examined the change or application of specific activities; in contrast, the present study involved categorizing a wider range of activities using expert ratings and investigating the changes within these categories. Therefore, on the one hand, this may mean that the change regarding the *kinds* of selected scriptlets is quite resistant to induced goals (at least with regard to learning goals). Moreover, a meta-analysis on goal induction (Noordzij et al., 2021) shows that to induce learning goals, it is important to relate this goal to a specific task (e.g., "While performing this task, it is your goal to… by …"). In comparison to this, the prompts used in our study may have been too vague. Thus, the goal induction may have been too weak at this point to have caused a change in the selection of kinds of scriptlets. On the other hand, these varying findings also raise the question of whether the assessments of the experts and learners might differ regarding which scriptlets are particularly useful for specific goals. For example, it is conceivable that some scriptlets are not considered particularly conducive to learning by students (e.g., based on their prior knowledge) and therefore are not used, whereas experts may categorize them as beneficial for learning (presumably based on their scientific knowledge). Future studies could therefore explore if and how the assessments of both diverge or, moreover, the basis on which learners come to use certain scriptlets in order to uncover the underlying mechanisms of students' scriptlet selection.

With respect to H2, however, and in contrast to the selection of scriptlets, the results of the ENA showed significant differences in the configuration of the scriptlets between the learning goal induction condition and the control condition in the posttest. This means that the participants in the different conditions specified significantly different sequences of scriptlets they would apply in a new collaborative case analysis. This partially supports our hypothesis and can be seen as evidence in favor of the configuration principle, at least regarding the differing sequence (if not the type; see H1) of scriptlets. Through ENA, we can see that particular scriptlets were mentioned more frequently in a specific order by the groups. As described, learners with pronounced learning goals are particularly motivated to engage in learning because they focus on improving their competence (Heyman and Dweck, 1992). Given this context and the additional combination of this analysis with the expert ratings, it could be assumed that especially cognitive and elaborative learning activities (e.g., "explain case," "compare solutions," which were also associated with learning goals by the experts) are carried out when learning goals are induced. Such activities imply that learners construct new knowledge that goes beyond the scope of the existing learning materials (Chi and Wylie, 2014). In contrast, the ENA revealed that when no goals are induced, learners display a rather mixed picture with many different connections, which, nonetheless, also encompass activities related to learning goals. Yet, it can be noted that a part of these relatively strong connections among the activities "read theory," "read case" and "read instructions" tends to reflect more superficial activities, with learners primarily engaged in merely receiving information. These activities, however, were not clearly assigned to any specific goal by the experts, likely because they could be interpreted as an inherent part of the instruction within the collaboration tool, independent of a specific goal of the learners. After all, further research is needed to examine which types and configurations of activities are most beneficial for a case analysis. However, the results of the ENA might suggest very goal-specific configurations which seem to largely be in line with results from research on achievement goals pointing to their context specificity (Daumiller, 2023).

To answer the second research question regarding the effects of goal induction on knowledge acquisition, we conducted a mixed ANOVA with the test score as dependent variable. Again, we excluded the performance goal condition due to the manipulation check, which is why the fourth hypothesis cannot be addressed. However, with respect to H3, we found a significant interaction effect for students' test scores. In line with our hypothesis and prior research indicating favorable outcomes of learning goals (e.g., Hulleman et al., 2010; Payne et al., 2007), the induction of a learning goal had a stronger positive effect on students' knowledge acquisition than the students carrying out the same tasks without goal induction. This highlights the significance of goal inductions not only on the configuration of learners' internal scripts, but also on the knowledge they acquire through collaboration. This is remarkable, especially considering that the intervention in the current study was relatively simple, incorporating only relatively few goal-related prompts into the case analysis process. Although the present study identified only a small to moderate effect on knowledge acquisition, it is possible that more frequent and specific prompts could amplify this effect.

6 Limitations

Of course, this study does not come without limitations. First, it is important to note that in the instrument we used to assess students' internal scripts, they selected from a range of activities, which means that they were not free in their choice of scriptlets, as certain activities were already suggested to them. It is quite conceivable that the students would also name other or further activities, possibly even more so if none were specified to them beforehand (Csanadi et al., 2021). Future studies could therefore include interviews, for example, to more validly capture script components and elicit their (re-) configuration more adequately (März et al., 2021).

Second, a type II error might have occurred. The effect sizes regarding the *selection* of scriptlets (H1) were very small ($\eta^2 < 0.01$). In contrast, the sensitivity analysis indicated that the sample size was sufficient to detect effect sizes of at least Cohen's $f = 0.12$ ($\eta^2 = 0.014$). Thus, future studies should use larger samples to ensure greater statistical power.

In this context, it is also important to emphasize that in the ENA, the initial internal collaboration script of the learners was not taken into account and therefore only the differences in the subsequently reported activities can be determined, but not in comparison to the initial internal collaboration script. Thus, it would also be worthwhile considering a more process-oriented approach and, for example, monitoring activities in real time or using a thinking aloud approach in order to record the activities carried out as validly as possible.

Furthermore, only scriptlets were examined as internal script components in this study. Thus, our data did not allow for a separation of different internal script components beyond the scriptlet level. It is conceivable that learners already have had very heterogeneously elaborated scripts and therefore also responded differently to the external script (Kollar et al., 2007; Vogel et al., 2017). In this regard, the interaction of learners' internal script levels and/or prior collaboration skills and goals might be an interesting research gap to look at in future studies.

A further potential limitation could be the presence of a selection bias. Although the study was incorporated into a university course of a large teacher education program, the decision to participate in data collection was voluntary and not rewarded. Consequently, the study may have attracted specifically students with pronounced learning goals and interest in their own competence development. Conversely, stronger performance goals could also have been induced because students felt that participation was still required as the study was part of the lecture. Nonetheless, it is important to point out that the present study found no significant differences in students' learning or performance goal orientations between the groups that might account for the differences in the analyses.

Moreover, we only manipulated one type of goal in this study successfully. This also raises the question of how to effectively induce performance goals. For instance, it is conceivable that performance-related goals become particularly decisive when learners are more clearly aware that they are evaluated by others (Urdan and Mestas, 2006). For this reason, the asynchronous and non-graded case analysis in this study may not have sufficiently created this impression. Beyond performance and learning goals, there are many different kinds of achievement goals learners may have that could also be taken into account (e.g., avoidance goals; Daumiller, 2023). On top of that, research on achievement goals not only suggests that goals can be very situation-specific, but learners can also pursue multiple goals. This might also indicate that different and multiple goals might be particularly important in different collaboration scenarios (e.g., relational goals). Future research should therefore also include or control for further goals of the learners.

7 Conclusion

In sum, the results of the ENA indicate that learners' internal collaboration scripts are configured differently depending on the induction of a learning goal. These results therefore support the StoG's configuration principle that learners' internal scripts are configured depending on learners' current (situational) goals. This constitutes an important step in the empirical validation of the StoG and contributes to our understanding of the way internal collaboration scripts are configured in real situations.

7.1 Implications for theory and research

These findings offer several implications for theory and research. First, collaborative learners seem to be more likely to adapt only the sequential organization of their internal collaboration scriptlets to a goal than to add or omit scriptlets from different categories. We conclude that from the findings that indicate changes in the sequential organization, but not in the addition or removal of kinds of scriptlets. Due to learners' prior internal collaboration scripts, they perhaps are more likely to modify the sequence of scriptlets in response to a goal induction (aligning with their prior internal collaboration scripts), rather than adding or omitting kinds of scriptlets they could be unfamiliar with. Future studies could therefore focus on how learners perceive and navigate the collaboration process and how prior internal collaboration scripts, external collaboration scripts, and goal-related prompts interact with each other. Moreover, this might also indicate the need to examine learners' internal scripts on a rather fine-grained level.

Secondly, a closer look at the scriptlets also provided further insight into how certain activities are configured depending on a learning goal (e.g., as indicated by the sequential organization of the scriptlets "explain case" and "link knowledge"). In light of this, it also seems worthwhile to investigate the underlying mechanisms that determine why and how specific goals result in a specific reconfiguration in collaborative learning, that is, why learners (do not) apply specific activities in a specific manner.

7.2 Implications for practice

Furthermore, a number of practical implications can also be drawn from our findings. To begin with, teachers should consider the potential of the induction of goals. The manipulation of a goal resulting in differences in learners' internal collaboration scripts and the subsequently higher knowledge acquisition highlights the importance of integrating prompts related to learning goals in CSCL to further tap into its potential for learning. For example, teachers may want to integrate prompts that target learning goals into the design of CSCL environments, possibly leading to script configurations and activities that are particularly conducive to student learning.

Consequently, there are also implications for teacher training programs. In teacher education, pre-service teachers should acquire knowledge about the goals of learners that particularly contribute to students' collaborative learning, and how these can effectively be fostered through respective prompts within external scripts. This approach could also lead to more adaptive designs for computer-supported collaborative learning processes within higher education in general.

Eventually, this line of research offers the potential to elucidate the causal mechanisms by which the induction of goals impacts collaborative learning. In the future, this insight can help educators to apply new and improved strategies for effectively guiding activities to support student learning.

In conclusion, our study provides direct evidence for the SToG configuration principle and holds important implications regarding the design of CSCL-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

Ethical approval was not required for the studies involving humans because all procedures performed in this study were in accordance with the 1964 Helsinki declaration, and the National Psychological Society's (DGPs) ethical guidelines. According to DGPs guidelines, experimental studies only need approval from an institutional review board if participants are exposed to risks that are related to high emotional or physical stress or when participants are not informed about the goals and procedures included in the study. Informed consent was obtained from all individual participants included in the study. 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

TÖ: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. MG: Data curation, Formal analysis, Methodology, Software, Visualization, Writing – review & editing. CW: Conceptualization, Funding acquisition, Methodology, Project administration, Writing – review & editing. AG: Supervision, Writing – review & editing. IK: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Supervision, 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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Appendix

TABLE A1 Overview of goal-related prompts for learning goal and performance goal condition.

Prompt learning goal	Prompt performance goal
Acquisition of script knowledge	
Please read the steps carefully *to understand how a case analysis can be carried out*.	Please read through the steps carefully *to be able to create particularly good case analyses.*
Acquisition of theoretical knowledge	
This knowledge is very important for you to *expand your skills*. The cognitive load theory/ICAP framework can be understood as part of the pedagogical-psychological professional knowledge of teachers. Reading the theoretical text and dealing with the case studies based on pedagogical-psychological theories represents an *important learning opportunity for you*. Various empirical studies in the field of psychology (e.g., Syring et al., 2015; Zumbach et al., 2008), as well as the experiences of practitioners suggest a positive effect of learning with authentic cases *on professional knowledge and later coping with problems in the classroom*. Therefore, take this opportunity to understand the cognitive load theory/ICAP framework as deeply as possible and *to be able to deal professionally* with problematic teaching situations.	This knowledge is very important in order to *achieve very good results in the state examination*. The cognitive load theory/ICAP model can be understood as part of the pedagogical-psychological professional knowledge of teachers. Reading the theoretical text and dealing with the case studies based on educational-psychological theories is *an important way for you to prepare for the exam so that you perform as well as possible in the state exam*. Various empirical studies in the field of psychology (e.g., Syring et al., 2015; Zumbach et al., 2008), as well as the experiences of practitioners suggest a positive effect of learning with authentic cases *on exam performance and subsequent performance in dealing with problems in the classroom. In addition, your performance will be assessed by the course tutors.* Therefore, take this opportunity to *demonstrate* your knowledge of the cognitive load theory/ICAP model and your ability to deal with problematic teaching situations *to the tutors and teachers of the course.*
Case analysis	
Please note that it is very important to complete the tasks conscientiously, *as this will allow you to deepen your knowledge and acquire important skills.*	Please note that it is very important to complete the tasks conscientiously, *as this will greatly increase your chances of being able to reproduce this knowledge later in exam situations and perform well.*

TABLE A2 List of activities with expert ratings.

read theory	search literature (L)
summarize	search peer mistake
underscore	show off complexity
list terms	have one's will (P)
read instructions	compare quality (P)
relate theory and case (L)	assess competencies (P)
imagine application (L)	use technical terms
link knowledge (L)	surpass peer (P)
imagine examples (L)	ask peer (L)
relate with experience (L)	help peer (L)
think of meaning (L)	question comprehension (L)
examine evidence	imagine importance for performance (P)
scrutinize text (L)	compare with peer (P)
solve contradictions (L)	explain case (L)
compare solutions (L)	solve case
memorize subject matter (P)	identify case
repeat notes	set goal (L)
memorize terms (P)	describe case
memorize content (P)	read case
discuss case or theory (L)	read peer's analysis

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Problem perception and problem regulation during online collaborative learning: what is important for successful collaboration?

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Background: University students frequently prepare for exams or presentations in self-organized study groups. For this purpose, they often use videoconferencing software. During their collaboration, they need to regulate emerging problems to ensure effective learning. We suppose that regulation is facilitated when (1) the group perceives their regulation problems homogeneously, (2) they choose regulation strategies that have the potential to solve the problems immediately, and (3) they execute these strategies with sufficient intensity.

Aims: We investigated which problems occur during online collaborative learning via videoconferencing and how homogeneity of problem perceptions, immediacy of the chosen strategies, and intensity of strategy use are related to regulation success.

Sample: University students ($N = 222$) from two lectures in pre-service teacher education and educational sciences in 99 study groups.

Methods: Students collaborated in a self-organized manner, that is, without a teacher present, to study the material of one lecture using videoconferencing software. After the collaboration, group members rated, individually, the intensity of different problems during collaboration, reported which strategies they used to overcome their biggest problem, and rated the success of their problem regulation, their satisfaction with their collaboration, as well as their learning gain. In addition, they answered a knowledge test.

Results: We found that most students rated technical issues as their biggest problem. Multilevel modeling showed that homogeneous problem perception moderated by problem intensity—contrary to immediate and intensive strategy use—predicted successful problem regulation and satisfaction with the collaboration but not knowledge gain. Case analyses illustrate the assumed mechanism that a homogeneous problem perception facilitates socially shared regulation.

Conclusion: We conclude that even in only slightly structured learning contexts, students might only need to jointly identify their problems, whereas the best possible regulation of these problems seems less relevant. Therefore, training students to foster regulation competencies might prioritize identifying problems.

KEYWORDS

collaborative learning, socially shared regulation, challenges, homogeneity, intensity, immediacy, videoconferencing

1 Problem statement

Many students deliberately form self-organized small study groups, e.g., to prepare for exams. Taking positive effects of collaborative learning on knowledge acquisition found in the literature into account (e.g., Chen et al., 2018; Jeong et al., 2019; Kyndt et al., 2013; Springer et al., 1999), this is a sensible decision. However, collaborative learning unfortunately is not always effective (Al-Samarraie and Saeed, 2018; Nokes-Malach et al., 2015; Weinberger et al., 2012). In fact, students may be confronted with a variety of problems during collaboration that may hinder effective learning (Al-Samarraie and Saeed, 2018; Järvenoja et al., 2013). Only if the group is able to regulate these problems successfully, collaborative learning is effective (Järvelä and Hadwin, 2013).

Yet, which problems occur during collaborative learning might be affected by how a meeting takes place. When groups cannot meet in person (e.g., at institutions for distance learning, in areas with large physical distances between students, or during times of a pandemic), collaborative learning typically happens online through videoconferencing tools such as Zoom or Skype. And indeed, when collaborating using videoconferencing software, technical issues such as a low stability of the network connection or difficulties in using the software functions arise and hinder effective collaborative learning (Belli, 2018; McCollum et al., 2019; Nungu et al., 2023; Rizvi and Nabi, 2021). This is also reflected in the finding that students' intention to use videoconferencing depends on whether students believe that they have the necessary resources, access to relevant information, and helpdesk services available (Camilleri and Camilleri, 2022).

Besides mere technical issues, the technically mediated nature of communication such as a low visibility of non-verbal cues like facial expressions or gestures (Jeitziner et al., 2024) might complicate the collaboration further. For example, the phenomenon known as Zoom fatigue was attributed to the difficulty to keep track of nonverbal behavior, especially for women (Fauville et al., 2023). Furthermore, social presence which is known to affect active collaborative learning and student engagement (Qureshi et al., 2021), should evidently be lower in online meetings. Also, the extent to which videoconferencing allows for building trust and getting to know others is related to basic psychological need satisfaction, which, in turn, is associated with students' behavioral and emotional engagement (Shi et al., 2024). Regarding, for example, building trust and the impression of others, eye-contact matters. If the video setup does not allow for the students to perceive eye contact, trust and the impression of others are negatively affected (Bohannon et al., 2013). Some of these problems might be mitigated when additional digital tools such as mapping tools are added to videoconferencing (Park et al., 2023). To summarize, collaborative learning through videoconferencing carries the risk of additional problems compared to learning collaboratively face-to-face.

However, not much is known about how the virtual context influences how students regulate problems occurring during collaborative learning, and respective findings were mixed: On the one hand, Capdeferro and Romero (2012) asked a relatively small sample of master students enrolled in a distance education university about their frustrations with online collaboration, which was text-based through discussion forums and email. Participants often reported to be frustrated due to various problems such as an imbalance in commitment, unshared goals, or communication difficulties. This frustration might indicate failed regulation of problems related to online collaboration. On the other hand, Tan et al. (2022) investigated how students used Microsoft Teams, applying an action research methodology. They found that students were able to collaborate relatively similar to face-to-face-settings.

From this state of the literature, we conclude the following research gaps: First, most of the literature reports students' responses at an aggregated level, that is, general problems or satisfaction with online learning during a whole study semester or course (except Belli, 2018, who have, compared to the current research aim, a very narrow focus on emotional reactions to technical problems in single interactional units). It does not report problems at the level of a single session of collaborative learning. At this level, students might report a much more accentuated picture of problems which would be typically averaged out at the general level.

Second, most studies investigating collaborative learning via videoconferencing did not investigate how students regulated these problems. Only outcomes such as emotional reactions or satisfaction were examined, not processes of regulation. However, knowledge about regulation processes is necessary to inform support measures.

Third, self-organized groups or conditions similar to self-organized groups were not investigated. All studies collected data from students that collaborated based on teacher instruction. For example, the students from the two studies that investigated the outcomes of regulation (Capdeferro and Romero, 2012; Tan et al., 2022) collaborated across several weeks on a task that teachers specifically designed as an effective collaborative task. However, self-organized study groups differ in this regard by definition. Their engagement is voluntary, not scaffolded by teachers, and they are on their own during collaboration. Therefore, it should be only up to the students how beneficial for learning their meeting will be.

In conclusion, self-organized study groups need the skills to regulate problems during a session of collaborative learning, but we do not know yet which problems occur in these sessions and how groups can regulate them successfully. Addressing these research gaps is important because it will inform training. As self-organized study groups are unassisted, they need to be equipped with all necessary regulation skills themselves. Consequently, they need to acquire these skills before they enter a self-organized study group. However, for research to be able to develop adequate training, we first need to know how self-organized study groups regulate the problems they encounter. Therefore, this study focuses on which problems occur and how problems are regulated in virtual collaborative learning through videoconferencing.

2 Regulation of problems in collaborative learning

According to Chen et al. (2018, p. 800), "collaborative learning […] emphasizes that knowledge is co-constructed through social interaction. It is a learning situation in which two or more students learn together to achieve a common goal or solve the task at hand, mostly through peer-directed interactions." Usually, collaborative learning is instructed by a teacher. However, students also self-organize and form study groups on their own initiative without teacher support. Therefore, they voluntarily meet outside the classroom or outside the regular virtual class context to study based on their own goals. Most likely, this happens to prepare for exams. In the present article, we use the conceptualization of "collaboration in self-organized study groups as an instance of (socially) self-regulated learning (Järvelä and Hadwin, 2013) that requires groups to make decisions on their own learning process (e.g., concerning questions such as when and how long to meet, how to approach comprehension problems, or what technology to use during collaboration)" by Melzner et al. (2020, p. 150).

Based on previous research (e.g., Järvenoja et al., 2019; Melzner et al., 2020), problems in collaborative learning (and consequently also in self-organized collaborative learning) can be divided into at least the following categories: (a) comprehension problems (e.g., learners may have difficulty understanding the task), (b) coordination problems (e.g., learners may have different goals for learning together), (c) motivation problems (e.g., the learning contents may be perceived as not useful), and (d) resource-related problems (e.g., a digital tool might lack a necessary function). For self-organized collaborative learning to be successful, groups should be able to cope with such problems successfully.

To conceptualize the processes involved in this problem regulation, Melzner et al. (2020) developed a heuristic process model (see Figure 1) following models of (socially shared) regulated learning (e.g., Hadwin et al., 2018; Winne and Hadwin, 1998). Based on these models, metacognitive processes are especially crucial for the successful regulation of problems in collaborative learning. By aid of such processes, students (1) perceive and classify these problems. Based on the assessment of a problem, they initiate a reaction to ensure that the goal is achieved despite the problem at hand. For this purpose, students (2) select a strategy to address the problem and (3) execute this strategy with a certain intensity. Along with Melzner et al. (2020), we assume that these three processes (problem perception, choice of regulation strategy, intensity of strategy execution) should predict success in the regulation of problems that occur during collaborative learning. The different parts of the model proposed by Melzner et al. (2020) are more deeply elaborated in the following.

2.1 Homogeneity of problem perception

At the beginning of the regulation process, learners perceive and classify a given problem (see Figure 1). Different group members may arrive at different problem assessments. Divergences can basically refer to two dimensions: On the one hand, students may perceive problems of varying types (see, e.g., Järvenoja et al., 2013). For example, while one learner may perceive a comprehension problem to be present (e.g., the subject matter is perceived as too difficult), another learner may identify a motivational problem (e.g., the subject matter is not useful for practical application). On the other hand, there may also be disagreement about the social level at which the problem is located. Using the classification of Järvelä and Hadwin (2013), it can be distinguished whether a learner is affected themselves (self-level), whether the problem affects individual other group members (co-level), or whether the whole group is affected (socially shared level). The homogeneity of the problem perception is thus to be understood in terms of (a) the type of problem and (b) the question who is affected by the problem.

We suspect that diverging perceptions of the problem within the group make collaborative learning more difficult. The reasoning is straightforward: From a perspective of regulated learning (Winne and Hadwin, 1998), students realize that there is a problem if the outcomes (= products) of learning operations do not match their standards, that is, learning does not proceed as it should. As a reaction, they modify

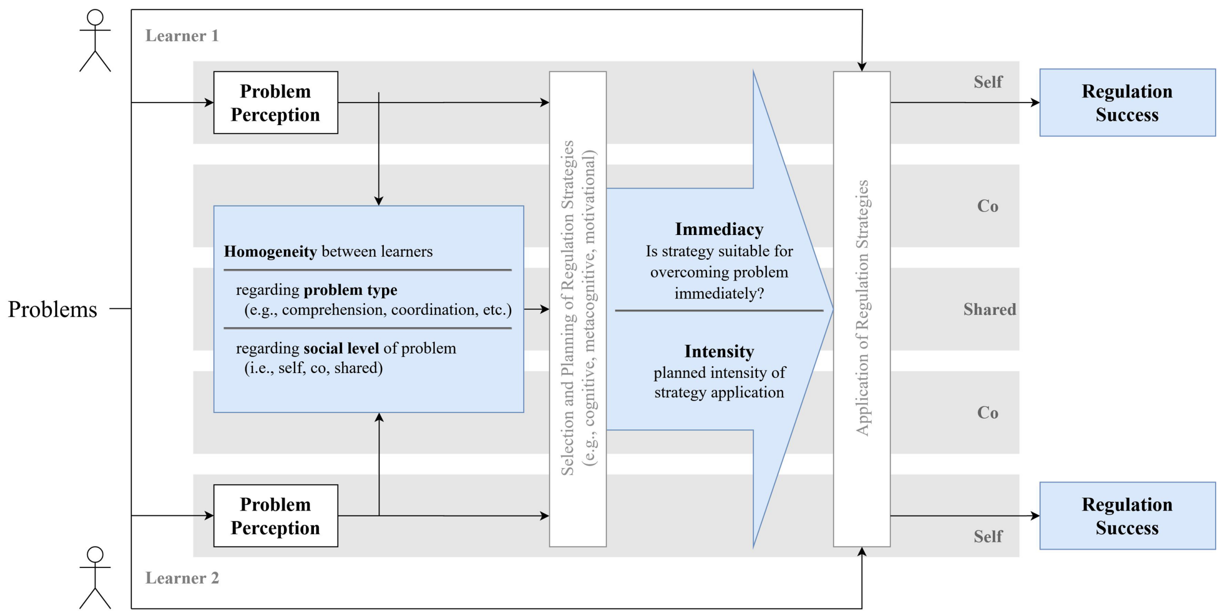

FIGURE 1
Theoretical model of the regulation of problems during collaborative learning (visualization inspired by Wecker and Fischer, 2014). Concepts in boldface are measured in the present study. Adapted by permission from Springer Nature: IJCSCL. Regulating self-organized collaborative learning: The importance of homogeneous problem perception, immediacy and intensity of strategy use (Melzner et al., 2020).

their operations (= control) to address this discrepancy. However, if different students assess different aspects of their collaboration or employ different standards, they see different problems, and, consequently, aim to modify their learning in different directions. Therefore, individual group members are less likely to coordinate their regulation efforts, just as a group of people walking into different directions has trouble to agree on a common pathway. If, in contrast, group members share a similar perception of problems that need to be regulated, this might help them to regulate the problem (Borge et al., 2018; Splichal et al., 2018). Indeed, Melzner et al. (2020) found that the more homogeneous students perceived their problems, the more satisfied they were with their collaboration.

2.2 Immediacy of regulation strategy use

Next, learners select a strategy for the regulation of the previously perceived problem (see Figure 1). Models of self-regulated learning (e.g., Winne and Hadwin, 1998; Zimmermann and Moylan, 2009) assume that at this point, the choice of a strategy that fits the learning goal is crucial. Collaborative learning groups that face a variety of problems need to use different strategies since not every strategy is supposed to be equally well suited to achieve a particular goal (e.g., Engelschalk et al., 2016; Malmberg, et al., 2015). In our view, a similar assumption may be made regarding the fit between an emerging problem and the chosen strategy for its regulation (e.g., Engelschalk et al., 2016). However, previous research has hardly made statements about what is meant by *fit*.

In order to operationalize fit, we have proposed the concept of *immediacy* (Melzner et al., 2020): A strategy is considered to be immediate for a problem if it is in principle possible to actually solve the problem without further strategies necessary when the respective strategy is executed optimally. An example of an immediate strategy would be to switch off cell phones when the group is distracted by incoming messages during learning. An example of a non-immediate strategy would be if learners make themselves aware of the importance of the exam they are preparing for in order to motivate them to continue learning despite the incoming messages. This strategy would only allow learners to continue learning despite the presence of the problem. However, it would not eliminate the source of distraction and thus would not immediately make the problem disappear.

Thus, for the operationalization of fit, a theoretical assignment of strategies to problems as immediate or non-immediate was proposed by Melzner et al. (2020) and was found to predict self-organized, offline groups' satisfaction with their collaboration. In addition, prior research often investigated the fit of various strategies for different learning situations via expert ratings (e.g., Artelt et al., 2009; Bäulke et al., 2018; Fett et al., 2021; Steuer et al., 2019; Waldeyer et al., 2019). For instance, Waldeyer et al. (2019) asked experts to rate the effectiveness of several resource strategies for the regulation of 60 resource demanding situations that learners might face during their studies. For 36 out of these 60 situations, experts agreed on one strategy as the most fitting strategy. Further, students who selected the same strategies as the experts for a given situation performed better in an exam. In comparison, Fett et al. (2021) asked experts from computer-supported collaborative learning and self-regulated learning research to rate how immediate strategies regulate a given problem in a collaborative learning setting. As a proof of concept, experts assigned strategies to problems very selectively and highly agreed on the immediacy for a large proportion of problem-strategy-pairs.

2.3 Intensity of the execution of the regulation strategy

To be effective, the selected strategy must be applied in the next step (see Figure 1). Depending on the severity of the problem, however, a single application of the strategy may not be sufficient to achieve the desired effect. For example, if learners who are bored by the learning material think only briefly about their goals for the future, this may have little effect on their motivation to devote effort toward understanding the material. However, if they work intensively on how the material will help them achieve their own goals, this should increase their motivation. We therefore assume that the intensity of strategy use is positively related to regulation success. However, not only the intensity of using immediate strategies should be relevant, since also the use of non-immediate strategies might increase regulation success, even if the specific problem is not solved that way. In line with this reasoning, it is not surprising that findings regarding the effects of regulation intensity on individual and group outcomes are mixed (Eckerlein et al., 2019; Melzner et al., 2020; Schoor and Bannert, 2012). Thus, more research is needed to clarify its influence on regulation success.

2.4 Operationalizing regulation success in collaborative learning

Once the regulation process is executed in accordance with the process model depicted in Figure 1, it should be successful. Yet, regulation success may be conceptualized and measured in various ways (e.g., Melzner et al., 2020; Noroozi et al., 2019; Zimmermann and Moylan, 2009). In this paper, we focus on four different conceptualizations: (1) successful regulation of the biggest problem which occurred during the collaborative learning (i.e., the extent to which the problem is overcome), (2) satisfaction with the collaboration, and (3) the subjective and (4) objective learning success resulting from the group learning session. So far, only satisfaction has been empirically investigated in this context (e.g., Bellhäuser et al., 2019; Melzner et al., 2020). For example, Bellhäuser et al. (2019) experimentally examined how group composition regarding group members' extraversion and conscientiousness affected their rating of how satisfied they were with the quality of their collaboration.

Yet, not much is known about how problem perception, immediacy and intensity of strategy use contribute to further measures of regulation success. It can be assumed that effects might differ in strength because the suggested variables differ in how proximate they are to regulation during collaborative learning: Successfully overcoming problems could be considered the prime and most direct outcome of regulation. Satisfaction with the collaboration is probably based on more variables besides successful problem regulation, for example task difficulty (Kirschner et al., 2009), task design, or group members' preference for group work (Shaw et al., 2000), or their achievement goals (Greisel et al., 2023), but it should still be linked closely to the regulation process (Melzner et al., 2020; Bellhäuser et al., 2019). Subjective knowledge gain, in turn, is more distal as it should also be affected by the effectiveness of the employed cognitive learning strategies, the quality of the task and the learning material, the learning goals, etc. Moreover, objective knowledge is also not dependent on the quality of the collaboration alone, as students can memorize learning content also outside of a collaborative setting. Nonetheless, groups' successful problem solving has repeatedly been linked with knowledge gain and performance outcomes empirically (e.g., Chen et al., 2018; Kirschner et al., 2011).

3 Research questions and hypotheses

We briefly summarize the research gaps mentioned so far: First, it is unclear which problems students in self-organized study groups experience when they collaborate using a videoconferencing tool *without teacher guidance*. Second, it is an open question to what extent the three processes proposed by Melzner et al. (2020, homogeneity of problem perceptions, immediacy of strategy use, and intensity of strategy use) predict successful regulation in collaborative online settings. Third, little is known about whether these three processes are differentially predictive of the four conceptualizations of regulation success described above. Therefore, our study aims to answer the following research questions:

I. Which problems do students experience to which extent while collaborating online via videoconferencing without teacher guidance?

II. How are homogeneity of problem perceptions, immediacy of strategy use, and intensity of strategy use associated with successfully overcoming problems during online collaboration via videoconferencing, satisfaction with the collaboration, subjective knowledge gain, and objective knowledge?

The first research question is investigated exploratorily as the current state of knowledge does not allow for predicting outcomes, whereas regarding the second research question, we formulated the following confirmatory hypotheses:

1. The more homogeneously learners perceive problems within their groups, the more positive are the results on different measures of regulation success.
2. Learners who use immediate strategies to regulate their problems achieve more positive results on different measures of regulation success than learners who use only non-immediate strategies.
3. The more intensively learners apply regulation strategies, the more positive are the results on different measures of regulation success.

4 Method

4.1 Sample

University students ($N = 222$) from two basic psychological lectures in German language within the majors educational sciences (29%) and teacher training (70%) from a university in Southern Germany learned collaboratively and anonymously answered an online questionnaire afterwards. They had an average age of 22 years ($M = 21.84$, $SD = 4.39$, 83% female), were on average in the third semester of their current study subject ($M = 2.78$, $SD = 1.50$) and in their third university semester overall ($M = 3.34$, $SD = 2.57$). Participating in this session of collaborative learning was voluntary (i.e., not necessary for being admitted to the exam at the end of the course). We advertised it as a good chance to learn the subject matter relevant to the exam. However, students experienced no disadvantages if they did not participate in the collaborative learning session or the study. Individual data were not provided to the lecturers of the courses.

Participants self-assigned into 99 small groups of three persons on average ($M = 2.92$, $SD = 0.27$, 11 groups with two persons, 88 groups with three persons, self-reported), but not all members of each group participated in the study. Therefore, we have data from $M = 2.24$ ($SD = 0.86$) persons per group only. In detail, 26 groups were represented by one person, 24 groups by two persons, 48 groups by three persons, and one group by four persons (all rows from the group with four persons seemed to represent distinct persons, therefore we decided to keep it though no group reported to have 4 persons). The data from the 26 groups which were represented in our data by a single person had to be excluded from all analyses that included the calculation of homogeneity of problem perception as this is possible only for groups with data of two or more learners.

4.2 Procedure

The study was embedded in two large lectures that mainly consisted of weekly uploaded recordings of PowerPoint-presentations (i.e., slides with audio-recorded lecturer voice) that were provided for individual, asynchronous studying during the summer term 2020 after the onset of the COVID-19 pandemic. One session of collaborative learning replaced the regular recorded lecture in the respective week. The subject matter of this week was not repeated or discussed in a later session, that is, we employed no flipped classroom pedagogy. Thus, learners acquired the knowledge only in a self-organized fashion. Learners were instructed to meet online at a time suitable for all group members using a videoconferencing software of their choice to study the lecture content on their own. Students collaborated for $M = 90.6$ ($SD = 40.6$) minutes (self-report). Only three students indicated a studying time of less than 30 min. As learning material, the regular presentation slides for this session (without audio) were provided alongside two excerpts from a textbook, each about one page long. Topics were the ICAP model of learning activities (Chi and Wylie, 2014) and the multi-store model of memory (Atkinson and Shiffrin, 1968). We did not structure or scaffold students' collaborative learning with additional instructions. We only provided them with the following tasks: "The goal of the group work is to work out the slide contents as well as possible together with your group members. You are welcome to use the additional texts provided." In addition, students were told to record the results of their group work in a shared concept map. Yet, besides this, learners were free to decide in which way, that is, with which activities or tools, they wanted to work on the topic. This instructional design should mimic learning in a self-organized study group as closely as possible. For learners who were not familiar with an online tool suitable to produce a concept map, we recommended www.mindmeister.com and provided a short tutorial video explaining all functions necessary to accomplish the task.

After the study meeting, participants were asked to individually answer an online questionnaire. The questionnaire was advertised as containing a knowledge test for which students would receive immediate feedback regarding correct and incorrect answers. The questions were comparable to the ones in the final exam in the corresponding lectures, so taking the test would be a good chance to practice for the "real" exam.

4.3 Measures

To measure the *prevalence of problems during collaborative learning*, we developed a questionnaire with 32 different problems represented by three items each. Each item had to be rated on a Likert-scale from 0 = *did not occur/no problem* to 4 = *big problem*. Based on problem typologies and theoretical classifications in the literature (e.g., Järvenoja et al., 2013; Koivuniemi et al., 2017), our questionnaire covered four broad categories of problems: comprehension-, coordination-, motivation-, and resource-related problems (see Figure 2 for a complete list of individual problems). For example, for the problem of "low value of learning method" (a motivational problem), a sample item was "Single/multiple group members did not find group work to be a useful learning method in the given situation." Cronbach's alpha was $M = 0.79$ ($SD = 0.07$; [0.59–0.92]) on average. After rating all problems, participants selected one of them as the biggest problem they encountered during the learning session.

To validate the factor structure of this problem scale, we conducted an extensive series of confirmatory factor analyses. As preparation, we first grouped items which are theoretically at least somewhat similar into different sets of similar items. An item could be part of several sets. This grouping was necessary because a confirmatory factor analysis with 32 latent variables and 96 indicators would not have been methodologically sound, given the sample size, the degrees of freedom, and the number of parameters to estimate. Then, we conducted multiple confirmatory factor analyses for each of these groups of similar items. Thereby, we compared the hypothesized factor structure (3 items per factor) to other theoretical plausible factor structures. Most of the time, this was a unidimensional model and models with slightly more or less factors, sometimes also with second order factors. In the end, we compared the model fits of these models to decide whether the hypothesized factors with three items per factor were distinguishable from each other, and whether the hypothesized factor solutions had the best fit to the data. This was the case for all problems, hence we decided to keep the intended factor structure with 32 problems and three items each.

To determine the *homogeneity of the within-group perceptions regarding the type of problem*, we calculated the deviation of each person's rating from the average ratings of the remaining group members. We did this for each problem separately and then determined the average deviation across all problems. To transform the deviation into a measure of homo- instead of heterogeneity, we multiplied it by −1. Thus, a value of 0 represents perfect homogeneity of problem perceptions, whereas the more negative the value is, the less homogeneous the perception was. To determine the *homogeneity of within-group problem perceptions regarding the social level*, we used three items measuring the extent to which the biggest problem affected the self-, co-, or shared level on a five-point Likert-scale from 1 = *not at all true* to 5 = *completely true*. The items were "The mentioned problem had effects on my personal learning process" (self), "The mentioned problem had effects on single other group members' learning process" (co), and "The mentioned problem had effects on the whole group's learning process" (socially shared). The ratings for each item were dichotomized by median split ($Md_{self} = 2$, $Md_{co} = 2$, $Md_{shared} = 3$), resulting in a zero–one-coding. Then, groups were coded as being homogeneous regarding the social level of problem perception when the social level at which they located the biggest problem matched the respective ratings of each other group member. For example, a group's problem perception was considered to be homogeneous when one person located the problem only at the self-level, while the two other group members located the problem only at the co-level.

To measure *immediacy and intensity of strategy use*, we asked participants to name the strategies they used to regulate the problem they marked as the biggest one at the self-, co-, and socially shared level in an open answer format (self-level: "What did you think/do/say for yourself to get to grips with the biggest problem?"; co-level: "What did you think/do/say for others to get to grips with the biggest problem?" and "What did others do/say for you to get to grips with the biggest problem?"; socially shared level: "What did you think/do/say as a group to get to grips with the biggest problem?"). These answers were segmented into single regulation strategies (interrater-agreement 90–91%). Then, each strategy was classified as one out of 27 possible types of strategies (for a list, see Melzner et al., 2020). Interrater reliability of two independently coding, trained student research assistants was sufficient (Gwet's AC1 = 0.73). Next, each strategy was assigned a value which expressed the extent to which experts considered this strategy to be immediate for the selected biggest problem. The expert ratings stem from another study which asked experts from CSCL and self-regulation to rate how immediately different regulation strategies solve a given problem on a scale from 0 to 4 (Fett et al., 2021). To determine the intensity of strategy use, we added up the number of valid regulation strategies reported at all social levels.

To measure *successful problem regulation*, we adapted three items from Engelschalk et al. (2016) (e.g., "During group learning, we got the biggest problem under control."). Each item had to be rated on a Likert-scale from 1 = *not at all true* to 5 = *completely true*. Cronbach's alpha was 0.96.

Satisfaction with the collaboration was measured by five items from the German version of the Satisfaction with Life Scale (SWLS; Glaesmer et al., 2011), which we adapted to the group learning context (e.g., "Our group work was excellent."). Each item employed a 5-point Likert scale ranging from 1 = *not at all true* to 5 = *completely true*. Cronbach's alpha was 0.92.

We assessed *subjective knowledge gain* by using six adapted items from the Training Evaluation Inventory (TEI; Ritzmann et al., 2014). Knowledge gain with regard to the ICAP model (Chi and Wylie, 2014) and knowledge gain with regard to the multi-store model of memory (Atkinson and Shiffrin, 1968) were measured separately by three items each (e.g., "I have the impression that my knowledge on the ICAP-Model/the multi-store model of memory has expanded on a long-term basis") on a 5-point Likert-scale from 1 = *not at all true* to 5 = *completely true*. Cronbach's alpha was 0.92.

As a measure of *objective knowledge*, we mimicked a typical standardized lecture exam: We constructed eight multiple choice questions with four dichotomous answer alternatives each (four questions for each theory). Sample answer options were "The production of new knowledge could be realized through the exchange of different perspectives of different learners" (ICAP) and "Sensory

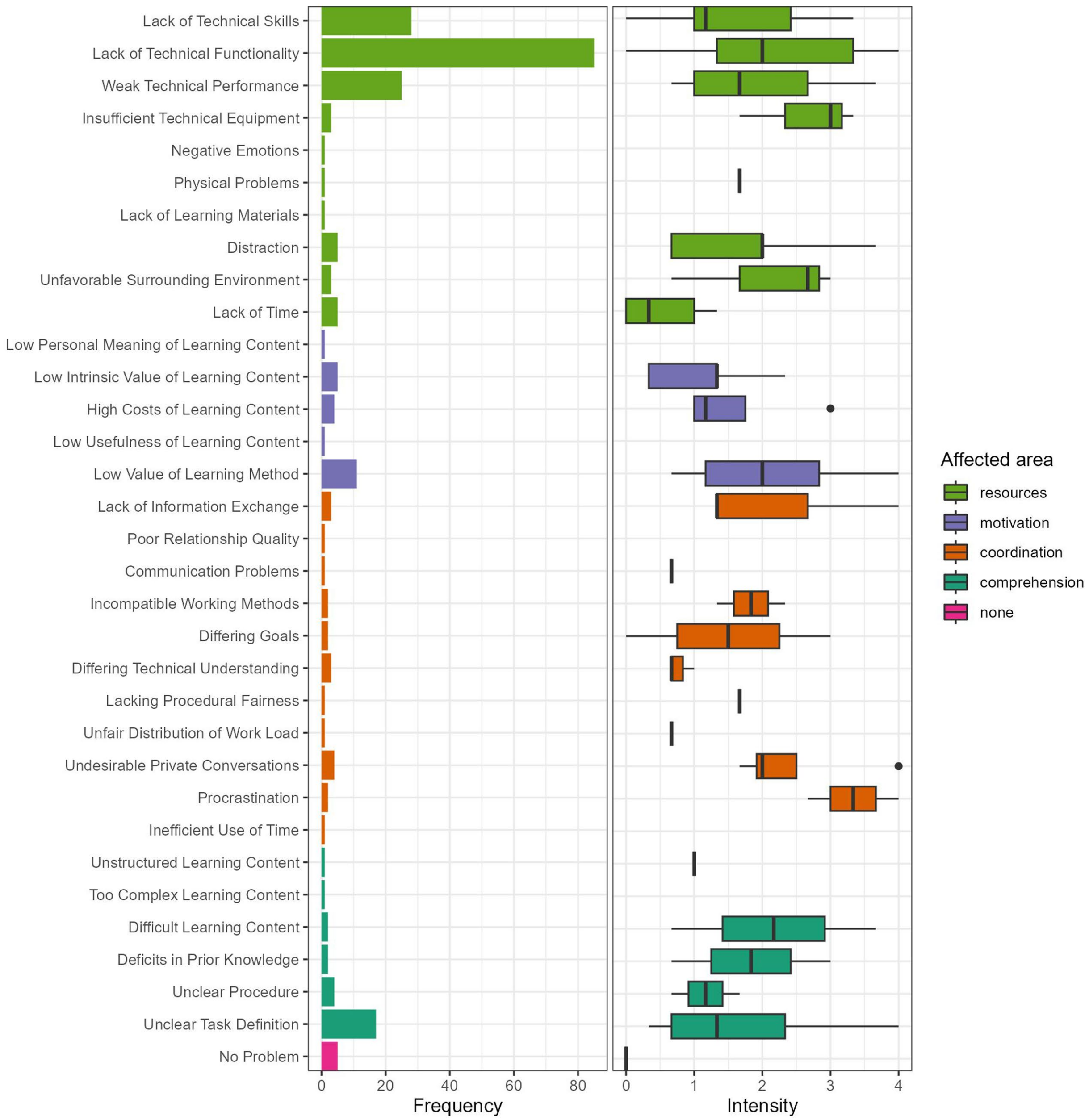

FIGURE 2
Frequency and intensity of problems selected as biggest problem during collaborative learning. Left panel shows how often participants selected a certain problem as biggest problem. Right panel displays boxplots of the problem intensities (only for those participants who selected the respective problem as biggest problem). Single vertical lines without surrounding box result if only one person selected this problem as biggest problem. Empty lines result if participants did select the respective problem as biggest problem but did not rate its intensity.

information is stored for a very short period of time but is then overwritten by new information" (multi-store model of memory). To validate this test, we inspected item difficulties and conducted a distractor analysis. We removed items which were correctly answered by more than 90% of the sample as these items did not differentiate between high and low scorer. In addition, we had to remove one item which was not clearly correct or false and one item which had an inverse relation to the total score even after reversing intentionally inverted items. As the distractor analysis indicated, the remaining items differentiated well between the upper, middle, and lower percentile of total scores. Corrected item-scale-correlations indicated that the items measured, as intended and typical for a knowledge test, different aspects of knowledge regarding the two theories and not a single homogeneous latent construct. Then, we calculated separate mean scores (= proportion of right answers) for each theory, and, finally, we averaged these two scores to get one total test score.

4.4 Analysis strategy

As preliminary analyses, we inspected descriptive statistics of predictor and criterion variables (see Table 1 and Table 2). In addition, we tested whether the nesting of students in courses needed to be considered. As a MANOVA showed no significant differences between the two courses in the dependent variables, $F(1, 216) = 0.73$, $p = 0.572$, we did not consider the course level in the further analyses. In contrast, the ICCs (see Table 1) indicated that belonging to a specific study group explained a considerable proportion of the variance of each dependent variable, thus we had to take the clustering of students in groups into account.

To answer Research Question 1, we investigated descriptively which problems participants selected as biggest problems and as how severe they assessed them. To answer Research Question 2, we conducted multilevel regression analyses with the REML estimator to account for the two-level structure (students in study groups) and covariations between predictor variables. Therefore, we used R [4.2.2] (R Core Team, 2022) with the package lme4 [1.1–31] (Bates et al., 2015) and lmerTest [3.1–3] (Kuznetsova et al., 2017). As an inspection of the scatter plots for the bivariate relations indicated, the relation between homogeneity regarding the problem type and the dependent variables described are more quadratic or cubic than linear curve. Therefore, we added quadratic and cubic terms for homogeneity of problem type to account for this. As problem intensity logically determines the possible variance of homogeneity regarding the problem type within each group, we controlled for the interaction of problem intensity with homogeneity.

To complement the quantitative analyses, we described the answers from two groups. This qualitative illustration serves two purposes. First, it illustrates the interaction effect found in the quantitative analyses. Second, it sheds light on the theoretically assumed mechanism how homogeneity of problem perceptions facilitates problem regulation. Therefore, we chose two contrasting cases which prototypically represented opposing values in homogeneity and intensity of the biggest problem.

5 Results

5.1 Descriptives and bivariate correlations

A minority of participants (21%) located the biggest problem at the same social level within their groups (see Table 2). The problems where this happened relative to the total number of notions most frequently were “unclear task definition” and “low value of learning method” (for a detailed list, see Table 3). Regarding immediacy, 71% of the participants applied at least one immediate regulation strategy to remedy the biggest problem. Regardless of the type, about four strategies were reported on average. Both successful problem regulation and satisfaction with the collaboration were rated on average with $M = 4.12$ (successful problem regulation: $SD = 1.07$; satisfaction: $SD = 0.84$) on a scale from 1 to 5 and consequently estimated to be rather high, while subjective knowledge gain was appraised a bit lower ($M = 3.76$, $SD = 0.89$). Of all test questions measuring objective knowledge, 74% were solved correctly on average ($SD = 0.12$). Predictor variables were not significantly associated with each other, except for problem intensity with homogeneity, $r = -0.39$, $p < 0.01$, and regulation intensity, $r = 0.14$, $p < 0.05$. In addition, satisfaction with the collaboration was associated with successful problem regulation, $r = 0.53$, $p < 0.01$, and subjective knowledge gain, $r = 0.33$, $p < 0.01$, which were also correlated with each other, $r = 0.33$, $p < 0.01$. Consequently, all subjective measures for regulation success were associated with each other. Correlation analyses between the predictor and outcome variables showed that only content-related homogeneity of problem perception was associated with satisfaction with the collaboration, $r = 0.46$, $p < 0.01$, successful problem regulation, $r = 0.27$, $p < 0.01$, and subjective knowledge gain, $r = 0.27$, $p < 0.01$. Objective knowledge was only related to regulation intensity, $r = 0.14$, $p < 0.05$.

5.2 Research question 1: Problems

Regarding Research Question 1, most students ($n = 102$) selected technical problems as their biggest problem during collaboration (Figure 2; Table 3). These were mostly centered around the recommended mind mapping-software. Only few students had insufficient equipment ($n = 3$). However, if this occurred, the problem was rather severe. Some students ($n = 9$) considered a low value of the learning method as their biggest problem, which had a medium intensity most of the time. The same applied to unclear task definition ($n = 16$; see Figure 2 and Table 3 for a complete list).

5.3 Research question 2: Predicting regulation success

Regarding Research Question 2, we calculated regression models (see Table 1). All hypotheses concerning main effects were not supported: Neither homogeneity regarding the problem type nor the social level, nor immediacy of strategy us, nor regulation intensity were associated with regulation success. However, explorative analyses showed that the interaction of homogeneity regarding the problem type and the problem intensity was a significant predictor of successful regulation of the biggest problem, $\beta = 0.25$, $p = 0.002$, and satisfaction with the collaboration, $\beta = 0.18$, $p = 0.022$. That is, for students who perceived the biggest problem in their group as severe, the more they perceived the problems similar to their group, the more successful they regulated the biggest problem and the more satisfied they were with the collaboration. However, for students who perceived the biggest problem in their group as only mild, homogeneity of their problem perception did not matter for successfully overcoming the problem and satisfaction (see Figure 3).

5.4 Qualitative analyses

Regarding the qualitative analysis, Group 55 (see Table 4) indicated a very homogeneous problem perception. All group members referred to a similar problem as the biggest problem, which they regarded as relatively severe. Consequently, they reported matching regulation strategies at different social levels. In the end, they assessed their biggest problem as solved and considered their collaboration as satisfactory.

In contrast, group members from Group 74 (see Table 5) perceived their problems more differently. Furthermore, each member selected a different problem as the biggest problem. The first two group members assessed it as relatively weak. Their regulation seemed to

TABLE 1 Multilevel modeling of four different measures of regulation success.

	Successful problem regulation					Satisfaction with collaboration					Subjective knowledge gain					Objective knowledge				
Predictors	*b*	CI	*p*	std. *β*	std. CI	*b*	CI	*p*	std. *β*	std. CI	*b*	CI	*p*	std. *β*	std. CI	*b*	CI	*p*	std. *β*	std. CI
(Intercept)	4.31	3.58 to 5.04	**<0.001**	0.10	−0.05 to 0.25	4.56	4.06–5.07	**<0.001**	0.08	−0.07 to 0.22	4.01	3.36–4.66	**<0.001**	0.03	−0.13 to 0.20	0.75	0.67–0.84	**<0.001**	−0.01	−0.18 to 0.16
Homogeneity	0.49	−2.72 to 3.70	0.762	0.58	−0.38 to 1.53	0.55	−1.72 to 2.82	0.633	0.50	−0.40 to 1.41	−0.84	−3.77 to 2.08	0.570	−0.16	−1.17 to 0.85	0.19	−0.19 to 0.57	0.327	0.43	−0.62 to 1.47
Problem intensity	0.06	−0.21 to 0.33	0.654	−0.32	−0.47 to −0.18	−0.00	−0.18 to 0.18	0.996	−0.27	−0.40 to −0.13	−0.12	−0.35 to 0.12	0.324	−0.26	−0.41 to −0.11	0.01	−0.02 to 0.04	0.574	0.16	0.00 to 0.32
Homogeneity quadratic	2.05	−2.61 to 6.71	0.386	0.84	−1.07 to 2.76	0.13	−3.14 to 3.41	0.938	0.07	−1.72 to 1.86	−2.38	−6.60 to 1.83	0.266	−1.13	−3.12 to 0.87	0.24	−0.32 to 0.80	0.396	0.90	−1.19 to 2.99
Homogeneity cubic	0.52	−1.30 to 2.35	0.572	0.31	−0.78 to 1.40	−0.23	−1.50 to 1.04	0.718	−0.19	−1.20 to 0.83	−1.37	−3.00 to 0.26	0.098	−0.94	−2.07 to 0.18	0.11	−0.11 to 0.33	0.324	0.59	−0.59 to 1.780
Homogeneity social	0.10	−0.26 to 0.46	0.589	0.04	−0.10 to 0.18	0.00	−0.26 to 0.26	0.992	0.00	−0.14 to 0.14	−0.09	−0.44 to 0.25	0.586	−0.04	−0.20 to 0.11	−0.03	−0.07 to 0.01	0.188	−0.10	−0.26 to 0.05
Immediacy	0.08	−0.05 to 0.20	0.232	0.08	−0.05 to 0.21	0.02	−0.06 to 0.11	0.625	0.03	−0.09 to 0.15	0.01	−0.10 to 0.12	0.870	0.01	−0.12 to 0.14	−0.01	−0.02 to 0.01	0.480	−0.05	−0.19 to 0.09
Regulation intensity	0.03	−0.03 to 0.09	0.290	0.07	−0.06 to 0.20	0.04	−0.00 to 0.08	0.053	0.12	−0.00 to 0.24	0.03	−0.02 to 0.08	0.215	0.08	−0.05 to 0.22	0.00	−0.00 to 0.01	0.348	0.07	−0.08 to 0.21
Homogeneity * Problem intensity	0.80	0.29 to 1.30	**0.002**	0.25	0.09–0.42	0.40	0.06 to 0.75	**0.022**	0.18	0.03 to 0.33	0.20	−0.24 to 0.64	0.371	0.08	−0.09 to 0.24	−0.02	−0.08 to 0.04	0.600	−0.05	−0.23 to 0.13
Random effects																				
σ2	0.84					0.37					0.59					0.01				
τ00	0.07 *GrNr*					0.07 *GrNr*					0.14 *GrNr*					0.00 *GrNr*				
ICC	0.08					0.17					0.19					0.12				
N	74 *GrNr*					74 *GrNr*					74 *GrNr*					74 *GrNr*				
Observations	194					198					198					197				
Marginal R^2/ Conditional R^2	0.195/0.258					0.285/0.403					0.147/0.307					0.048/0.159				

p-values in bold face < 0.05.

10.3389/fpsyg.2024.1351723

TABLE 2 Means, standard deviations, and correlations.

Variable	M	SD	1	2	3	4	5	6	7	8
1. Homogeneity problem type	−0.46	0.30								
2. Homogeneity social level	0.21	0.41	0.04							
3. Immediacy	1.27	1.09	0.04	−0.03						
4. Regulation intensity	3.99	2.39	−0.02	0.10	0.05					
5. Problem intensity	1.86	1.16	−0.39**	−0.08	0.06	0.14*				
6. Successful problem regulation	4.12	1.07	0.27**	0.11	0.08	0.08	−0.38**			
7. Satisfaction with the collaboration	4.12	0.84	0.46**	0.06	0.04	0.09	−0.42**	0.53**		
8. Subjective knowledge gain	3.76	0.89	0.27**	−0.01	−0.01	0.04	−0.28**	0.33**	0.33**	
9. Objective knowledge	0.74	0.12	0.02	−0.11	−0.00	0.14*	0.08	0.03	−0.06	0.07

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

be sufficient to overcome the problems, though the group as a whole was not engaged in regulating each problem. In comparison, the third group member reported an intense problem. As the group members' statements depicted in Table 5 show, this problem was also not regulated by other group members or the group as a whole, and it was not regulated successfully. We will interpret these observations in the next section.

6 Discussion

This study investigated which problems occurred during a session of (relatively) self-organized online collaborative learning and how groups regulated these problems. Descriptive analyses of problem ratings and means of regulation success variables draw a picture of a rather successful learning experience: The problem each participant selected as their biggest problem had medium intensity only, and, at the same time, subjective measures of regulation success indicated successful regulation of these problems, high satisfaction and solid subjective knowledge gain. Overall, students seem to be prepared to successfully collaborate in this realm. At first glance, this finding contrasts with the results of Capdeferro and Romero (2012) who found students to report frustrations about online collaborative learning more frequently. A closer look at the concrete problems students reported to be the most intense reveals that technical issues were by far most often considered to be the biggest obstacles to collaborative learning. This mirrors findings from the literature which report the very same obstacles for whole courses or studying online during a whole semester (Belli, 2018; McCollum et al., 2019; Nungu et al., 2023; Rizvi and Nabi, 2021). Notions of Zoom fatigue (Fauville et al., 2023) in the literature might be represented in our data in the problem low value of the learning method which at least some of the students perceived. In contrast, problems regarding the communication, for example due to reduced visibility of non-verbal cues (Jeitziner et al., 2024) or social presence and trust (Bohannon et al., 2013; Qureshi et al., 2021; Shi et al., 2024), were not evident in our study. Maybe, the use of a digital visualization tool mitigated these potential pitfalls as Park et al. (2023) reported. Though lacking functionality or difficulties with using the mind-mapping software were the most reported problems, students seem to have regulated them successfully in most cases, for example, through switching to another tool. In general, the prevalence of problems specific to digital collaboration via videoconferencing indicates that students might indeed be less effective when they collaborate using a videoconferencing and a mind-mapping tool.

The main question of this study was how homogeneity of problem perceptions within study groups and immediacy and intensity of regulation strategy use would be associated with different measures of regulation success. In sum, homogeneity of problem perception was the only significant predictor of successful application of regulation strategies and satisfaction with the collaborative learning when moderated by the intensity of the biggest problem. If the problem was big, then a homogeneous perspective was associated with successful application of regulation strategies and satisfaction with the collaboration. If the problem was small, it did not matter how homogeneously the problems were perceived. This might mean that groups who have a commonly shared perspective on what their problems are are more successful in regulating their problems as soon as these problems become more severe. This finding is similar to the finding of Melzner et al. (2020).

The qualitative case examples illustrate this interaction effect and the potential mechanism behind it. In Group 55, an intense problem was seen homogeneously, regulated as a shared effort, and, therefore, overcome successfully. In Group 74, perspectives on what the main problem was differed more strongly. The group overcame the problems with low intensity nonetheless, but the problem with high intensity remained unresolved.

The comparison between these groups illustrates the interaction of homogeneity and problem intensity we found in the quantitative analyses. Perceiving the problems within a group homogeneously seems to be necessary to solve severe problems, but groups were able to solve mild problems without relying on a shared problem view. The case examples also shed light on the assumed mechanism driving this association between homogeneous problem perception and regulation success. We assumed that a homogeneous problem perception facilitates selecting regulation strategies (no matter if immediate or not) and executing them because it provides a common ground for all group members and a shared goal for regulation. This facilitation of regulation should matter especially when a problem is severe, that is, it challenges students' resources to regulate it. Indeed, in the homogeneous Group 55, students regulated at different social levels all directed toward the same goal. In contrast, in the heterogeneous Group 74, students reported that they did not help each other to overcome the biggest problems they mutually perceived. There are two possible mechanisms explaining this lack of mutual help. It might be that the problem view was not shared; thus, no shared regulation regarding these problems developed because learners did not know about the problems other group members experienced. The

10.3389/fpsyg.2024.1351723

TABLE 3 Cross-tabulation of the biggest problem and homogeneity of within-group problem perceptions regarding the social level.

Biggest problem	Social homogeneity		Total
	No	Yes	
No problem	4 2%	0 0%	4 2%
Unclear task definition	9 4.5%	7 3.5%	16 8%
Unclear procedure	3 1.5%	0 0%	3 1.5%
Deficits in prior knowledge	1 0.5%	0 0%	1 0.5%
Difficult learning content	2 1%	0 0%	2 1%
Too complex learning content	0 0%	0 0%	0 0%
Unstructured learning content	1 0.5%	0 0%	1 0.5%
Inefficient use of time	0 0%	0 0%	0 0%
Lack of time	2 1%	1 0.5%	3 1.5%
Unfair distribution of work load	0 0%	0 0%	0 0%
Lacking procedural fairness	1 0.5%	0 0%	1 0.5%
Differing technical understanding	3 1.5%	0 0%	3 1.5%
Differing goals	1 0.5%	1 0.5%	2 1%
Incompatible working methods	2 1%	0 0%	2 1%
Communication problems	1 0.5%	0 0%	1 0.5%
Poor relationship quality	0 0%	0 0%	0 0%
Lack of information exchange	2 1%	0 0%	2 1%
Unfavorable surrounding environment	2 1%	1 0.5%	3 1.5%
Distraction	3 1.5%	0 0%	3 1.5%
Undesirable private conversations	3 1.5%	0 0%	3 1.5%
Lack of learning materials	0 0%	0 0%	0 0%
Physical problems	0 0%	0 0%	0 0%
Low value of learning method	4 2%	5 2.5%	9 4.5%
Low usefulness of learning content	0 0%	0 0%	0 0%
High costs of learning content	3 1.5%	0 0%	3 1.5%
Low intrinsic value of learning content	4 2%	1 0.5%	5 2.5%
Low personal meaning of learning content	0 0%	0 0%	0 0%
Procrastination	0 0%	1 0.5%	1 0.5%
Negative emotions	0 0%	0 0%	0 0%
Insufficient technical equipment	3 1.5%	0 0%	3 1.5%
Weak technical performance	21 10.6%	4 2%	25 12.6%
Lack of technical functionality	62 31.3%	14 7.1%	76 38.4%
Lack of technical skills	20 10.1%	6 3%	26 13.1%
Total	157 79.3%	41 20.7%	198 100%

low homogeneity values for this group and the statement of Alina that she is only assuming the other group members' goals support this explanation. However, it might also be that the learners actually did know about other members' problems but did not care enough to engage in respective co-regulation or socially shared regulation. Nonetheless, whatever mechanism was in place here, it resulted in that the severe problem had not been overcome.

Despite these significant effects regarding successful regulation of the biggest problem and satisfaction with the collaboration, subjective knowledge gain and objective knowledge were not associated with homogeneity of problem perceptions. The reason might be that students' task to learn the lecture content was not a "real" group task including positive interdependence (Johnson and Johnson, 2009): An individual student could excel in this task even if the group fails to collaborate. Consequently, homogeneity might be associated only with variables concerning the collaboration directly, not the, in this case, very distal measures regarding knowledge gain.

Homogeneity regarding the social level at which the biggest problem was located was not significantly associated with any outcome variable. Seemingly, it did not matter for collaborative learning whether groups agreed on who was affected by the biggest problem. This might be explained as follows: A homogeneous perspective on the social localization of a problem means that students are sure who has a problem and who does not. However, to achieve this clarity, an explicit conversation about who is affected by a problem and to which extent might be necessary (Borge et al., 2018; Hadwin et al., 2018). Yet, to solve this problem, students need to focus on the content of the

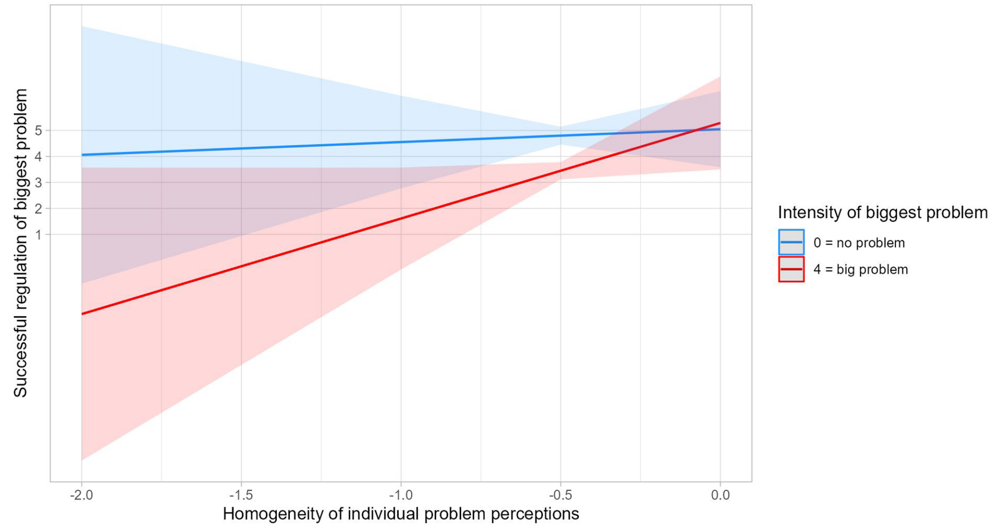

FIGURE 3
Interaction of homogeneity of individual problem perceptions and the intensity of the biggest problem.

problem and provide solutions for it. Therefore, a conversation about who is affected exactly might—at least in this case—be a waste of time. In the end, groups might be better off if they focus on the content of the problem and thereby ignore the social localization of it. By doing so, homogeneous and heterogeneous groups (regarding problem localization) might equally effectively regulate a problem.

Contrary to Melzner et al. (2020), we did not find immediacy and intensity of strategy use to be associated with regulation success. This also contrasts with Engelschalk et al. (2016), who found strategies to be selectively used for different kinds of problems, but it is in line with Schoor and Bannert (2012), who also did not find an effect of intensity of regulation strategy use on regulation success. To better interpret this finding, it is informative to take the difference between this study and the study by Melzner et al. (2020) into account: Melzner et al. (2020) investigated completely self-organized groups preparing for important exams for an extended period of time, while the present study explored a single session of collaborative learning during a regular lecture. Thus, we compare an extensive, high stakes setting to a less extensive, lower stakes setting. In addition, the level of autonomy and instructional support differed: In Melzner et al. (2020), the learning content, materials, and method were completely self-selected, while in the present study, learning content, respective resources and materials, and some aspects of the learning method were fixed. In other words, in the present study, the instructional context might have helped to pave the way for collaborative learning enough, so that the specific strategy choice and intensity of its application did not matter for regulation success as much, because just any regulation strategy (applied with random intensity) might have been good enough to overcome a (rather) insignificant problem. In addition, students might have had more than usual practice with acquiring knowledge through studying digital learning material and videoconferencing in the first semester of online learning in the COVID-19 pandemic.

The fact that the instructional support in the present study seemed to be sufficient is slightly surprising though: When taking recommendations for instructional design of instances of collaborative learning (Strauß and Rummel, 2020) into account, only few principles were realized here. Strauß and Rummel derived these empirically supported principles from the literature to guide instructors to organize effective collaborative learning. "They greatly increase the probability that students will engage in beneficial interaction (Strauß and Rummel, 2020, p. 256)." Our realization of collaborative learning did not contain much learner support that makes a successful collaboration particularly likely. This was, of course, on purpose because we wanted to mimic the conditions of self-organized study groups. For example, we did not support students' monitoring or script their interaction. Also, we did not design the task to create positive interdependence and did not adapt the level of complexity (all recommendations for effective instructional design from Strauß and Rummel, 2020). Instead, the task was designed to mirror the goal of self-organized study groups who usually have the goal to understand and memorize a given subject matter for an exam. For these reasons, we had to expect problems to occur similarly to self-organized collaborative studying and for learning to be less effective than with optimal instructional support.

The same is true for the technical realization: Only three out of seven affordances for computer supported collaborative learning that were proposed by Jeong and Hmelo-Silver (2016) were used here (video chat as communication means, concept map as representational tool, and facilitation of group formation). This constitutes only a basis for an interaction to happen, but it does not provide technological support for high-quality interaction. For example, sharing of not commonly shared knowledge was not encouraged, structuring the interaction was not enhanced, and monitoring and regulation was not supported by technology (Jeong and Hmelo-Silver, 2016). Therefore, it was likely that common problems of ineffective collaboration such as free riding, a lack of transactive dialogue (Vogel et al., 2016), and, consequently, an only superficial processing of the subject matter may have occurred.

These concerns are corroborated by considering what we know for sure regarding which concrete actions students performed themselves. As the instructional and technological design did not

TABLE 4 Case example Group 55.

Person (fictitious name)	Homogeneity	Biggest problem	Problem intensity	Biggest problem description	Self-regulation	Co-regulation (receiving support)	Co-regulation (giving support)	Socially shared regulation	Successful problem regulation	Satisfaction with the collaboration
Lisa	−0.23	Lack of technical functionality	4.00	Our group did not understand the software (Mind-Meister). The feature to create new bubbles and connect them with others did not work. We then switched to word, one edited the mind map and shared his screen. That worked faster and less complicated.	We noticed that we did not get along with the Mind-Meister program, so we agreed that one member of the group creates the mind map in a word document while sharing his screen. This was completely in line with my opinion.	Nothing, since we solved the problem together. We all had the same thoughts.	Since the problem with the software wasn't due to the group members, we were all looking for a solution together. I did not need to think for others.	We noticed that we did not get along with the Mind-Meister program, so we agreed that one member of the group creates the mind map in a word document while sharing his screen.	5	5.0
Carina	−0.27	Lack of technical functionality	1.33	Designing the mind map together was complicated and complex.	NA	NA	NA	We created the mind map using word and only one person drew and wrote it.	5	3.4
Vanessa	−0.20	Lack of technical skills	2.00	As a group we had the difficulty of not being able to use the Mind-Meister website because the website did not offer any operating assistance.	I need to talk to the others about the problem and look for an alternative together.	One group member took over the drawing of the mind maps, so that it was easier for us as a group to continue working productively and leave the technical problems behind us.	I talked to the others about the technical difficulties and together we found an alternative.	One group member created the mind map on Word and shared her screen with us so that we could follow and discuss the creation of the mind map via Skype.	5	4.6

10.3389/fpsyg.2024.1351723

10.3389/fpsyg.2024.1351723

TABLE 5 Case example Group 74.

Person (fictitious name)	Homogeneity	Biggest problem	Problem intensity	Biggest problem description	Self-regulation	Co-regulation (receiving support)	Co-regulation (giving support)	Socially shared regulation	Successful problem regulation	Satisfaction with the collaboration
Sabrina	−0.57	Lack of technical functionality	1.67	The Mind-Meister program did not work as we had imagined.	We wrote down the mind map differently than we wanted to.	The others also tried to understand the program.	I tried to understand the program.	We tried to understand the program.	5	3.2
Nicolas	−0.85	Unclear task definition	1.00	At the beginning, the task was not entirely clear to me. However, this became clear while working on it. I only realized what should be on the map and why when I reread the task.	I read through the task step by step (before the group work) and formulated it with my own words. The previous emails with the instructions for the task were not clear to me at first, but the problem was then clarified without disturbing the group dynamic.	There was no assistance by my group members for better understanding. Didn't explicitly ask for it either. Because the members understood the task well, I took even more time to understand it.	Not necessary. The problem was resolved before the start of the group phase.	Not necessary.	4	3.2
Alina	−1.13	Differing goals	3.00	Some group members were only aiming a quick completion of the work assignment, which also had a negative impact on the learning success of others.	I thought that I would take a closer look at the learning content for myself after the video conference so that I would at least remember some of the content. I would have wished for the content to be talked about and discussed more intensively, but I also did not want to hold the group back, since they—as I assume—wanted to be finished as quickly as possible, even though it then was done sloppily.	I went through parts of the presentation aloud with them, gave own examples, asked questions.	There's no point in just making everything quick and wishy-washy.	It does not have to be perfect, unnecessary effort can be spared.	2	2.8

particularly encourage students to engage in high-quality interaction, it remains unclear if students applied more than two strategies out of 10 (MacMahon et al., 2020), namely scheduling uninterrupted work and creating a shared concept map, which the authors recommended to students for effective learning.

In summary, we provided only very simple instructional and technical support (basically only initiating the collaboration and demanding a visualization) that distinguished the current setting from truely self-organized studying with zero instructional guidance. Nonetheless and surprisingly, our findings indicated that students did not need to employ the theoretically most beneficial regulation (i.e., immediate) strategies and to use strategies with sufficient intensity to succeed in this collaborative learning. This may mean that a low-level instructional support already makes a big difference and helps to simplify the dynamics of self-organized collaborative learning in a way that students cope successfully with upcoming problems.

We conclude that the full model of problem regulation shown in Figure 1 might only apply to truly self-organized learning contexts with sufficient prevalence of problems, while problem regulation might follow a simpler process that involves only relying on a shared problem perception when problems are low due to effective instructional support. Yet, further research is needed to test this interpretation.

7 Limitations

When interpreting the results, we have to take the following limitations into account. First, neither the predictor variables nor the subjective measures of regulation success were associated with the results of the objective knowledge test. In addition to the explanation regarding the nature of the task discussed above, there are several further possible explanations for this: It might be that the actual knowledge is influenced by many other variables not in the scope of this study which might increase unsystematic error variance, making it difficult to find small effects. Alternatively, the lack of a significant association might be due to the low prevalence of problems which might have created a ceiling effect, therefore reducing variance and possible covariation. Previous research indicated that groups dedicate only a small amount of a session of collaborative learning to regulation of problems (Nguyen et al., 2023). The vast majority is available to focus on the subject matter. Therefore, it is unlikely that regulation has a large impact on learning gains as long as the problem intensity is generally low. Furthermore, a lack of validity of the test might also be responsible for the lack of associations with other variables in this study. We have no data on validity of the test beyond item analyses and our careful mapping of learning material content to test items to test this possibility.

Second, all measures (except the knowledge test) were based on self-report, though regulation strategies were measured by open-ended questions at least in order to reduce social desirability bias. True associations might be different.

Third, localizing the biggest problem at different social levels might be difficult for students. Especially, it might be hard to guess how much others were affected by a problem. Therefore, our measurement might include a lot of random variation which obscures any potential effect.

Fourth, we operationalized regulation intensity using the number of strategies which students mentioned. However, this represents the construct of intensity only partly. In principle, learners could have exhibited a single strategy very intensely, too. Prior research mostly used only frequency of regulation strategies as indicator of regulation intensity (Cumming, 2010; Schwinger et al., 2009; Su et al., 2018). Though, in principle, intensity might be measured by how often and how long students tried a certain strategy, and how much effort they invested to try to make that strategy work. Therefore, a more comprehensive measurement of intensity should include both aspects, number of strategies and implementation frequency, duration, and effort for each strategy. Such a measurement of intensity might yield stronger effects on regulation or learning success.

Fifth, the study took place in the first semester following the onset of the COVID-19 pandemic. At that time, students might not have been as familiar with videoconferencing as they are now, although the study was more at the end of the semester. This might explain some of the technical difficulties students had, qualifying this part of the descriptive findings presented in Figure 2.

Sixth, descriptive results of problem intensity might be biased. In principle, it is possible that groups who encountered severe problems broke off from the collaboration and did not answer the questionnaire afterwards. Therefore, especially the most severe problems might not be represented in the data. Unfortunately, we have no data to check whether this was the case. We can only say that the available rating scale was used to full extent (see Figure 2).

Seventh, we do not know how well group members knew each other or whether they already worked together in other courses. In other studies, subjective outcomes are fostered by group members familiarity with each other (Crompton et al., 2022; Janssen et al., 2009; Zhang et al., 2023a; Zhang et al., 2023b), whereas findings regarding objective performance are less conclusive and often find no effect (Crompton et al., 2022; Janssen et al., 2009). As the two lectures were large and students came from many different subjects, we assume that a considerable proportion of group members might have been unfamiliar with each other. However, with our data, we cannot determine to which extent familiarity with each other moderates our findings.

Eighth, our findings should not be generalized to other group sizes. In our study, group sizes ranged from two to three. These group sizes should reflect typical sizes of self-organized study groups. Larger groups might suffer from more coordination issues and a higher likelihood of free-riding and other phenomena indicating a reduced individual engagement. However, research draws a differentiated picture of an optimal group size (Wang et al., 2023), favoring either two, three, or four people per group. Therefore, groups with four or more students might function differently.

8 Implications

The interpretation of the differences between the findings in the previous study by Melzner et al. (2020) and the results in the present study has important implications for theory building: A new theoretical model of problem regulation during collaborative learning needs to be developed that (a) includes problem intensity as a moderator of the relations between problems, their regulation, and learning outcome, and (b) takes the context regarding its incentive structure (i.e., low vs. high stakes) into

10.3389/fpsyg.2024.1351723

account. For teaching practice, the study might imply that recommendations of good instructional design for collaborative learning (see above) also apply to relatively self-organized online collaborative learning and that simple and few scaffolding aids might already help to reach satisfying collaboration success.

Data availability statement

The dataset presented in this study can be found in the online repository Open Science Framework at: https://osf.io/68by5/.

Ethics statement

Ethical approval was not required for the study involving humans because the study complies with the ethical guidelines of the German Psychology Association. The study was conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

MG: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Visualization, Writing – original draft, Writing – review & editing. LS: Conceptualization, Investigation, Methodology, Project administration, Writing – review & editing. KF: Conceptualization, Investigation, Methodology, Project administration, Writing – review & editing. IK: Conceptualization, Funding acquisition, Methodology, Supervision, 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

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Virtually isolated: social identity threat predicts social approach motivation via sense of belonging in computer-supported collaborative learning

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Collaboration improves multiple academic and social outcomes. Accordingly, computer-supported collaborative learning (CSCL) can be beneficial in distance education contexts to overcome the issues specific to online learning (e.g., underperformance, low identification with university). Distance universities often attract a substantial number of non-traditional students (e.g., students with disability, students with migration background). Despite their representation, non-traditional students face negative stereotypes and associated social consequences, including social identity threat, diminished sense of belonging, and less motivation for social interactions. In the context of online learning, where there is little individuating information, social categories like socio-demographic group memberships become salient, activating stereotypes. Consequently, socio-demographic group memberships can have detrimental consequences for the integration of non-traditional students. The purpose of the present study was to (a) determine the extent of social identity threat for students in higher distance education, (b) explore the social consequences of this threat in the same context, (c) validate these findings through longitudinal analyses embedded in a CSCL task, and (d) use learning analytics to test behavioral outcomes. In a longitudinal study with three measurement occasions over 8 weeks (N = 1,210), we conducted path analyses for cross-sectional associations and Random Intercept Cross-Lagged Panel Models for longitudinal predictions. The results showed that non-traditional students mostly reported higher social identity threat than traditional students. While the expected longitudinal within-person effects could not be demonstrated, we found stable between-person effects: students who reported higher levels of social identity threat also reported lower sense of belonging and lower social approach motivation. Exploratory analyses of actual online collaboration during CSCL offer potential avenues for future research. We conclude that social identity threat and its social consequences play an important role in higher distance education and should therefore be considered for successful CSCL.

KEYWORDS
behavioral data, higher distance education, collaborative writing, social psychology, random intercept cross-lagged panel model

1 Introduction

Underperformance, dropout, and low identification with the university are commonly discussed issues in higher distance education (e.g., Stoessel et al., 2015). Computer-supported collaborative learning (CSCL) is a promising format to address these issues (Kirschner et al., 2004). Collaborative learning formats are associated with positive academic and social outcomes, such as improved performance and class attendance, student familiarity with the faculty, and understanding of diversity (Panitz, 1999; Roberts, 2005). CSCL uses technology to improve learning in the context of reading and writing tasks (Stahl et al., 2006) through collaboration. Research has shown that the key aspect of collaboration, namely social learning (Roschelle and Teasley, 1995), is associated with improved academic achievement (Talan, 2021), more frequent interactions with peers (Shin et al., 2020), and problem-solving skills. CSCL thus has the potential to address the described issues related to academic and social outcomes in higher distance education.

The high degree of temporal and spatial flexibility in higher distance education leads to a heterogeneous student body and an overrepresentation of non-traditional students at distance education institutions (i.e., students from sociodemographic groups who have been underrepresented in higher education in the past; e.g., students with disability, students with migration background; Schneller and Holmberg, 2014; Stoessel et al., 2015). However, non-traditional students are particularly at risk of underachievement and dropping out of higher education (Stoessel et al., 2015). Therefore, we argue that given the above-mentioned advantages, digital collaborative learning can be beneficial especially for non-traditional students. Moreover, the reduction of performance gaps between traditional and non-traditional students is an important goal especially at higher distance education institutions (Stoessel et al., 2015) and could be motivated by diversity being associated with several advantages for all students, e.g., increased intercultural competencies, understanding, and empathy, better preparation for employment in the global economy, or increased engagement in political issues and participation in democratic processes (Wells et al., 2016). Furthermore, the financial and reputation-related losses due to student dropout from the universities' perspective (Raisman, 2013) might contribute to the motivation to reduce academic underperformance of specific groups.

1.1 Social identity threat as a potential risk in higher distance education

Despite the advantages of higher distance education for non-traditional students and the potential benefits of CSCL described above, social-psychological research has identified risks of increased stereotyping and associated negative consequences for non-traditional students during computer-mediated communication. In the current research we investigate CSCL in the form of a collaborative writing task spanning several weeks. This type of CSCL predominantly involves asynchronous computer-mediated communication, where information about individual traits and characteristics of a person (i.e., individuating information) is less frequent than information about social category memberships (e.g., age, gender, ethnicity). Social categories are more salient compared to face-to-face contexts (Postmes et al., 2001; Spears et al., 2002) and we therefore assume that stereotypes associated with social categories are prone to be activated in CSCL as investigated in the current research.

The diverse student body in higher distance education includes numerous student groups that are stereotypically associated with low academic competence (e.g., students with chronic illness, students with non-German native language; Bick et al., 2022). These student groups are thus at risk of experiencing detrimental consequences when negative competence-related stereotypes are activated. One prominent consequence of stereotype activation is social identity threat (Steele and Aronson, 1995; Schmader et al., 2008; Spencer et al., 2016). According to social identity theory (Tajfel and Turner, 1979), people strive for a positive social identity (i.e., a positive differentiation or distinction of one's own group from other groups). Negative stereotypes threaten this positive social identity, which leads to impairments in various domains. For example, as second-language learners are often stereotypically associated with low verbal competence, a student with non-native language might worry that their contributions in a collaborative writing task might be negatively evaluated by others in the CSCL group. This worry in turn makes it more difficult for them to show their full intellectual potential and feel like they fit in at university and the CSCL group. A large number of studies has shown performance-related consequences of social identity threat in face-to-face contexts, e.g., for women (Schmader, 2002; Bell et al., 2003), older people (Hess et al., 2003; Lamont et al., 2015), or immigrants (Steele and Aronson, 1995; Appel et al., 2015). However, to our knowledge a systematic investigation of social identity threat in higher distance education is still lacking. Additionally, a first study about widespread stereotypes about student groups in distance education showed that stereotypes about student groups are to some extent specific to the context of higher distance education (e.g., positive evaluation of older students; Bick et al., 2022). Therefore, the first aim of the current research is to investigate the extent of social identity threat experienced by students identifying with different sociodemographic student groups at a large German distance university.

1.2 Consequences of social identity threat for social relationships

In addition to the well-investigated performance-related consequences of social identity threat, a growing body of research focuses on social consequences of social identity threat (Good et al., 2012; Martiny and Nikitin, 2019; Rahn et al., 2021; Froehlich et al., 2022). As CSCL is inherently a social activity, the second aim of the current research is therefore to investigate these social consequences of social identity threat in higher distance education. One consequence is that people disengage with the academic field in which the negative stereotype occurs and no longer identify with it (Steele et al., 2002; Woodcock et al., 2012). Accordingly, disidentification from academia is most common among students who face negative stereotypes in higher distance education, i.e., non-traditional students (e.g., Gopalan and Brady, 2020). One aspect of disidentification is the questioning of one's social ties and the feeling of not "fitting in" (i.e., belonging uncertainty; Walton and Cohen, 2007). A lower sense of belonging to academia is in turn associated with academic disadvantage (Mahoney and Cairns, 1997; Walton and Cohen, 2011; Good et al., 2012) as well as lower engagement for studying and lower intention to stay at university, particularly for ethnic minority students (Zea et al., 1997; Just, 1999; Wolf et al., 2021). Non-traditional students might therefore be disadvantaged due to a lack of social connectedness (Yildirim et al., 2021).

Most research on sense of belonging in the educational domain focuses on students' sense of belonging to academia in general or to their academic institution (e.g., Meeuwisse et al., 2010; Abdollahi and Noltemeyer, 2018; Martiny and Nikitin, 2019). Differentiating specific domains to which students report they belong led to a more accurate understanding of which domain is relevant to students in different contexts (e.g., Good et al., 2012). In higher distance education, students might only weakly identify with the university as they rarely visit the campus. When students collaborate in virtual study groups, their sense of belonging to the study group might in fact be more important than their sense of belonging to the university. Research with high-school students in face-to-face education has shown different findings with regard to sense of belonging to the class or school (Froehlich et al., 2023). Therefore, in the present research we assess sense of belonging to the CSCL group and to the university. We expect sense of belonging to the CSCL group to be more closely linked to social identity threat and our outcome variables related to social relationships. We also investigate whether the results with sense of belonging to the university are comparable to the results with sense of belonging to the CSCL group.

The main outcome variables in the current research are students' motivation and behavioral tendencies to form peer relationships and their collaboration behavior during the CSCL task. We base our predictions for these outcome variables on previous research conducted in face-to-face learning contexts, extend the research focus to computer-mediated communication, and use learning analytics to shed light on the potential social consequences of social identity threat in CSCL. In studies with immigrant students in Norway and Germany, students who reported higher social identity threat also reported lower sense of belonging (Froehlich et al., 2022, 2023). In addition, these studies examined sense of belonging as a mediator between social identity threat and social approach motivation, as well as behavioral intentions for contact as outcome measures for social connectedness. Social approach motivation (i.e., the motivation to initiate and maintain social relationships; Elliot et al., 2006) is associated with less loneliness and more satisfaction with social ties (Gable, 2006), which in turn is associated with physical health and subjective well-being (Hawkley and Cacioppo, 2010; Nikitin et al., 2012). Especially for non-traditional students who are struggling with family obligations or chronic illness, or who have difficulties in accessing information due to language difficulties, social approach motivation in educational contexts might play a crucial role, as social relationships at university bring study-related advantages (e.g., Ma and Yuen, 2011; Raaper et al., 2022).

1.3 Methodological advancements when investigating social identity threat in distance education: longitudinal analysis and learning analytics

Previous research has found that sense of belonging mediates the relationship between social identity threat and social approach motivation among participants with different social identities, of different age, and in different European countries (Martiny and Nikitin, 2019; Rahn et al., 2021; Froehlich et al., 2022, 2023). The present study aims to replicate these findings with heterogeneous student groups in higher distance education and thus to corroborate the generalizability of the effect. Moreover, the social consequences of social identity threat have so far mainly been investigated in cross-sectional studies which provide only limited evidence on the directionality of the effects. The third aim of the present research is therefore to investigate the meditation of social identity threat and social approach motivation by sense of belonging in a longitudinal design to test the proposed directionality of effects. CSCL tasks often involve collaboration over several weeks during the semester so that multiple measurement occasions can be integrated into the online learning environment. A longitudinal design allows us to test whether associations can be replicated at the level of individual students (within-person effects), while the between-person effects are statistically accounted for in a Random Intercept Cross-Lagged Panel Model (RI-CLPM; Hamaker et al., 2015). Thus, within- and between-person effects that have been confounded in previous cross-sectional studies can be disentangled to investigate whether the hypothesized associations of social identity threat, sense of belonging, and social outcomes are between-person (i.e., reflecting a stable rank order between students in classrooms or distance education courses) or within-person (i.e., reflecting psychological processes that unfold over time at the intraindividual level).

The fourth and final aim of the present research is to expand the outcome variables concerning the social consequences of social identity threat and make use of behavioral data available through learning analytics in the context of distance education. To complement previous research in face-to-face contexts (Froehlich et al., 2022), we assessed the same self-report outcome variables of social approach motivation and behavioral intentions for contact with other students. The assessment of behavioral intentions is common in social psychology because the measurement of actual behavior is difficult and resource-intensive in many traditional study designs. However, there is usually a gap between intentions and actual behavior (Webb and Sheeran, 2006). The mainly asynchronous CSCL context of the present study, in which students' behavior is stored in databases and logfiles, provided a unique opportunity to combine established self-report measures with measures of student behavior in virtual groups using collaborative distance learning tools. To this end, we used data from students' interactions around a collaborative writing task to conduct social network analysis directly reflecting the social relationships between students. These data refer to the group communication and coordination in a course-related

Moodle forum and the actual shared writing process in a real-time collaborative text editor.

1.4 The present research and hypotheses

Based on the considerations outlined above, we argue that low social identity threat, high sense of belonging, and high social approach motivation are important prerequisites to successful CSCL. Furthermore, we are convinced that collaboration can be especially beneficial for non-traditional students who are overrepresented in higher distance education. Thus, the higher distance education context is very suitable for the investigation of the role of social identity threat and sense of belonging for social approach motivation and peer relationships. Accordingly, the Hypotheses of the present study are threefold. First, we descriptively investigate perceived social identity threat for different student groups to identify groups who are particularly at risk for social identity threat in higher distance education. Second, we expect to replicate the cross-sectional findings on the relationship between social identity threat and social approach motivation via sense of belonging, previously shown in face-to-face contexts (e.g., Martiny and Nikitin, 2019; Froehlich et al., 2022, 2023), in the context of higher distance education. Third, we apply data-driven methods in a longitudinal field study to validate self-report findings with data from actual learner interactions over time. We apply a learning analytics approach combining self-report data and behavioral data. During a CSCL task spanning several weeks, we collected self-report data at multiple occasions. In addition, we collected fine-grained process data (e.g., Moodle forum activity, writing/ deleting/ copying/ pasting/ formatting text) of learning activities taking place within the online learning environment. At the beginning of the semester, students participated in a demographic survey (T0). After being assigned to the CSCL groups and a phase of getting to know each other, students participated in the first survey (T1). This was followed by two working phases of the CSCL task with an interim survey (T2) and a final survey (T3).

We investigated the following pre-registered Research Question (RQ) and Hypotheses (H[1]) which are depicted in Figure 1: We descriptively investigated perceived social identity threat for different student groups at different measurement occasions (RQ). We hypothesize a simple cross-sectional mediation with higher social identity threat negatively predicting self-reported social approach motivation via lower sense of belonging at T1 (H1). Further, we hypothesize a serial cross-sectional mediation with social identity threat as the predictor, sense of belonging and social approach motivation as mediators, and self-reported behavioral intentions as outcome at T1 (H2). Third, in a simple longitudinal mediation model, we expect higher social identity threat at T1 to negatively predict social approach motivation at T3 via lower sense of belonging at T2 (H3). Furthermore, in another longitudinal mediation model, we expect that higher social identity threat at T1 negatively predicts the behavioral measure of the individuals' integration in the CSCL group (i.e., discussion outdegree) during the final cooperation phase (between T2 and T3) via lower sense of belonging at T2 (H4).

2 Materials and methods

The study was conducted in accordance with open science principles (pre-registration of Hypotheses, open materials, open data). The pre-registration, materials, data, and script can be found on the OSF: https://osf.io/axq7k/.

2.1 Participants and data collection

Data collection for this study was embedded in a superordinate project implemented in a mandatory course of the introductory module of the Bachelor's degree program in psychology at a large distance university. The beginning of the Bachelor's degree is an important academic transition to higher distance education. In addition, it provides the best opportunity to investigate social identity threat and its consequences, as the dropout rate is highest in the first two semesters when the introductory module takes place (Neugebauer et al., 2019). During the course, students interacted in a course-related Moodle forum. The longitudinal design consisted of three voluntary measurement occasions with self-report questionnaires in Unipark[2] with two- or three-week intervals. At the beginning of the semester, students completed a demographic survey (T0). They were then assigned to CSCL groups of eight and had 2 weeks to get to know each other. The first main measurement (T1) was conducted before the first CSCL phase started. The first CSCL phase consisted of 3 weeks in which students collaborated to summarize the introduction and the methods sections of a peer-reviewed journal article. The second measurement (T2) was conducted afterwards. The subsequent second CSCL phase again consisted of 3 weeks in which the results and discussion sections of the same article were summarized, followed by the final measurement (T3). Both CSCL tasks were completed online in individual Etherpad Lite instances[3,4] for each CSCL group which were provided by a Collaborative Learning Platform to support collaborative writing in large-scale distance education (Burchart and Haake, 2023). Each CSCL group was provided with an individual Etherpad Lite instance containing only the Etherpad documents (Pads) of the particular group. Therefore, the actual collaboration took place during the working phases in the shared text documents of the group, whereas the Moodle forum served as a communication platform during all three phases. The self-report measures (i.e., group identification, social identity threat, sense of belonging, social approach motivation, behavioral intentions for contact) were presented in the final section of the superordinate project's survey at all three measurement occasions (T1–T3) and the demographic survey (T0).However, self-report measures at T0 were incomplete (i.e., only group identification, social identity threat, and sense of belonging to the university assessed) due to a programming issue. Students were informed about data protection, the content and duration of the

1 https://osf.io/rymzb/

2 https://www.unipark.com/

3 https://github.com/ether/etherpad-lite

4 https://etherpad.org/

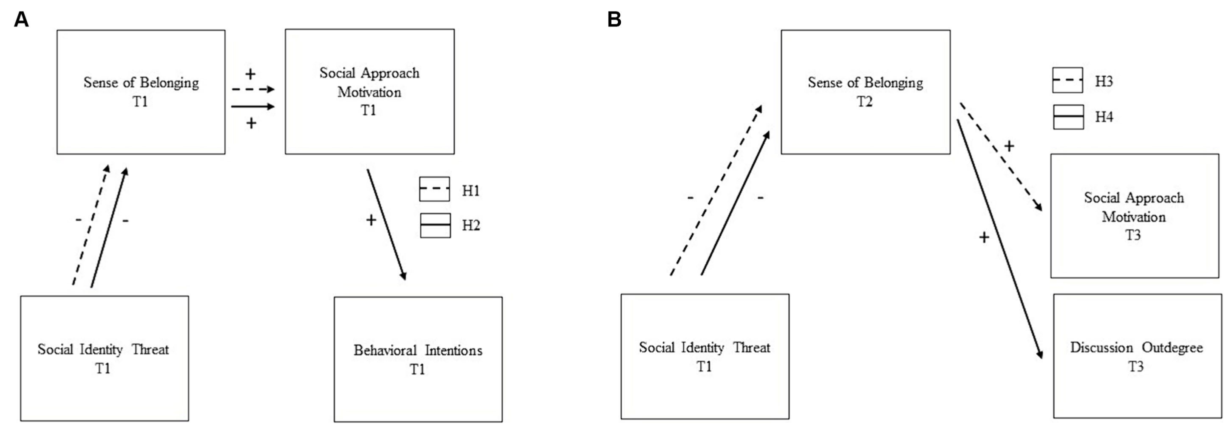

FIGURE 1
Expectations regarding cross-sectional **(A)** and longitudinal **(B)** Hypotheses. All variables depicted in **(B)** were assessed before/ at T1, T2, and T3. To reduce complexity, only the time points relevant to our hypotheses are presented. The corresponding RI-CLPM are shown in Figures 4, 5.

survey, and provided written consent for participation according to EU General Data Protection Regulations and research ethics guidelines by the American Psychological Association (APA), the German Psychological Association (DGPs), and the Declaration of Helsinki (World Medical Association Declaration of Helsinki, 2013). Within each main measurement occasion, students started with indicating which student group(s) they identified with. Next, items on sense of belonging to the university and the CSCL group, social approach motivation, and behavioral intentions for contact were completed. Finally, the students provided written consent to the scientific use of their data. To match data from the surveys, students generated an individual pseudonymized code. Survey data were matched with behavioral data from Moodle and Etherpad Lite by an independent data trustee. Since data were collected using three different systems (Unipark, Moodle, Etherpad Lite) students were assigned to individual identifiers in each system. It was ensured that none of the researchers involved had technical access to more than one of these three systems. The data trustee replaced the respective identifiers of the individual systems with a unique key for each student. The unique key consisting of a 41-digit hexadecimal code was generated using a hash function including a secret salt. For ensuring data privacy requirements, this unique key can only be related to the identifiers of the three systems by the data trustee but not by the involved researchers, administrators, or teachers.

Data were collected from October to December 2022. Survey participation was compensated with course credit. We applied the following pre-registered exclusion criteria: After excluding participants who did not answer any of our main items ($n=631$), did not consent to the scientific use of their data ($n=22$), or did not identify with at least one of the student groups ($n=57$), $N=1{,}210$ undergraduate psychology students were included in the sample. Of those who completed the demographic survey at T0 ($n=694$), 52.7% were under the age of 30 and 46.8% were 30 years or older. Furthermore, 69.8% indicated a female and 28.7% a male gender. Around a quarter (25.5%) stated that they have a migration background and 14.0% reported that their native language is not German. More than a third (35.3%) reported to be in full-time employment. Due to dropout during the course, the CSCL groups differed regarding their number of active students. On average, 4 to 5 of the 8 students assigned to each group actively contributed to the CSCL task, $M_{T1}=4.4$, $SD_{T1}=1.3$; $M_{T2}=4.8$, $SD_{T2}=1.5$; $M_{T3}=4.3$ $SD_{T3}=1.3$.

Sample size was determined by the number of students in the introductory module of the Bachelor's degree program in psychology who voluntarily participated in the survey. We therefore relied on pre-registered rules of thumb to determine the statistical power for testing our Hypotheses. According to Pan et al. (2018, tbl. 5), our sample was sufficiently large (i.e., $N>544$) for a longitudinal mediation analysis based on Bootstrap estimation with three measurement points, high intra-class correlation (ICC = 0.90), and small effects (i.e., $b=0.14$) for the a and the b path. Note that we incorrectly referred to Table 4 (medium intra-class correlation; ICC = 0.60) instead of Table 5 (Pan et al., 2018) in the pre-registration, resulting in a smaller pre-registered sample size ($N=385$). However, the achieved sample of $N=1{,}210$ was larger than the required minimum sample sizes in both tables so the statistical power was sufficiently large to test the pre-registered Hypotheses.

2.2 Measures

2.2.1 Self-report measures

As a measure of *group identification,* students indicated which sociodemographic student group(s) they identified with at university over the course of the semester. Ten student groups were presented based on previous research on stereotypes about student groups in higher distance education (Bick et al., 2022): female students (students who identify with the female gender), male students (students who identify with the male gender), students with chronic illness (students who have a chronic-somatic or mental illness), students with disability (students with a self-reported disability or a health-related impairment), students with children (who raise at least one [own] child under the age of 18), full-time employed students (students who are employed for at least 30 h per week), older students (students who are older than 30 years of age), younger students (students who are up to 30 years of age), students with migration background (students who have at least one parent who was born in another country or who were born in another country themselves), and students with non-German native language (students who have a native language other than German). When participants indicated that they did not identify with any of the 10 groups, the option to choose other responses as well was deactivated.

All further self-report measures were assessed on a five-point Likert scale from "does not apply at all" to "fully applies." *Social identity threat* was measured separately for each group the students indicated with four items based on Martiny and Nikitin (2019): "I am concerned that I will confirm stereotypes about the abilities of #Group# at university," "I am concerned that stereotypes about #Group# might hinder my performance at university," "I am concerned that the stereotypes about #Group# are true," "I am concerned that the stereotypes about #Group# might influence how others judge my performance at university."

Sense of belonging to university was measured with an eight-item scale based on Good et al. (2012): "At the FernUniversität, I feel accepted," "At the FernUniversität, I feel respected," "At the FernUniversität, I feel valued," "At the FernUniversität, I feel appreciated," "I feel like I belong at the FernUniversität," "I feel like a member of the group of students at the FernUniversität," "I feel connected to other students at the FernUniversität," "I feel like I am a part of the students at the FernUniversität." The same eight items were applied for sense of belonging to the CSCL group by only replacing "university" by "study group."

Social approach motivation was measured with four items based on Gable (2006) which were already applied in the context of higher education by Froehlich et al. (2022): "I try to get a deeper relationship with other students," "I try to get relationships with other students that develop positively," "I try to strengthen bonds and intimacy in my relations to other students," "I try to share many fun and meaningful experiences with other students."

Behavioral intentions for contact were assessed with three items based on Froehlich et al. (2022): "I plan to join an organization to meet other students in the near future," "I will contact other students to start/join a study group in the near future," and "I will volunteer at various events that the university holds in the near future."

Off-system behavior, a control variable, was measured with three self-generated items: "In our group, we have used other media than Moodle for task-related exchange," "In our group, we have used other media than Moodle for content-related collaboration on the task," "In our group, we have used other media than Moodle for personal exchange." Further measures collected for the superordinate project are available on request.

2.2.2 Behavioral measures

During each phase of the collaboration (getting to know each other, CSCL phase 1, CSCL phase 2), forum activity in the course-related Moodle discussion boards was collected. Applying social network analysis, we computed *discussion outdegree* (i.e., number of replies to other students' threads in the course-related Moodle forum) as our main behavioral measure for student interaction.

Access to the data on student activity in the Etherpad Lite was not available at the time of the pre-registration of the present study. We only received access to this measure after the end of the semester and included exploratory analyses with the Etherpad Lite data as a measure of actual task collaboration. With another social network analysis, we computed *Etherpad outdegree* (i.e., edits made by a student in a text that has been written by another student). Additionally, *Etherpad text edits* (i.e., sum of all operations of a student in the text, e.g., writing/ deleting/ copying/ pasting/ formatting) was investigated for the exploratory analyses since these measures best represented behavior aligned with social approach motivation in the CSCL context. Furthermore, key-strokes, clickstreams, and scroll data in the Etherpads were collected for analyses in the scope of another project.

2.3 Data analysis

All multi-item measures had sufficient reliability ($\alpha s > 0.82$) and were aggregated into scales. Social identity threat was additionally aggregated across all groups to which each student had responded. For cross-sectional and longitudinal mediation analyses, all predictor variables were z-standardized. Because of the large differences in range and variances between self-report and behavioral data, we z-standardized all predictor and outcome variables before computing bivariate correlations. Since RI-CLPM consider only one level of nested data in the exploratory analyses (i.e., measurements nested within individuals), we accounted for the second level (i.e., students nested in CSCL groups) by conducting robustness checks including clustering for the CSCL group level for all pre-registered Hypotheses. Detailed results of robustness checks are reported in Supplementary material S1. We applied robust Maximum Likelihood estimation to consider the outcome variable of discussion outdegree which violated the assumption of normality as it was left-skewed. Additionally, we implemented Full-Information Maximum Likelihood estimation to take missing data into account.

The forum interaction data was represented as a social network graph $G = (S, L)$, where S is a set of nodes representing forum participants s and L is a set of directed edges of which the included elements are called *links* representing forum posts of respondents answering forum posts of original posters. Social network centrality measures were computed to analyze interactions within Moodle forum discussions. Each response to a forum post was interpreted as establishing a directed *link* $l \{s_x, s_y\}$ between two participants, where the respondent s_x is connected to the original poster s_y. *Discussion outdegree* was calculated as the number of outgoing links (answers to different original posters) from each student, reflecting their social connection in the forum discussions. This approach allowed for a comprehensive analysis of the social dynamics within the Moodle forums, identifying key actors and understanding the flow of interactions.

Etherpad Lite stores individual text edits of the collaborative text editor using the Easysync Protocol which encodes the affected characters, their position in the text, and the applied formatting operations. The edits collected from Etherpad Lite were used to determine the overall number of edits per students and time period. For each edit, the authors of the character on the left and right side of the inserted or removed character were identified at the respective time and document status. Thus, we counted how often a student had changed the document at a specific position in the text given that the neighboring characters were previously contributed by themselves or another student in the same group. Furthermore, it was counted whose text has been added to or deleted by another student. In this way, it was possible to quantify students' task-related collaboration in the text. For social network analysis, a graph $G = (S, L)$ was constructed, where S is a set of *nodes* representing students s in the group, and L is a set of paired and directed vertices of which the included elements are called *links*. Each *link* l $\{s_x, s_y\}$ represents an editing operation of student s_x directly next to the text that was formerly added by s_y. We calculated *Etherpad outdegree* as the outdegree of a node which indicates the number of times a student s made changes (adding, removing, formatting) to a text that was previously contributed by another student in the same group. Although it is most closely aligned with self-reported social approach motivation and *discussion outdegree*, it reflects only a limited range of all potential collaborative writing activities. Therefore, we also computed *Etherpad text edits* to get a more encompassing measure of what each student contributed to the CSCL assignment.

Hypothesis testing was conducted with R version 4.2.2 and RStudio version 2023.06.0 + 421 (R Core Team, 2022; Posit team, 2023). To investigate Research Question 1, we computed an analysis of variance (ANOVA) with Bonferroni-corrected post-hoc tests with stats (R Core Team, 2022). Cross-sectional Hypotheses (H1 and H2) were tested with path analyses using lavaan (Rosseel, 2012). Longitudinal Hypotheses (H3 and H4) were tested with RI-CLPM (Hamaker et al., 2015) using lavaan (Rosseel, 2012).

3 Results

Descriptive statistics and bivariate correlations of all variables included in the analyses are presented in Table 1. Social identity threat was negatively associated with sense of belonging but not with social approach motivation. Sense of belonging was positively associated with social approach motivation and behavioral intentions for contact with peers. Social approach motivation was positively associated with behavioral intentions. Discussion outdegree was not associated with any other measure.

We report the results for sense of belonging to the CSCL group as the main mediator throughout the manuscript. The results of additional analyses with sense of belonging to the university as an alternative mediator were similar to the results for sense of belonging to the CSCL group except for one path that is shown in Supplementary Table S2e. Detailed results with sense of belonging to the university as a mediator are reported in Supplementary material S2.

3.1 Levels of social identity threat in different student groups

To investigate Research Question 1, we compared perceived social identity threat for different student groups at all measurement occasions. As depicted in Figure 2, students with chronic illness, students with disability, students with children, full-time employed students, and students with non-German native language reported higher levels of social identity threat across all measurement occasions, whereas female students, male students, older students, younger students, and students with migration background reported lower levels of social identity threat.

3.2 Cross-sectional analyses

Path models to test Hypotheses 1 and 2 are depicted in Figure 3. To investigate Hypothesis 1, we computed a manifest cross-sectional simple mediation model with social identity threat as the predictor, sense of belonging to the CSCL group as the mediator, and social approach motivation as the outcome. All variables were assessed at T1. The model was fully identified (i.e., included all possible paths). Results revealed that social identity threat negatively predicted sense of belonging, $\beta = -0.22$, 95% CI [−0.29, −0.15], $SE = 0.03$, $p < 0.001$, and positively predicted social approach motivation, $\beta = 0.09$, 95% CI [0.02, 0.16], $SE = 0.03$, $p = 0.008$. In turn, sense of belonging positively predicted social approach motivation, $\beta = 0.35$, 95% CI [0.28, 0.42], $SE = 0.03$, $p < 0.001$. As expected, the indirect effect was negative and significant, $\beta = -0.08$, 95% CI [−0.11, −0.05], $SE = 0.01$, $p < 0.001$, reflecting that social identity threat was associated with a reduced feeling of fitting in and in turn a reduced motivation to approach others.

To investigate Hypothesis 2, we computed a cross-sectional serial mediation model with social identity threat as the predictor, sense of belonging to the CSCL group as the first mediator, social approach motivation as the second mediator, and behavioral intentions for contact as the outcome. Again, the model was fully identified and all variables were assessed at T1. Results showed that social identity threat negatively predicted sense of belonging and positively predicted social approach motivation (see Table 2). Sense of belonging positively predicted social approach motivation. Social approach motivation positively predicted behavioral intentions for contact. Again, as expected the indirect effect was negative and significant. Results for cross-sectional Hypotheses did not differ in additional models including robustness checks (see Supplementary material).

3.3 Longitudinal analyses

To investigate Hypothesis 3, we conducted a RI-CLPM with social identity threat, sense of belonging to the CSCL group, and social approach motivation at the three measurement occasions (T1-T3). The models included autoregressive paths and the hypothesized within-person effects: social identity threat at earlier measurement occasions predicted sense of belonging to the CSCL group and social approach motivation at later occasions. Additionally, sense of belonging to the CSCL group at earlier occasions predicted social approach motivation at later occasions (see Figure 4). According to Hamaker et al. (2015) and our Hypotheses, we only allowed first-order autoregressive effects and cross-lagged paths from one measurement occasion to the next. The only path across two measurement occasions included in the model was the direct effect from social identity threat at T1 on social approach motivation at T3, since it was necessary for testing the longitudinal mediation Hypothesis. Random intercepts and residual variances were allowed to correlate. The model showed good fit, χ^2 (8) = 11.73, RMSEA =0.02, CFI = 1.00, TLI = 0.99, SRMR = 0.01. Social identity threat at T2 positively predicted sense of belonging at T3, $\beta = 0.17$, $SE = 0.06$, $p = 0.008$. However, there were no further significant direct effects of social identity threat on sense of belonging and social approach motivation or of sense of belonging on social approach motivation (see Supplementary material S3). Furthermore, the expected within-person indirect effect of social identity threat at T1 on social approach

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TABLE 1 Means, standard deviations, and correlations of all variables.

Variable	*M*	*SD*	Social identity threat T1	Social identity threat T2	Social identity threat T3	Sense of belonging T1	Sense of belonging T2	Sense of belonging T3	Social approach motivation T1	Social approach motivation T2	Social approach motivation T3	Behavioral intentions T1
Social identity threat T1	1.7	0.7										
Social identity threat T2	1.6	0.7	0.70** [0.66, 0.74]									
Social identity threat T3	1.7	0.8	0.69** [0.64, 0.73]	0.73** [0.69, 0.77]								
Sense of belonging T1	3.8	0.8	−0.21** [−0.27, −0.14]	−0.17** [−0.24, −0.09]	−0.19** [−0.27, −0.11]							
Sense of belonging T2	3.7	1.0	−0.13** [−0.21, −0.05]	−0.17** [−0.23, −0.11]	−0.19** [−0.26, −0.11]	0.47** [0.41, 0.53]						
Sense of belonging T3	3.7	1.0	−0.15** [−0.23, −0.07]	−0.12** [−0.19, −0.04]	−0.14** [−0.21, −0.07]	0.40** [0.33, 0.47]	0.68** [0.64, 0.72]					
Social approach motivation T1	2.8	1.0	0.03 [−0.04, 0.10]	0.03 [−0.05, 0.11]	0.06 [−0.03, 0.14]	0.32** [0.26, 0.38]	0.26** [0.19, 0.33]	0.18** [0.10, 0.26]				
Social approach motivation T2	2.5	1.1	0.00 [−0.08, 0.08]	0.02 [−0.05, 0.08]	−0.04 [−0.11, 0.04]	0.21** [0.14, 0.29]	0.33** [0.27, 0.38]	0.30** [0.27, 0.37]	0.69* [0.65, 0.73]			
Social approach motivation T3	2.5	1.1	−0.02 [−0.10, 0.06]	0.02 [−0.05, 0.10]	0.01 [−0.06, 0.08]	0.18** [0.10, 0.26]	0.26** [0.18, 0.33]	0.33** [0.26, 0.39]	0.67** [0.62, 0.71]	0.75** [0.71, 0.78]		
Behavioral intentions T1	2.5	0.9	0.05 [−0.02, 0.12]	0.02 [−0.06, 0.10]	0.08 [−0.00, 0.16]	0.22** [0.15, 0.29]	0.23** [0.15, 0.30]	0.21** [0.13, 0.29]	0.64** [0.59, 0.68]	0.54** [0.48, 0.60]	0.52** [0.45, 0.57]	
Behavioral intentions T2	2.4	1.0	0.03 [−0.05, 0.11]	0.09** [0.02, 0.15]	0.06 [−0.01, 0.14]	0.16** [0.08, 0.24]	0.23** [0.16, 0.29]	0.27** [0.20, 0.34]	0.60** [0.55, 0.65]	0.61** [0.57, 0.65]	0.60** [0.54, 0.64]	0.73** [0.69, 0.77]
Behavioral intentions T3	2.1	1.0	0.08 [−0.00, 0.16]	0.10** [0.03, 0.18]	0.12** [0.05, 0.19]	0.24** [0.16, 0.31]	0.20** [0.13, 0.28]	0.26** [0.20, 0.33]	0.48** [0.42, 0.54]	0.45** [0.39, 0.51]	0.58** [0.54, 0.63]	0.64** [0.59, 0.69]
Discussion outdegree T1	1.48	1.19	0.01 [−0.06, 0.09]	0.02 [−0.05, 0.09]	−0.00 [−0.08, 0.07]	−0.03 [−0.11, 0.04]	0.03 [−0.04, 0.10]	−0.03 [−0.11, 0.04]	−0.03 [−0.10, 0.05]	0.04 [−0.03, 0.11]	0.01 [−0.06, 0.08]	−0.08* [−0.15, −0.00]
Discussion outdegree T2	2.59	2.96	0.05 [−0.03, 0.13]	−0.00 [−0.08, 0.07]	−0.02 [−0.10, 0.07]	−0.10* [−0.18, −0.02]	−0.02 [−0.09, 0.06]	−0.01 [−0.09, 0.07]	−0.04 [−0.12, 0.04]	−0.06 [−0.13, 0.02]	−0.04 [−0.12, 0.04]	−0.06 [−0.14, 0.02]
Discussion outdegree T3	1.45	1.48	0.07 [−0.03, 0.17]	0.05 [−0.05, 0.14]	0.04 [−0.06, 0.14]	0.00 [−0.10, 0.10]	0.00 [−0.09, 0.10]	−0.06 [−0.16, 0.03]	−0.03 [−0.13, 0.07]	−0.03 [−0.12, 0.07]	−0.05 [−0.15, 0.05]	−0.12* [−0.22, −0.02]
Groupsize T1	4.4	1.4	0.01 [−0.06, 0.08]	0.06 [−0.02, 0.14]	0.04 [−0.04, 0.12]	0.02 [−0.05, 0.09]	0.04 [−0.04, 0.12]	0.04 [−0.05, 0.12]	−0.05 [−0.12, 0.02]	0.03 [−0.05, 0.11]	−0.01 [−0.10, 0.07]	−0.06 [−0.13, 0.01]
Groupsize T2	4.8	1.5	0.06 [−0.02, 0.14]	0.05 [−0.02, 0.11]	0.09* [0.01, 0.17]	−0.01 [−0.09, 0.07]	0.05 [−0.02, 0.11]	0.11** [0.03, 0.18]	−0.04 [−0.12, 0.04]	−0.01 [−0.07, 0.06]	0.00 [−0.07, 0.08]	−0.03 [−0.11, 0.05]

(Continued)

TABLE 1 (Continued)

Variable	*M*	*SD*	Social identity threat T1	Social identity threat T2	Social identity threat T3	Sense of belonging T1	Sense of belonging T2	Sense of belonging T3	Social approach motivation T1	Social approach motivation T2	Social approach motivation T3	Behavioral intentions T1
Groupsize T3	4.3	1.3	0.05 [−0.03, 0.13]	−0.00 [−0.08, 0.08]	0.04 [−0.02, 0.11]	0.09* [0.01, 0.18]	0.10** [0.03, 0.18]	0.08* [0.02, 0.15]	−0.02 [−0.10, 0.06]	0.02 [−0.05, 0.10]	0.03 [−0.04, 0.10]	−0.03 [−0.11, 0.05]
Off-system behavior T1	3.3	1.1	−0.03 [−0.10, 0.04]	−0.03 [−0.11, 0.05]	0.00 [−0.08, 0.08]	0.16** [0.09, 0.22]	0.06 [−0.02, 0.14]	−0.01 [−0.09, 0.07]	0.16** [0.09, 0.23]	0.11** [0.03, 0.18]	0.11** [0.03, 0.19]	0.12** [0.05, 0.18]
Off-system behavior T2	3.2	1.0	−0.03 [−0.11, 0.05]	−0.01 [−0.07, 0.06]	−0.01 [−0.08, 0.07]	0.15** [0.07, 0.23]	0.17** [0.10, 0.23]	0.12** [0.05, 0.20]	0.11** [0.03, 0.19]	0.14** [0.07, 0.20]	0.08 [−0.00, 0.15]	0.08 [−0.00, 0.15]
Off-system behavior T3	3.3	1.0	0.05 [−0.03, 0.13]	−0.07 [−0.15, 0.01]	0.00 [−0.06, 0.07]	0.12** [0.04, 0.20]	0.20** [0.13, 0.28]	0.18** [0.11, 0.24]	0.07 [−0.01, 0.16]	0.12** [0.04, 0.19]	0.07* [0.00, 0.14]	0.05 [−0.03, 0.14]
Etherpad outdegree T2	148.24	195.14	0.05 [−0.02, 0.12]	0.01 [−0.06, 0.07]	−0.00 [−0.07, 0.07]	−0.06 [−0.13, 0.01]	−0.06 [−0.13, 0.00]	−0.01 [−0.08, 0.06]	−0.03 [−0.10, 0.04]	0.02 [−0.05, 0.08]	0.00 [−0.07, 0.07]	−0.04 [−0.11, 0.03]
Etherpad outdegree T3	119.68	186.00	0.02 [−0.05, 0.09]	−0.02 [−0.09, 0.05]	−0.04 [−0.11, 0.03]	−0.01 [−0.08, 0.07]	−0.02 [−0.08, 0.05]	0.06 [−0.01, 0.13]	−0.02 [−0.09, 0.05]	0.05 [−0.01, 0.12]	0.06 [−0.01, 0.13]	−0.06 [−0.13, 0.01]
Etherpad text edits T2	936.2	1121.1	0.06 [−0.01, 0.13]	0.04 [−0.02, 0.11]	0.02 [−0.05, 0.09]	−0.09* [−0.16, −0.02]	−0.15** [−0.21, −0.08]	−0.12** [−0.19, −0.05]	−0.03 [−0.10, 0.04]	−0.02 [−0.09, 0.04]	−0.04 [−0.10, 0.03]	−0.06 [−0.13, 0.01]
Etherpad text edits T3	694.8	876.8	0.01 [−0.07, 0.08]	−0.02 [−0.09, 0.05]	−0.02 [−0.09, 0.06]	−0.01 [−0.09, 0.06]	−0.08* [−0.14, −0.01]	−0.04 [−0.11, 0.03]	−0.06 [−0.13, 0.01]	−0.01 [−0.08, 0.06]	−0.02 [−0.09, 0.05]	−0.11** [−0.18, −0.03]

Variable	Behavioral intentions T2	Behavioral intentions T3	Discussion outdegree T1	Discussion outdegree T2	Discussion outdegree T3	Groupsize T1	Groupsize T2	Groupsize T3	Off-system behavior T1	Off-system behavior T2
Behavioral intentions T3	0.71** [0.67, 0.74]									
Discussion outdegree T1	−0.08* [−0.15, −0.01]	−0.07 [−0.14, 0.01]								
Discussion outdegree T2	−0.09* [−0.16, −0.01]	−0.06 [−0.14, 0.02]	0.32** [0.25, 0.38]							
Discussion outdegree T3	−0.07 [−0.16, 0.02]	−0.02 [−0.12, 0.08]	0.41** [0.33, 0.48]	0.56** [0.50, 0.62]						
Groupsize T1	−0.02 [−0.10, 0.06]	−0.03 [−0.12, 0.05]	0.14** [0.07, 0.21]	0.01 [−0.07, 0.10]	0.00 [−0.10, 0.10]					
Groupsize T2	−0.01 [−0.08, 0.05]	−0.01 [−0.08, 0.07]	0.07 [−0.00, 0.14]	−0.03 [−0.10, 0.05]	−0.08 [−0.17, 0.01]	0.47** [0.41, 0.53]				
Groupsize T3	−0.01 [−0.09, 0.06]	0.00 [−0.07, 0.07]	0.08* [0.00, 0.15]	−0.07 [−0.15, 0.01]	−0.04 [−0.14, 0.05]	0.46** [0.39, 0.52]	0.48** [0.41, 0.53]			

(Continued)

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TABLE 1 (Continued)

Variable	Behavioral intentions T2	Behavioral intentions T3	Discussion outdegree T1	Discussion outdegree T2	Discussion outdegree T3	Groupsize T1	Groupsize T2	Groupsize T3	Off-system behavior T1	Off-system behavior T2
Off-system behavior T1	0.08* [0.00, 0.16]	0.08 [−0.00, 0.16]	−0.16** [−0.23, −0.08]	−0.28** [−0.35, −0.20]	−0.20** [−0.29, −0.10]	0.03 [−0.04, 0.10]	0.07 [−0.01, 0.15]	0.06 [−0.02, 0.14]		
Off-system behavior T2	0.11** [0.04, 0.17]	0.05 [−0.02, 0.13]	−0.10** [−0.17, −0.03]	−0.39** [−0.46, −0.33]	−0.25** [−0.33, −0.16]	0.12** [0.04, 0.19]	0.06 [−0.00, 0.13]	0.15** [0.08, 0.23]	0.37** [0.30, 0.44]	
Off-system behavior T3	0.08 [−0.00, 0.15]	0.02 [−0.05, 0.09]	−0.12** [−0.19, −0.05]	−0.38** [−0.44, −0.31]	−0.30** [−0.39, −0.21]	0.08 [−0.01, 0.16]	0.07 [−0.00, 0.15]	0.13** [0.06, 0.19]	0.27** [0.20, 0.35]	0.74** [0.71, 0.78]
Etherpad outdegree T2	−0.02 [−0.08, 0.05]	−0.03 [−0.10, 0.04]	0.10** [0.04, 0.16]	0.18** [0.12, 0.25]	0.14** [0.06, 0.22]	0.01 [−0.06, 0.08]	0.01 [−0.06, 0.07]	0.06 [−0.01, 0.13]	−0.08* [−0.15, −0.01]	−0.08* [−0.14, −0.01]
Etherpad outdegree T3	0.02 [−0.05, 0.08]	−0.00 [−0.07, 0.07]	0.06 [−0.01, 0.12]	0.08* [0.01, 0.15]	0.12** [0.03, 0.20]	−0.03 [−0.10, 0.05]	0.02 [−0.05, 0.09]	0.04 [−0.03, 0.11]	−0.04 [−0.11, 0.03]	−0.01 [−0.08, 0.05]
Etherpad text edits T2	−0.04 [−0.11, 0.02]	−0.03 [−0.10, 0.04]	0.05 [−0.02, 0.11]	0.09* [0.02, 0.16]	0.06 [−0.02, 0.14]	−0.03 [−0.10, 0.04]	−0.03 [−0.09, 0.04]	−0.00 [−0.07, 0.07]	−0.03 [−0.10, 0.04]	−0.10** [−0.16, −0.03]
Etherpad text edits T3	−0.02 [−0.08, 0.05]	−0.02 [−0.09, 0.05]	0.03 [−0.04, 0.09]	0.10** [0.03, 0.17]	0.09* [0.00, 0.17]	−0.03 [−0.10, 0.04]	−0.05 [−0.11, 0.02]	−0.02 [−0.09, 0.05]	−0.04 [−0.11, 0.04]	−0.07* [−0.14, −0.01]

Variable	Off-system behavior T3	Etherpad outdegree T2	Etherpad outdegree T3	Etherpad text edits T2
Etherpad outdegree T2	−0.11** [−0.18, −0.04]			
Etherpad outdegree T3	0.00 [−0.07, 0.07]	0.24** [0.18, 0.29]		
Etherpad text edits T2	−0.12** [−0.19, −0.05]	0.57** [0.53, 0.61]	0.23** [0.17, 0.29]	
Etherpad text edits T3	−0.08* [−0.15, −0.01]	0.26** [0.20, 0.31]	0.61** [0.57, 0.65]	0.47** [0.42, 0.51]

Confidence intervals are depicted in square brackets at the 95% level. * indicates $p < 0.05$. ** indicates $p < 0.01$.

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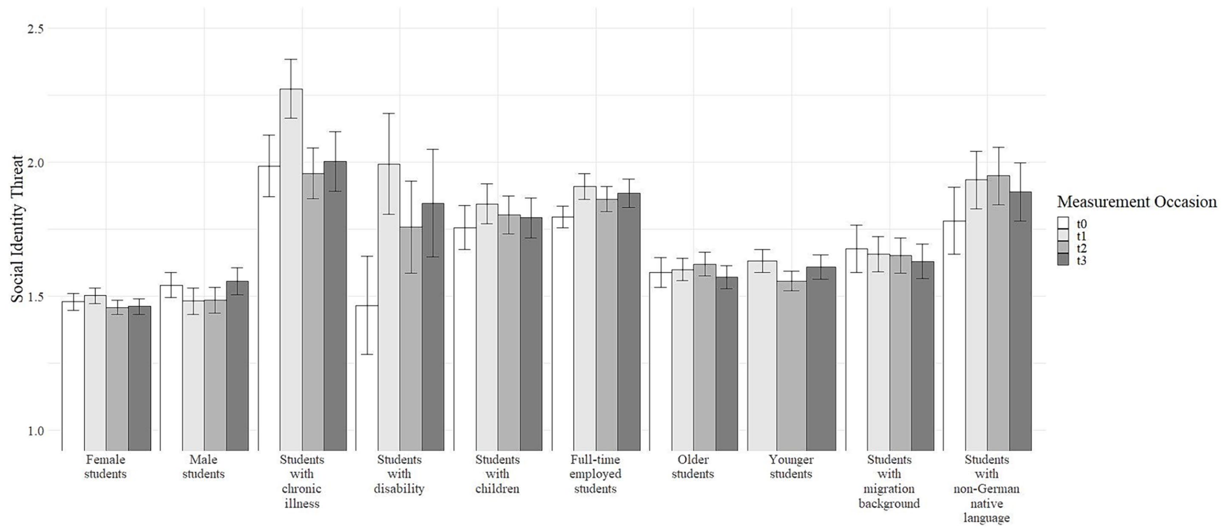

FIGURE 2
Means and standard errors of social identity threat for all student groups over all measurement occasions. Please note that values of social identity threat at T0 for younger students were not available due to a programming issue.

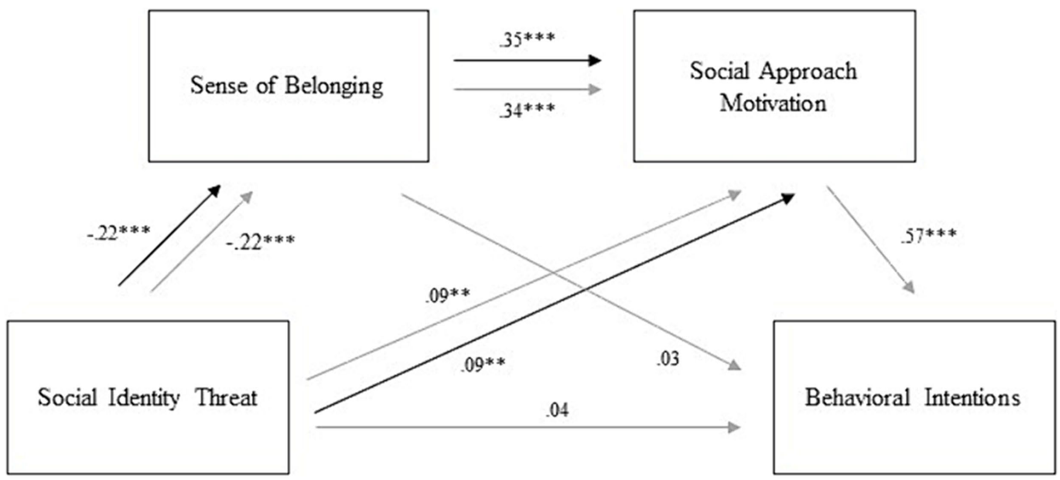

FIGURE 3
Path model for cross-sectional analyses. Black arrows depict paths and results for H1 whereas gray arrows depict paths and results for H2. * Indicates $p < 0.05$, ** indicates $p < 0.01$, and *** indicates $p < 0.001$.

motivation at T3 via sense of belonging to the CSCL group at T2 was not significant, $\beta = 0.002$, $SE = 0.01$, $p = 0.651$. Results were similar when taking the clustering for the CSCL group into account as an additional robustness check. Interestingly, the random intercept for social identity threat was negatively correlated with the random intercept for sense of belonging to the CSCL group, $r = -0.20$, $SE = 0.03$, $p < 0.001$, which in turn was positively correlated with the random intercept for social approach motivation, $r = 0.26$, $SE = 0.04$, $p < 0.001$. In other words, stable across measurement occasions, students with social identity threat above the sample average reported sense of belonging to the CSCL group below the average. In turn, students with sense of belonging below the average had lower-than-average motivation for contact with other students.

To investigate Hypothesis 4, we computed an analogous RI-CLPM with discussion outdegree as the behavioral outcome measure (see Figure 5). The RI-CLPM showed good fit, $\chi 2\ (8) = 5.82$, RMSEA <0.001, CFI = 1.00, TLI = 1.01, SRMR = 0.01. Again, social identity threat at T2 positively predicted sense of belonging at T3, $\beta = 0.15$, $SE = 0.06$, $p = 0.009$. Sense of belonging at T1 negatively predicted outdegree at T2, $\beta = -0.35$, $SE = 0.16$, $p = 0.030$. No further significant direct effects from social identity threat on sense of belonging and discussion outdegree or from sense of belonging on discussion outdegree were found. In contrast to our expectations, there was no significant indirect effect of social identity threat on discussion outdegree via sense of belonging to the CSCL group on the within-person-level, $\beta = -0.002$, $SE = 0.01$, $p = 0.802$. Results were

TABLE 2 Results of the path model testing H2.

Direct effects												
		Consequent										
		Sense of belonging				Social approach motivation				Behavioral intentions		
Antecedent		*b* [95% CI]	*SE*	*p*		*b* [95% CI]	*SE*	*p*		*b* [95% CI]	*SE*	*p*
Social identity threat	a_1	−0.22 [−0.29; −0.15]	0.03	<0.001	a_2	0.09 [0.02; 0.16]	0.03	0.008	c_p	0.04 [−0.01; 0.09]	0.03	0.043
Sense of belonging		–	–	–	d_{21}	0.34 [0.28; 0.42]	0.03	<0.001	b_1	0.03 [−0.02; 0.09]	0.03	0.268
Social approach motivation		–	–	–		–	–	–	b_2	0.57 [0.52; 0.62]	0.03	<0.001

Indirect effect				
		b [95% CI]	*SE*	*p*
Social identity threat ➔ Social approach motivation ➔ Sense of belonging ➔ Behavioral intentions	$a_1d_{21}b_2$	−0.04 [−0.06; −0.03]	0.01	<0.001

similar when taking the clustering for the CSCL group into account as an additional robustness check. On the between-person-level, the random intercept for social identity threat was negatively correlated with the random intercept for sense of belonging to the CSCL group, $r = -0.20$, $SE = 0.03$, $p < 0.001$. However, the random intercept for discussion outdegree was not significantly correlated with the random intercepts for social identity threat or sense of belonging to the CSCL group. Detailed results of H4 are reported in Supplementary material S4.

3.4 Exploratory analyses

Since Etherpad Lite data were available only for the two CSCL phases, RI-CLPM could not be computed. As analyses with the Etherpad Lite data were exploratory, we report bivariate correlations of social identity threat, sense of belonging, discussion outdegree, Etherpad outdegree, and Etherpad text edits (see Table 1). Similar to the outcomes of the main analyses, neither Etherpad outdegree nor Etherpad text edits were significantly related to social identity threat. Etherpad outdegree was also not significantly related to sense of belonging to the CSCL group. However, Etherpad text edits in working phase 1 were negatively related to sense of belonging to the CSCL group at all measurement occasions. Etherpad text edits in working phase 2 were negatively related to sense of belonging to the CSCL group at T2.

Since the number of active students in the CSCL groups might have influenced sense of belonging to the CSCL group and activity in the group (in the forum as well as in the Etherpads), we repeated all cross-sectional analyses controlling for group size. Results did not change when controlling for group size (see Supplementary material S5). In longitudinal analyses, the models did not converge when group size was added as control variable due to insufficient model identification. Correlations revealed that group size at T2 was positively related to social identity threat at T3, $r = 0.09$, 95% CI = [0.01, 0.17] and to sense of belonging to the CSCL group at T3, $r = 0.11$, 95% CI = [0.03, 0.18]. Group size at T3 was positively related to sense of belonging to the CSCL group at T1, $r = 0.09$, 95% CI = [0.01, 0.18], T2, $r = 0.10$, 95% CI = [0.03, 0.18], and T3, $r = 0.08$, 95% CI = [0.02, 0.15].

4 Discussion

This study contributes to understanding the social consequences of perceived social identity threat in distance learning when there is no face-to-face contact between students. First, we showed that perceived social identity threat varies between different student groups in higher distance education. Second, we replicated the cross-sectional findings from face-to-face contexts in higher distance education, namely, the mediation of social identity threat on social approach motivation via lower sense of belonging. Third, the current study has shown that within- and between-person effects need to be separated. Fourth, based on research showing an intention-behavior gap, we included self-reported and behavioral outcome measures collected via Learning Analytics in the same study.

4.1 (Some) non-traditional student groups are particularly at risk of experiencing social identity threat in CSCL

In line with research on stereotypes about non-traditional students in higher distance education (Bick et al., 2022), we found that social identity threat differed between student groups. After this earlier research has demonstrated that negative competence-related stereotypes about specific student groups are widespread in higher distance education, the present study goes beyond this by showing that negative stereotypes also threaten these students' social identities. In detail, the non-traditional student groups (i.e., students with chronic illness, students with disability, students with children, full-time employed students, students with non-German native language) that we found to report higher levels of social identity threat show a strong overlap with the groups that were negatively stereotyped on ability in Bick et al. (2022) (i.e., students with migration background, students with chronic illness, students with disability, students with non-German native language). Interestingly, the traditional student groups that reported lower values of social identity threat in our study (i.e., male students, younger students) were the groups with the lowest values on the competence-related stereotype facets of conscientiousness (both) and ability (younger students only).

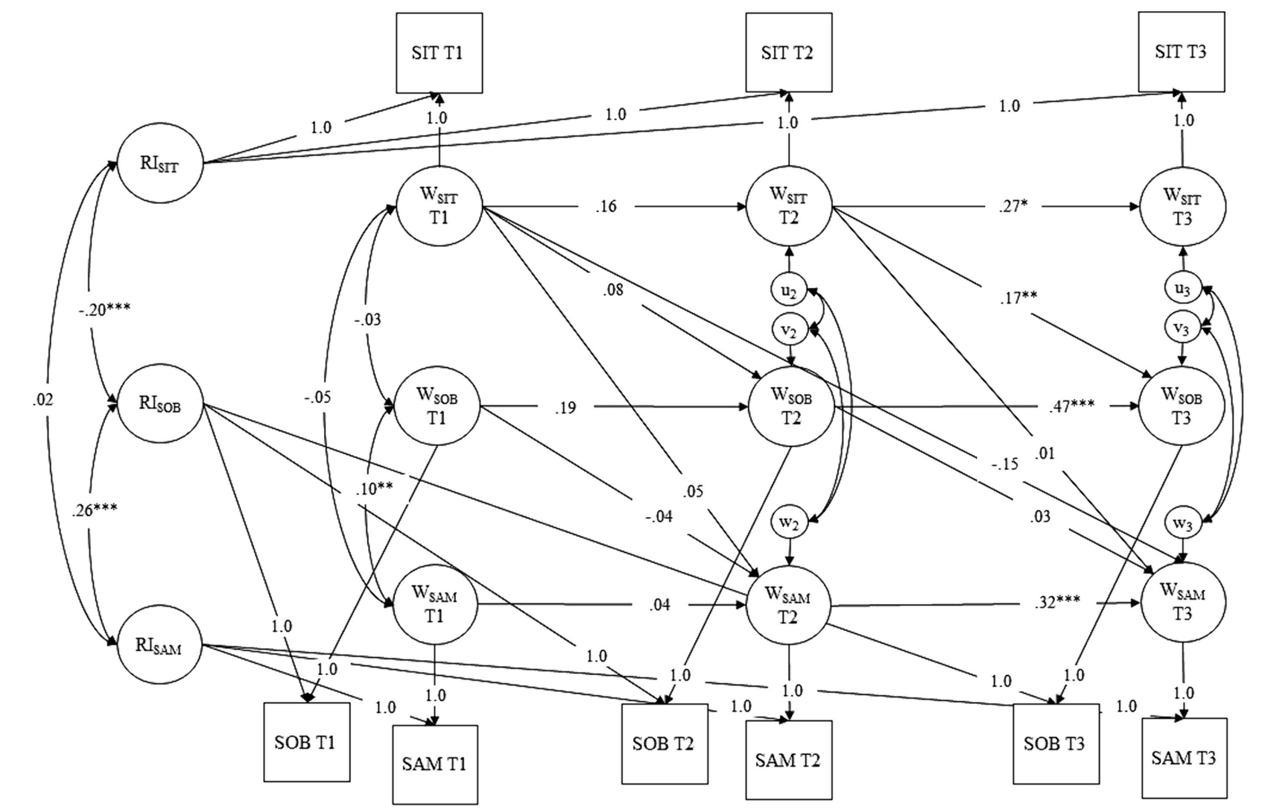

FIGURE 4
RI-CLPM for Hypothesis 3. Social identity threat is abbreviated with SIT, sense of belonging to the CSCL group is abbreviated wit SOB, and social approach motivation is abbreviated with SAM. Between-subject-variation is represented in RIs whereas within-subject variation is represented in Ws. * Indicates $p < 0.05$, ** indicates $p < 0.01$, and *** indicates $p < 0.001$.

However, these divergent findings can be explained by the fact that although male and younger students are negatively stereotyped in the specific context of a psychology course at a distance university where most students are female and older than 30 years, these groups do not often face negative competence-related stereotypes in other contexts (e.g., Fiske et al., 2002). Furthermore, since informal communication at a distance university is not common, these groups might not even be aware of these negative stereotypes, which is a prerequisite for social identity threat (Spencer et al., 2016). Thus, the present research substantiated earlier findings reporting higher vulnerability of non-traditional student groups in the context of higher distance education (e.g., Stoessel et al., 2015).

Female students and students with migration background reported comparably low levels of social identity threat in the current study, although both groups meet the definition of non-traditional students and were found to be negatively affected by social identity threat in face-to-face contexts in previous studies (Spencer et al., 1999; Froehlich et al., 2022). In the case of female students, the large proportion of female students in psychology (usually around 70%) might lead to lower social identity threat since females represent the majority group in this specific context. However, it remains an open question whether this result is generalizable or domain-specific. In contrast to the current research which investigated CSCL in the domain of scientific reading and writing, future research should investigate whether female students report higher social identity threat in psychology courses that reflect more traditional gender stereotypes about women's mathematical competence (e.g., research methods and statistics; Martiny and Nikitin, 2019).

In the case of students with migration background, the following reasons might explain the comparably low levels of social identity threat. When asking which groups students identified with, both students with migration background and students with a non-German native language were presented. Only half of the students who identified as students with migration background also identified as having a non-German native language. Students who identified as students with migration background but perceive German to be their first language might be second- or third-generation immigrants and therefore might have developed dual social identities (i.e., simultaneously identifying with their ethnic group of origin and the national group of the residence country), which acts as a buffer against the social consequences of social identity threat (Froehlich et al., 2023). Students identifying with both student groups might have contrasted stereotypes about the two groups and attributed negative stereotypes and associated social identity threat to the group of students with non-German native language, resulting in lower levels of reported social identity threat regarding the identification with students with migration background. Future research is needed to verify this post-hoc explanation.

Interestingly, we found the highest levels of social identity threat among students with chronic illness. This result is surprising because based on the social identity model of deindividuation effects (SIDE; Postmes et al., 2001; Spears et al., 2002), we had expected social categories that are easily recognizable in online interactions such as

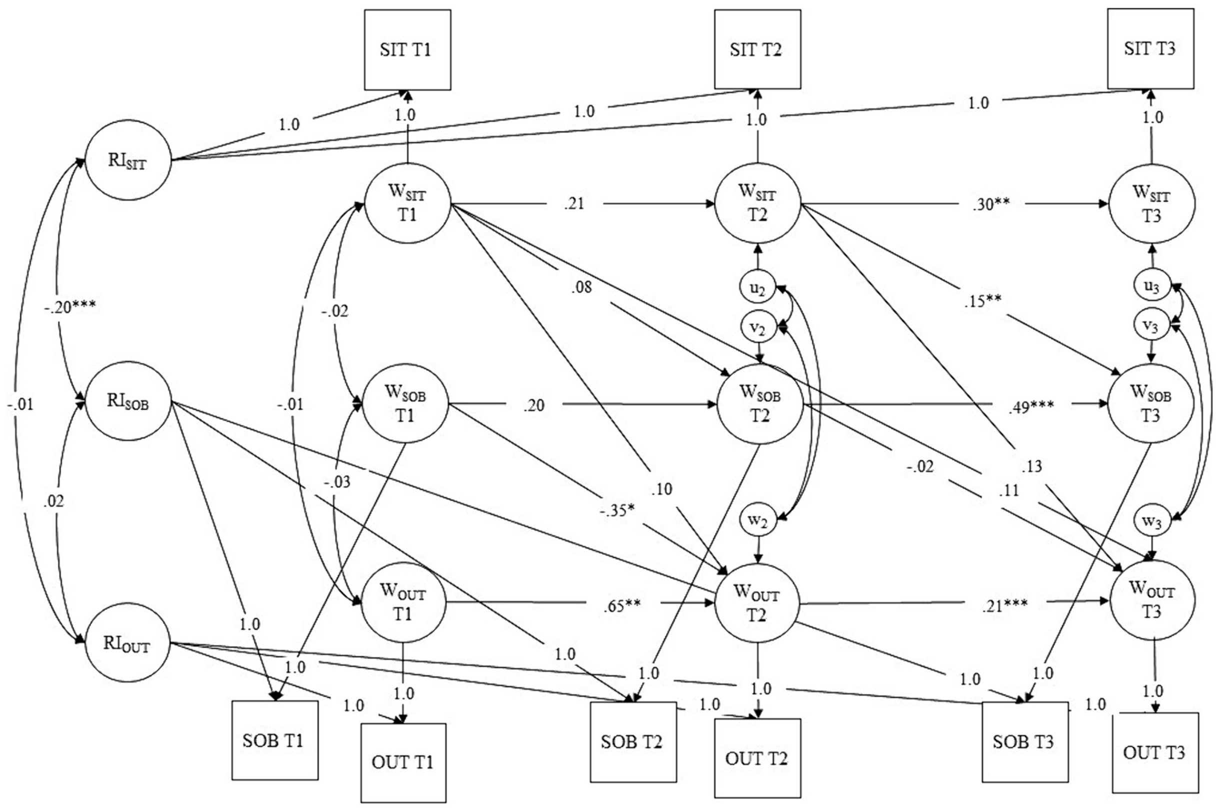

FIGURE 5
RI-CLPM for Hypothesis 4. Social identity threat is abbreviated with SIT, sense of belonging to the CSCL group is abbreviated wit SOB, and discussion outdegree is abbreviated with OUT. Between-subject-variation is represented in RIs whereas within-subject variation is represented in Ws. * Indicates $p < 0.05$, ** indicates $p < 0.01$, and *** indicates $p < 0.001$.

gender, ethnicity/ native language, or age to be most salient in higher distance education. In contrast, it is often not immediately apparent in online contexts whether peers have a chronic illness or not. Nevertheless, students who identified as members of the group of students with chronic illness were relatively worried about being negatively stereotyped because of their group membership. In line with Clair et al. (2005), students with chronic illness may be repeatedly confronted with the need to disclose their chronic illness to their peers, as in collaborative contexts "those with an invisible chronic illness must find ways to explain or hide symptoms from others" (Clair et al., 2005, p. 91). Therefore, belonging to the group of students with chronic illness might be similarly relevant or, in line with our data, even more relevant than belonging to visible groups as social identity threat is intensified by the conflict of whether or not to disclose the chronic illness to peers.

The current research aggregated self-reported social identity threat across all students in the data set and did therefore not consider the extent to which students identified with one or another group. In the present study, sample sizes for subgroups of non-traditional students were too small to examine whether the associations between social identity threat and the outcome variables differed between the traditional and non-traditional student subgroups (see Supplementary material S6). Furthermore, students were clustered in CSCL groups, so that not only membership of individual students to sociodemographic groups was important, but also the multi-attributional diversity at the CSCL group level. Research at the group level has shown that in groups with high sociodemographic diversity, task-related prior knowledge and skills cannot be optimally utilized for group performance (Voltmer et al., 2022a,b, 2024). Future research should therefore simultaneously consider the membership of individual students in sociodemographic groups targeted by negative stereotypes and the impact of the demographic composition of the CSCL groups. For example, van Dijk et al. (2017) explain that stereotypes and social identity threat play an important role for microdynamics in teams that can impact collaboration and performance. It was however beyond the scope of the current manuscript to investigate these complex interrelations.

4.2 Self-reported consequences of social identity threat in CSCL

The present study aimed to replicate and better understand the social consequences of social identity threat shown in face-to-face contexts (Martiny and Nikitin, 2019; Rahn et al., 2021; Froehlich et al., 2023) in the emerging and important context of higher distance education. Since findings from face-to-face contexts cannot directly be translated to online collaborative learning contexts (Kreijns et al., 2024), we argue that testing the generalizability of earlier findings to higher distance education settings was a crucial part in this study. We replicated previous results on the mediating role of sense of belonging for the association between social identity threat, social approach motivation, and behavioral intentions for peer contact in cross-sectional analyses. This result indicates that findings on social identity threat from traditional educational contexts with face-to-face classrooms can be generalized to digital educational contexts with mostly asynchronous computer-mediated communication. These findings further support that group membership is especially salient in online contexts which amplifies the likelihood of stereotype activation (Postmes et al., 2002; Spears et al., 2002) and in turn, social identity threat and its consequences.

In contrast, the longitudinal investigation of social identity threat, sense of belonging, and social approach motivation revealed unexpected findings. Due to the repeated measurements implemented during a CSCL task over several weeks, we were able to conduct state-of-the-art analyses including RI-CLPM. As Hamaker et al. (2015) emphasize, the main advantage of the RI-CLPM is its ability to disentangle within- and between-persons components of variance in longitudinal data. Consequently, the application of the RI-CLPM allowed us to investigate whether the hypothesized mediation model reflects psychological intraindividual processes that unfold over time. The results of the current study do not support this. Interestingly, the correlations of the random intercepts, which represent a stable between-person variance, indicated that the mediation might be a between-person effect. Students with a higher average social identity threat over time also had lower average levels of sense of belonging to the CSCL group and in turn a lower average social approach motivation over time. Such an association of the random intercepts would argue for more stable rank-order effects in a given classroom or course, rather than psychological processes unfolding in individuals over time. This finding supports and specifies the mediation effect that has been found in previous research (Martiny and Nikitin, 2019; Froehlich et al., 2022, 2023).

4.3 Behavioral consequences of social identity threat in CSCL

In addition to self-reported social approach motivation and behavioral intentions, the current study used learning analytics to compute social network analysis based on data generated during the actual CSCL collaboration. The main behavioral outcome variable was discussion outdegree, reflecting a student's responses to postings of their peers in course-related Moodle forums. Contrary to our expectations, discussion outdegree was unrelated to our main predictor variables of social identity threat and sense of belonging. One possible explanation for the diverging results for the self-report and the behavioral data is that there is a gap between intention and behavior as actual collaborative behavior might be influenced by additional factors beyond social approach motivation and behavioral intentions to interact with peers. For example, students might have wanted to interact more with peers but did not have time, e.g., due to family commitments. An alternative explanation is that discussion outdegree encompasses merely students' discussion about the CSCL task, but not actual collaborative writing activities. Our data on this task-related discussion are probably also incomplete, as students might have used not only the designated Moodle forums, but also other communication channels outside of the learning environment. In fact, students indicated that they used other media than the course-related Moodle forum for communication about the course (i.e., off-system behavior). However, statistically controlling for off-system behavior did not change the results of cross-sectional analyses (see Supplementary material S7).

In exploratory analyses, we investigated correlations between social identity threat and sense of belonging with further behavioral outcomes collected via Etherpad Lite instances for each CSCL group. Etherpad outdegree and Etherpad text edits reflect the closest measures of actual collaborative behavior in the current study. Similar to the results for discussion outdegree, Etherpad outdegree was also unrelated to social identity threat and sense of belonging. It should be noted that Etherpad outdegree reflects only the edits a student made in the text written by another student, but no initial writing of the text or edits made in the text that was initially written by themselves. Furthermore, as the behavioral measure in Moodle (i.e., discussion outdegree), we only considered outdegree representing outgoing activity from a student but not indegree representing incoming activity like messages that were sent to this person or number of answers towards their threads in Moodle or changes another student had made in their text in the Etherpads, respectively. Since actual interaction and not only the initiation of contact is relevant for social outcomes like belonging (Walton and Cohen, 2007), a more comprehensive investigation of social network analysis measures might be reasonable for future studies. Etherpad text edits were unrelated to social identity threat but negatively related to sense of belonging to the CSCL group. Research about frustration in CSCL at a Spanish distance learning university revealed that the main source of frustration in CSCL was imbalance of commitment in group tasks which was further described as "sometimes I run into someone whose contribution was almost nothing. When that happens, I tend to do more than I can, to compensate, and this makes me feel nervous, causes some discomfort and feeling of injustice" (Capdeferro and Romero, 2012). In line with these findings, it could be argued that also in the present sample, students were frustrated about being forced to invest more because other students invested less, independent of the size of the CSCL groups. As Capdeferro and Romero (2012) recommend, instructions on effective collaboration and the communication of realistic expectations for the course might help online learners to overcome frustration and to enhance belonging to the CSCL group in collaborative courses at distance learning universities.

We conclude that our behavioral outcomes (i.e., discussion outdegree, Etherpad outdegree, and Etherpad text edits) did not reveal any expected findings although they were carefully selected and collected in different platforms which should have ruled out effects of, for instance, off-system behavior. Due to the novelty of using this kind of behavioral data as proxy for task-related integration in a group, we recommend further research to focus on understanding why the behavior did not reflect the indicated intentions. With fine-grained collaboration data as it is provided in the Etherpads and with the large samples that can be collected in higher distance education institutions, much more detailed analyses can potentially reveal reasons for our findings. Further quantitative approaches can shed light on roles of specific students during a collaborative task (e.g., produce text, modify wording/ structure), temporal dimensions of collaboration (a−/synchronous) which could, maybe in combination with a qualitative investigation, complement the reasons for our findings.

4.4 Limitations and practical implications

Notwithstanding the outlined contributions of this work, some limitations should be discussed more extensively. First, the longitudinal analyses were conducted over a total of 8 weeks with intervals of 2–3 weeks, which might not have been enough time for the intraindividual effects to unfold (Cook et al., 2012). In addition, longitudinal studies with the goal of investigating cross-lagged associations should ideally be conducted under stable conditions. In contrast, in our study, the changing CSCL tasks in the different phases (getting to know each other, working phases 1 and 2) and the transition to a new academic institution (measurement during the first weeks of the first semester in the Bachelor's program) were a source of high variability. This lack of stability over time is also reflected in the often weak or insignificant autoregressive paths in the longitudinal analyses. Future research should therefore replicate the results under more stable conditions in order to ensure more reliable interpretation of the reported results. Second, we cannot ensure generalizability of all our findings to other (distance) universities. We assume that the findings we replicated are well generalizable to other universities (i.e., non-traditional student groups reporting higher social identity threat, cross-sectional (serial) mediation of social consequences of social identity threat). However, due to the novelty of the longitudinal analyses, we encourage researchers to investigate comparable hypotheses at other universities to get more insights into whether our findings were specific to our design and sample. Third, as we aimed to understand the social consequences of social identity threat in a field study, only psychology students participated which clearly biased our sample regarding, e.g., gender. Furthermore, the voluntary participation in the study has probably led to selection effects (e.g., Wagner, 2012). However, we still collected a large sample size and found substantial variation in the data so we assume that our results adequately represent psychology students at a large distance university. Fourth, it was possible for participants to indicate self-identification with several student groups simultaneously. Due to the complex data structure (measurements nested in individuals nested in CSCL groups), we aggregated items of social identity threat across groups per individual. Adjusting for student groups as a further level of clustering in combination with the level of CSCL groups was not possible with current statistical software. An investigation of intersectionality (i.e., the psychological relevance of specific combinations of group memberships) was beyond the scope of the current study. Future research could investigate the extent and consequences of social identity threat for different intersections of student groups.

Despite these limitations, the present study has a high practical value for different stakeholders, especially in higher distance education. The finding that specific student groups are at risk of perceiving social identity threat implies that higher distance education institutions should develop and implement interventions to reduce social identity threat in these specific student groups to foster educational equity (Walton et al., 2015; Liu et al., 2021). Teachers in such institutions should be sensitized to the existence of negative effects of social identity threat in order to prevent them from even unintentionally activating stereotypes (e.g., by using biased study materials or language). Finally, students should be provided with information on potential issues arising from social identity threat and how to deal with it (Alter et al., 2010). The exploratory finding that the association of social identity threat, sense of belonging, and social approach motivation was a between- instead of the expected within-person effect indicates that for effectively reducing social identity threat, individuals prone to its negative consequences must be identified and specifically addressed which again underlines the above-mentioned need for tailored interventions. Since easily available information like sociodemographic group membership that has traditionally been used to determine whether a recipient will benefit from an intervention or not (e.g., Walton and Cohen, 2011) will most probably not adequately represent the individual students' need for an intervention (but also, e.g., the setting; see Spencer et al., 2016), further research will be needed to identify individuals prone to social identity threat and its consequences based on reliable individual and situational characteristics. Using learning analytics for understanding and predicting students' need for interventions is a promising route for further research with the potential to unfold more specific implications for higher distance education.

5 Conclusion

"To close achievement gaps, it is necessary both to eradicate psychological threats embedded in academic environments and to remove other barriers to achievement including objective biases, the effects of poverty, and so forth" (Walton and Spencer, 2009, p. 1137). The present study is a first step towards eliminating psychological threats in online learning environments, as it found that most non-traditional student groups in higher distance education are at risk of experiencing social identity threat. The present study thus underpins earlier research that points to problems faced by non-traditional student groups at university (e.g., Yildirim et al., 2021). Furthermore, we substantiated the mediation of social identity threat on social approach motivation via reduced sense of belonging by replicating it in the novel context of higher distance education. Finally, this study has taken a first step towards integrating learning analytics into research on social identity threat and belongingness in CSCL and found interesting effects that can be subject of future research aimed at improving the prerequisites of successful CSCL.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found at: https://osf.io/axq7k/.

Ethics statement

The studies involving humans were approved by Ethikkommission der Fakultät für Psychologie, FernUniversität in Hagen. 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

NB: Conceptualization, Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing, Investigation, Validation. LF: Conceptualization, Methodology, Supervision, Writing – review & editing, Investigation, Validation, Formal analysis, Resources. J-BV: Formal analysis, Methodology, Writing – review & editing, Data curation, Project administration, Conceptualization. JR: Project administration, Writing – review & editing, Investigation, Conceptualization. NR-S: Project administration, Writing – review & editing, Conceptualization. NS: Formal analysis, Resources, Writing – review & editing, Data curation, Conceptualization, Software. MB: Formal analysis, Resources, Software, Writing – review & editing, Conceptualization. SM: Writing – review & editing, Conceptualization, Resources. JN: Writing – review & editing, Conceptualization, Resources. SS: Project administration, Resources, Writing – review & editing, Conceptualization. AM: Methodology, Writing – review & editing, Conceptualization.

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Conflict of interest

MB was employed by Research Institute for Telecommunications and Cooperation e.V. This research institute is a legally independent organization at the FernUniversität that is connected to the FernUniversität regarding staff, place, and organizationally but is no part of the university.

The remaining 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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Peering into the team role kaleidoscope: the interplay of personal characteristics and verbal interactions in collaborative problem solving

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The objective of this study is to explore the relationship between personality and peer-rated team role behavior on the one hand and team role behavior and verbal behavior on the other hand. To achieve this, different data types were collected in fifteen professional teams of four members (N = 60) from various private and public organizations in Flanders, Belgium. Participants' personalities were assessed using a workplace-contextualized personality questionnaire based on the Big Five, including domains and facets. Typical team role behavior was assessed by the team members using the Team Role Experience and Orientation peer rating system. Verbal interactions of nine of the teams (n = 36) were recorded in an educational lab setting, where participants performed several collaborative problem-solving tasks as part of a training. To process these audio data, a coding scheme for collaborative problem solving and linguistic inquiry and word count were used. We identified robust links and logical correlation patterns between personality traits and typical team role behaviors, complementing prior research that only focused on self-reported team behavior. For instance, a relatively strong correlation was found between Altruism and the Team builder role. Next, the study reveals that role taking within teams is associated with specific verbal interaction patterns. For example, members identified as Organizers were more engaged in responding to others' ideas and monitoring execution.

KEYWORDS

personality, team role behavior, verbal interaction, audio data, learning analytics, collaborative problem solving

1 Introduction

Collaborative problem-solving (CPS) competencies are increasingly vital for enhancing efficiency, effectiveness, and innovation in contemporary society (Graesser et al., 2018; Neubert et al., 2015). CPS is "a process whereby two or more agents attempt to solve a problem by sharing the understanding and effort required to come to a solution and pooling their knowledge, skills and efforts to reach that solution" (OECD, 2017, p. 47). Despite the crucial role of CPS competencies in the job market, research conducted by organizations such as the OECD (2017) reveals that learners are often inadequately prepared for future job requirements demanding these competencies.

To effectively foster CPS competencies through training, a deep theoretical understanding of the underlying processes and the complex factors that influence them is needed (Fiore et al., 2018; Graesser et al., 2018; Macfarlane and Mayer, 2005). According to Graesser et al. (2018), team roles and personality traits could significantly influence CPS processes. However, these factors have yet to be documented empirically (Graesser et al., 2018).

Most research on team roles in collaborative learning (e.g., Raes et al., 2016; Pozzi, 2011; Schellens et al., 2007) has focused on the impact of assigning scripted roles to students on collaborative learning processes. Recent literature has also focused on roles that naturally emerge (e.g., Aranzabal et al., 2022; Marcos-García et al., 2015; Stahl et al., 2014). In general, and especially in the context of CPS, research on these emergent roles that are not pre-assigned needs further attention. Our study aims to address this gap by investigating the link between typical team role behavior and verbal interactions in CPS.

Role-taking can also be related to various personal characteristics, such as gender (Anderson and Sleap, 2004; Balderson and Broderick, 1996), job occupation (Balderson and Broderick, 1996), and personality traits (Davies and Kanaki, 2006; Marjanović et al., 2023). For instance, Davies and Kanaki (2006) showed that individuals with dominant interpersonal characteristics are more likely to take on roles involving organizing and coordinating tasks.

Most research on the link between personality traits and team roles has utilized Belbin's (1993) team role structure (see Supplementary Appendix A). However, due to various shortcomings of this framework, Mathieu et al. (2015) developed the Team Role Experience and Orientation (TREO) framework (see Supplementary Appendix A). Research on the relationship between the TREO roles and personality traits is limited to Mathieu et al. (2015) study, which focused on self-reported team roles and involved participants from a limited number of contexts (i.e., military officers and business students). Therefore, this study aims to deepen the examination of the relationship between personality and typical team role behavior, evaluated by colleagues who are long-term collaborators with whom the participants have shared close working relationships, often spanning several years.

2 Theoretical framework

In what follows, we present the theoretical framework, organized as follows. The first section elaborates on the core concept of this study: team roles. This section introduces two foundational frameworks: the TREO framework (Mathieu et al., 2015) which will be used in this study, and Belbin's (1993) model, which has been more frequently used in previous research. In the second section, the discussion centers on the interplay between team roles and personality traits. This discussion draws on prior research that utilizes the aforementioned team role frameworks and includes additional studies concerning team behavior and team effectiveness. The third section reviews previous research on the analysis of interactions among team members within the context of CPS. This section emphasizes the analysis of verbal interactions and outlines earlier investigations into the relationship between these verbal interactions and the concept of role-taking in collaborative contexts.

2.1 Team roles

Within teams, individual members assume various roles, each contributing unique strengths and capabilities to the group's collective performance. Stewart et al. (2019) define a team role as a set of interrelated behaviors that an individual exhibits within a specific setting, especially during recurring interactions with others. These behaviors are not isolated actions but rather characteristic patterns of behaviors that individuals adopt in response to the demands of their environment and the dynamics of group interaction. Researchers have developed various taxonomies and frameworks to classify and understand the dimensions of role fulfillment (e.g., Barry, 1991; Belbin, 1993; Mumford et al., 2008).

2.1.1 The Belbin team roles

Among the widely recognized frameworks, Belbin (2011) presents a notable one. This framework identifies nine distinct team roles; Resource investigator, Teamworker, Coordinator, Plant, Monitor evaluator, Specialist, Shaper, Implementer, and Completer finisher. Each role is associated with unique behavioral characteristics and strengths that individuals bring to a group setting. Descriptions of these roles are provided in Supplementary Appendix A.

Although Belbin's framework has been extensively used in various organizational contexts, it has also faced criticism (Broucek and Randell, 1996). For instance, research by Aritzeta et al. (2007) suggests that the Team Role Self-Perception Inventory (Belbin, 2011) shows strong associations between some team roles, indicating weak discriminant validity among certain scales. Additionally, according to Mathieu et al. (2015), many other theories and frameworks for team roles (e.g., Barry, 1991; Mumford et al., 2006) lack comprehensive validation evidence.

2.1.2 The team role experience and orientation framework

In response to this gap, Mathieu et al. (2015) synthesized the aforementioned theories and proposed the TREO framework. The TREO framework comprises six roles distributed across three categories: task-oriented, change-oriented, and socio-emotional. According to Gardner (2017), the study presented by Mathieu et al. (2015) provides evidence of discriminant validity for the TREO roles as measured by the TREO survey, affirming their distinctiveness from the Big Five personality domains. In the following paragraphs, we outline each of the TREO team roles and their documented connection with the Big Five personality domains, as identified by Mathieu et al. (2015) using a self-report survey measure of the TREO roles. An overview of the TREO team roles is provided in Supplementary Appendix A. This table also describes the hypothetical relationships between the Belbin and TREO team roles, based on Mathieu et al. (2015).

Within the task-oriented category of the TREO framework, two key roles are highlighted: the Organizer and the Doer. The Organizer takes on the responsibility of providing structure and direction to the group's activities, taking on tasks such as observing, coordinating, and organizing (Griggs et al., 2021). Additionally, Organizers keep track of the group's progress, ensuring that it aligns with established goals and timelines. Complementing the Organizer, the Doer takes on the tasks necessary for achieving group success, ensuring that deadlines are met and tangible outcomes are produced (Mathieu et al., 2015).

In the change-oriented category, the Challenger and Innovator roles help explore alternative perspectives and problem-solving approaches to avoid premature decision-making. The Challenger encourages the group to delve into different aspects of its assignment, often questioning the rationale behind decisions and ideas (Mathieu et al., 2015). This role involves behaviors such as asking "why" and critically evaluating the group members' contributions (Griggs et al., 2021). Conversely, the Innovator generates novel knowledge, creative ideas, and innovative strategies to address challenges (Griggs et al., 2021; Mathieu et al., 2015).

The socio-emotional category includes the roles of Team builder and Connector, both of which focus on fostering a positive and collaborative group atmosphere. The Team builder plays a vital role in establishing group norms, facilitating decision-making processes, and maintaining a harmonious work environment (Mathieu et al., 2015). This role involves behaviors such as active listening, calming tense situations, and providing emotional support to team members (Griggs et al., 2021). On the other hand, the Connector is responsible for building and nurturing external relationships to ensure effective collaboration and a broader network of support (Mathieu et al., 2015).

Mathieu et al. (2015) explored the effectiveness of their self-report TREO predisposition measures in predicting peer-rated team role behaviors in group settings. Their findings indicate that the TREO self-report measure predicted peer ratings of role-related behaviors to some extent, with correlations ranging from.10 to.33 between self-ratings and peer ratings of the same TREO role.

2.2 The link between personality traits and team roles

According to Burch and Anderson (2009), the link between personality and teamwork is becoming increasingly prominent and needs further attention. To this end, previous research has been done studying the relationship between personality and self-report team role measures. Fisher et al. (2001) suggest that connections can be drawn between the Big Five domains of personality, and specific roles within Belbin's framework. For example, Broucek and Randell (1996) have found moderate to strong positive correlations between the personality domain Conscientiousness and the team roles Implementer and Completer finisher. Similarly, research has looked into the relationship between the Big Five domains and the TREO survey. This exploration of the relationships between the TREO dimensions and the Big Five personality traits is an initial step in mapping the TREO's nomological network (Gardner, 2017). Mathieu et al. (2015) investigated this relationship using a condensed version of the International Personality Item Pool scale (Donnellan et al., 2006). Following the correlation guidelines outlined by Gignac and Szodorai (2016), their research reports several significant and relatively strong correlations (i.e., equal to or higher than.30). Specifically, the Team builder demonstrated strong positive correlations with Agreeableness, Extraversion, and Conscientiousness. Both the Organizer and Doer role exhibited strong positive correlations with Conscientiousness and Extraversion. The Innovator role showed positive correlations with Extraversion and Openness. The Challenger role correlated relatively strongly with Openness and Extraversion, and the Connector role displayed the strongest relationship with Extraversion. To the best of our knowledge, Mathieu et al. (2015) is the only study reporting on the relationship between Big Five and the (self-reported) TREO roles. To date, no research has systematically explored the association between facets underlying the Big Five domains (i.e., the traits defining these domains, as exemplified by McCrae, 2020) and typical team role behaviors, as observed by peers.

2.3 Role-taking and verbal interactions in CPS

Beyond examining the link between personality traits and team roles, there is a need to investigate the link between these team roles and verbal interactions within collaborative environments. Particularly, in the context of CPS, researchers (e.g., Graesser et al., 2018) have emphasized the need for (semi-)automated assessments of CPS processes to facilitate both formative and summative feedback. As highlighted by Griggs et al. (2021), this involves gaining insights into team roles through observable indicators. Considering prior research on multimodal learning analytics in the context of CPS, various indicators can be used to evaluate this association. The following section provides an overview of these indicators, followed by a deeper exploration of the anticipated relationships between these indicators and team roles using the TREO framework.

2.3.1 Verbal and non-verbal interactions in CPS

Given the advancements in technologies and techniques, including applications of artificial intelligence, research on the analysis of CPS interactions is evolving in multiple ways. These interactions among team members during CPS encompass both non-verbal and verbal aspects (Buseyne et al., 2023a). For example, through their Nonverbal Indexes of Students' Physical Interactivity framework, Cukurova et al. (2018) describe how CPS can be assessed in students using video data. Praharaj et al. (2022) highlight various non-verbal indicators of collaboration quality, including pitch, intensity, total speaking time, interruptions, and speech overlap. For example, speaking time can be used as an indicator of the quantity of participation (Bachour et al., 2008; Terken and Sturm, 2010).

The quantity of participation can also be measured through verbal aspects of communication, including total word count and the number of utterances per team member (e.g., Buseyne et al., 2023a). Additionally, content analysis has been used to analyze the type of interactions in CPS (e.g., Stewart et al., 2019, 2021, 2023). In the following section, we will elaborate on this type of analysis.

2.3.2 Content analysis using natural language processing

Content analysis is crucial for gaining deeper insights into the types of verbal interactions in CPS. During this process, team members' utterances are annotated based on CPS-related categories (e.g., Sun et al., 2020), enabling researchers and observers to better understand the dynamics and effectiveness of CPS. Various schemes are used for coding CPS utterances. For example, Xu et al. (2024) used the PISA CPS framework to categorize chat interactions in an online environment. However, many of the frameworks, including the PISA CPS framework, are merely competency frameworks and were not specifically designed for coding CPS utterances. In contrast, the generalized competency model for CPS by Sun et al. (2020) contains specific indicators for the latent categories of CPS. Specifically, Sun et al. (2020) distinguish three main CPS facets: constructing shared knowledge, negotiation and coordination, and maintaining team function.

In the past, this annotation was mainly carried out manually. However, new natural language processing (NLP) techniques have emerged to automate the process. NLP, a subset of artificial intelligence, uses computational algorithms to process and interpret human language. Automatic speech recognition, a branch of NLP, enables faster transcriptions of team conversations. Additional NLP techniques ais in classifying utterances. For example, Stewart et al. (2021) used multiple techniques to build automated detectors for three critical facets of CPS: construction of shared knowledge, negotiation and coordination, and maintaining team function (Sun et al., 2020). According to Tan et al. (2022), such techniques can be adopted to support and assess collaborative processes, both for group outcomes and social interactions.

2.3.3 Analysis of verbal interactions using linguistic inquiry and word count

In addition to analyzing verbal interactions at the utterance level, alternative methods exist for word-level analysis, such as linguistic inquiry and word count (LIWC), developed by Pennebaker et al. (2015a). LIWC analyses written or spoken language and categorizes it based on a predefined dictionary of linguistic and psychological categories. These categories include linguistic elements (e.g., pronouns, prepositions, articles), psychological attributes (i.e., emotions, cognitive processes), and summary statistics (e.g., words per sentence, word count).

Several LIWC categories are of interest for the analysis of CPS interactions. First, as mentioned earlier, word count and words per sentence are valuable for mapping the quantity of participation for an individual member. Second, personal pronouns (e.g., I, you, we) play an important role in CPS interactions. Research has shown that inclusive pronouns (e.g., we, us) contribute to a sense of group membership and cohesion within a team (Demmans Epp et al., 2017). Personal pronoun use is also linked to one's orientation, whether self-oriented or collectively oriented, and to an individual's status within the group (Boyd and Schwartz, 2021). Furthermore, the use of personal pronouns can reveal something about one's status within the group. According to Tausczik and Pennebaker (2010), individuals with higher status more often make statements that involve others, while individuals with lower status tend to use more self-oriented language (i.e., first person personal pronouns). Third, negations (e.g., no, never) and interrogatives (e.g., how, what) may relate to specific linguistic behaviors of CPS team members. For example, negations may express opposition to an idea during negotiations (Stewart et al., 2019). Interrogative statements can indicate questioning actions, such as seeking clarification or challenging a proposed solution (e.g., Sun et al., 2020). Fourth, emotion words, including both positive (e.g., nice) and negative (e.g., hate) emotion words, are valuable sources of information in the context of CPS. Emotions provide insights into the cognitive, motivational, and relational aspects of CPS (Avry, 2021). Research indicates that LIWC effectively detects emotional expressions in language usage (Tausczik and Pennebaker, 2010). Fifth, cognitive process words (e.g., think, know, perhaps) and time words (e.g., end, until) are of interest for analyzing verbal interactions in CPS. Stewart et al. (2019) found that among the LIWC categories, certain cognitive process words, such as causations, insights, and differentiations, exhibit strong correlations with CPS processes associated with negotiation and coordination. Similarly, time-related words are associated with the category time management, referring to how team members deal with time limitations (Meier et al., 2007).

2.4 The link between role-taking and verbal interactions in CPS

Considering the aforementioned literature, several connections can be drawn between role-taking and verbal interactions in CPS. In what follows we give a brief overview of each team role based on the TREO framework.

Within the task-oriented category of the TREO framework, Organizers and Doers are primarily focused on task completion (Mathieu et al., 2015; Griggs et al., 2021). Previous research indicates that the behaviors of Organizers often involve setting goals, summarizing or clarifying team members' contribution, and coordinating team actions (Griggs et al., 2021). These behaviors align with CPS categories such as responding to others' ideas or proposed solutions, monitoring execution, time management, technical coordination, discussing strategies, and coordinating task division (Mathieu et al., 2015; Meier et al., 2007; Sun et al., 2020).

For the Doer, task completion is a prevalent behavior, and sharing knowledge and understanding of the task is essential for achieving completion (Belbin, 2011; Mumford et al., 2008). Therefore, Doers are expected to exhibit behaviors corresponding to sharing knowledge and understanding of problems and solutions (Griggs et al., 2021; Mathieu et al., 2015; OECD, 2017; Sun et al., 2020).

The change-oriented category, as described by Mathieu et al. (2015), encourages members to consider alternative approaches. The Challenger role encourages the team to explore all aspects of the task and consider alternative explanations and solutions (Griggs et al., 2021; Mathieu et al., 2015). This aligns with CPS behaviors such as establishing common ground (e.g., asking for further clarification, and giving feedback on the understanding of what the other is saying and asking questions). Challengers, who explore alternative solutions, are expected to use more interrogatives (e.g., why; Griggs et al., 2021).

The Innovator engages in generating new knowledge and strategies for task resolution (Mathieu et al., 2015). This aligns with CPS behaviors such as sharing knowledge and understanding of problems and solutions and discussing strategies (Sun et al., 2020).

Lastly, in the socio-emotional category, Team builders' interpersonal processes are directed toward ensuring team success by integrating team members' expertise and perspectives. This aligns with CPS behaviors such as coordinating task division and establishing common ground (Sun et al., 2020, 2022). Additionally, Team builder are expected to take initiatives to advance collaboration processes (Sun et al., 2020, 2022). Team builders, devoted to maintaining a positive work atmosphere, are expected to use more positive emotion words in their verbal interactions. Furthermore, Team builders' interactions are expected to be more team-oriented, observable through the use of first-person plural pronouns.

2.5 Objectives and research questions

In summary, this study is based on two primary research objectives.

We observed that, to the best of our knowledge, research studying the relationship between TREO roles and the Big Five personality traits is limited to the study by Mathieu et al. (2015), which primarily focuses on results obtained in a military context and among business students. Further research is needed to gain additional insight into this relationship. This knowledge can enhance the formation, selection, training, and development of teams. Therefore, the primary objective of this study is to investigate the relationship between team members' personality traits and their role-taking tendencies, using the peer rating system described by Mathieu et al. (2015). In line with this objective, the first research question (Q1) is formulated as follows: How does personality relate to typical team role behavior, as conceptualized through the TREO framework? Supplementary Appendix A includes the hypotheses related to this research question. These hypotheses are based on meta-analytic summaries of the correlations between TREO and the Big Five across four independent samples in Mathieu et al.'s (2014) study. In addition to the Big Five domains, this study includes personality facets to gain a more nuanced understanding.

Previous research (e.g., Griggs et al., 2021) has highlighted the need for more research on the relationship between role-taking and verbal interactions in different contexts. Therefore, our study's second objective is to build upon existing research by exploring this relationship, especially within the CPS domain. The second, exploratory research question (Q2), is formulated as follows: How does a team member's typical team role behavior, as conceptualized through the TREO framework, affect their verbal interactions in the context of CPS? Given the exploratory nature of this research question, no specific hypotheses are formulated. We employ innovative techniques to analyze verbal interactions, aiming to gain a better understanding of team role behavior.

3 Method

This study received ethical approval from the Ethical Committee of KU Leuven (G-2022-5202). Before participating, all participants received an information letter outlining the study's objectives and data collection procedures. Additionally, participants completed an informed consent form. In the subsequent sections, we will provide a comprehensive overview of the study's context and data collection procedures, followed by explanations of the data processing and data analysis methods employed.

3.1 Study context

This study was conducted as part of a larger project titled Supporting Teamwork in Ambient Learning Spaces. Within the scope of this project, a training program focusing on CPS was developed for workplace teams. Multiple training sessions were conducted in an educational laboratory setting, called the Edulab, located at KU Leuven in Kortrijk, Flanders, Belgium. This location was chosen because the Edulab is equipped with the necessary infrastructure and hardware for audio and video recordings. The CPS training program was structured into five phases. For a comprehensive overview of the training's design, refer to Buseyne et al. (2023b). Data collection for this study occurred during the second phase of the training, which incorporated a CPS task enriched with several game elements.

3.2 Participants

3.2.1 Full sample for examining the relationship between personality and team roles

Participants ($n = 60$; 35 males, 24 females, and 1 other) were recruited from 15 pre-existing teams, representing a mix of private and public organizations within the Flemish region. Participants had diverse backgrounds and held various job functions. In terms of age distribution, one participant was aged between 18 and 24, while 37% fell within the age range of 25 and 34, 43% between 35 and 44, and 12% between 45 and 54. Additionally, one participant fell within the age range of 55 to 64. Participants had an average tenure of 6.75 years ($SD = 6.01$) within their current organization. Their average duration of employment within the specific team involved in the study was 3.98 years ($SD = 4.07$).

3.2.2 Selected sample for examining the relationship between role taking and verbal interaction

For the second research objective, we used a reduced sample of nine teams (36 participants, 21 males and 15 females) selected based on the availability and quality of the audio data. Among these participants, one was aged between 18 and 24, 36% were in the age group of 25 to 34, 39% between 35 and 44, and 19% were 45 and 54. One participant was aged between 55 and 64. The average duration of employment within their current organization was 8.5 years ($SD = 6.97$), while the average duration of employment within their current team was 4.60 years ($SD = 4.95$).

3.3 Data collection

In the days leading up to the start of the training, participants were completed two questionnaires. The first, the Business Attitudes Questionnaire (BAQ; Vrijdags et al., 2014) is a workplace-contextualized personality instrument certified by the British Psychological Society (2023). This questionnaire evaluates personality using the Big Five domains, each broken down into four specific sub-traits or facets. Additionally, the questionnaire assesses five compound traits, collectively categorized under the term "Professionalism." The 25 BAQ facet scores are calculated by averaging the scores of six items per facet, while Big Five domain scores are calculated by averaging the scores of the related facets. A detailed overview of all BAQ facets and their grouping under the Big Five domains is provided in Table 1, while the interpretation of each facet is described in Supplementary Appendix A. The BAQ has been shown to correlate well with other personality inventories, both work-contextualized and non-contextualized, and to predict job

TABLE 1 Overview of the different facets per domain of the Business Attitudes Questionnaire.

Emotional stability	Extraversion	Openness	Altruism	Conscientiousness	Professionalism
Relaxed	Leading	Abstract	People-oriented	Organized	Ambitious
Optimistic	Communicative	Innovative	Cooperating	Meticulous	Critical
Stress-resistant	Persuasive	Change-oriented	Helpful	Rational	Results-oriented
Decisive	Motivating	Open-minded	Socially Confident	Persevering	Strategic
					Autonomous

For a detailed description of each of the Business Attitudes Questionnaire facets, we refer the reader to Supplementary Appendix A.

performance (e.g., Wille et al., 2018). This suggests that the BAQ is a reliable and valid measure of personality traits relevant to the workplace.

In the second questionnaire, participants evaluated their colleagues' team role behaviors, based on the six roles outlined in the TREO model (Mathieu et al., 2015; see Supplementary Appendix A). Participants used a five-point Likert scale to rate to what extent each team member typically exhibits behaviors associated with the six TREO roles during their everyday collaborative efforts. To facilitate this evaluation, participants received concise descriptions for each role. Additionally, they had the option to note instances where they felt unable to assess a specific role behavior for a team member. For example, for the Innovator role, participants rated behaviors such as: "someone who regularly generates new and creative ideas, strategies, and approaches for how the team can handle various situations and challenges. An Innovator often offers original and imaginative suggestions" (Mathieu et al., 2015, p. 16). Out of the 1,080 cases (i.e., three individual ratings for four team members across six roles), 91% were successfully coded. If at least two out of three members rated their colleague, the average score, across raters, for each role, was calculated for that particular member. If a colleague did not receive sufficient ratings, no score was utilized, resulting in missing data.

During the second phase of the training, participants engaged in an activity intentionally designed to stimulate CPS. The primary objective of this activity was to collectively solve as many problems as possible within a 30-min time limit. Each of these problems is referred to as a problem-solving interval. The problems spanned a range of abilities, including verbal, numerical, logical reasoning, spatial insight, detail orientation, and memory. Participants were not provided with specific instructions or guidelines on how to approach these tasks. Instead, each team had the autonomy to decide whether to assign specific roles to individual members during the task. Throughout the CPS activity, team-level conversations were recorded using individual headsets, overhead microphones, and computer microphones. Additionally, the process was video recorded using the video infrastructure of the educational lab.

3.4 Verbal data processing

For the second research objective, the audio data were transcribed manually by one of the researchers because automatic speech recognition software performed inadequately for the Flemish context. Participants' utterances were annotated using a coding scheme for content analysis in computer-supported CPS (see Table 2 and Supplementary Appendix A), based on Meier et al. (2007) and Sun et al. (2020). An independent data coder received training on the coding scheme. To ensure coding reliability, both the appointed data coder and one of the authors independently coded the transcribed data from one of the nine teams. Differences between the coded utterances were discussed, and the coding scheme was refined to suit the specific context of this research. Inter-rater reliability testing was conducted for the coded utterances of one team, resulting in substantial agreement at both the overall item level ($\kappa = 0.75$) and the aggregated sub-category level ($\kappa = 0.79$) based on Cohen's (1960) kappa (e.g., Landis and Koch, 1977). The remaining parts were coded by the appointed data coder. After completing the coding process, the relative frequency of each coding category (i.e., a percentage) was calculated per person and per task within the CPS activity. Specifically, per task, the relative frequency per problem-solving interval was determined by dividing the total number of utterances of a person for a specific coding category by the total number of utterances by that person.

Next, LIWC (Pennebaker et al., 2015a,b) was used to assess affective, social and cognitive dimensions of participants' interactions per problem-solving interval within the CPS task. The analysis reported in this article was performed using LIWC2015 with the Dutch dictionary (van Wissen and Boot, 2017). In our study, the LIWC output variables provide percentages of total words per person per problem-solving interval, similar to the relative frequencies of the CPS categories described earlier. For instance, a value of 10.1 for personal pronouns signifies that 10.1 percent of all the words used by a person in a specific problem-solving interval were personal pronouns. However, some measures are calculated differently; for example, utterance count, word count, and words per sentence represent absolute values.

3.5 Statistical analyses

Data analyses for this study were performed using R (version 4.3.1). For the analyses of Q1, regarding the relationship between personality traits and team roles, single-level correlation analyses were performed. The correlation coefficients were calculated using the stats package (version 3.6.2) and the corresponding p-values were calculated using the psych package (version 2.3.6). Corrected p-values are reported to control for the family-wise error (i.e., multiple hypothesis testing) using Bonferroni correction (Onwuegbuzie and Daniel, 1999).

Next, for Q2, i.e., to assess the relationship between role taking (i.e., independent variables) and verbal interactions (i.e., dependent

TABLE 2 Overview of the categories and sub-categories of the coding scheme for analyzing verbal interactions during CPS.

Category	Sub-category
A: Establishing, constructing and maintaining shared knowledge and understanding	A1: Sharing knowledge and understanding of problems and solutions
	A2: Establishing common ground
B: Negotiating and coordinating for task completion and problem solving	B1: Responding to others' ideas or proposed solutions
	B2: Monitoring execution
	B3: Time management
	B4: Technical coordination
	B5: Discussing strategies
C: Maintaining team function and organization	C1: Taking initiatives to advance collaboration processes
	C2: Coordinating task division

For a detailed overview of the coding scheme, we refer the reader to Supplementary Appendix A.

variables), multiple multilevel linear regression models, using the restricted maximum likelihood procedure, were performed with the lme4 package (version 1.1–34). These models account for the fact that each dependent variable was measured multiple times per person by including the person as a level 2 variable. Additionally, group and task were included as covariates in all models. According to Leyland and Groenewegen (2020), with limited higher-level units, it is "better to perform a single-level analysis and include dummy variables for the higher-level units" (p. 38). Therefore, groups were not added as an extra level due to the limited number of groups. The Connector role was excluded from the Q2 analysis because the behaviors associated with this role, such as communicating with people outside the team, could not be observed in this study.

4 Results

4.1 Correlations between personality and typical team role behavior

Descriptive statistics for each of the personality domains, facets, and team roles are presented in Supplementary Appendix B. In what follows, we present the results of correlations between the TREO roles and the domains and facets of the BAQ. Only relatively large correlations with the BAQ domains are presented in the text. For a full overview of all correlation results, including non-significant correlations and correlations with the BAQ facets, refer to Table 3. Following Funder and Ozer (2019) and Gignac and Szodorai (2016), correlations of.30 or higher were considered relatively large. A simplified overview of these relationships is presented in Supplementary Appendix C.

Regarding the Organizer, significant positive correlations were observed with two BAQ domains: Extraversion ($r = 0.45$) and Altruism ($r = 0.40$). These correlations were also relatively large for most of the facets related to these domains (i.e., Leading, Communicative, Persuasive, Motivating, People oriented, Cooperating, and Helpful). For the Doer role, a significant and relatively large correlation was found with the facet cooperating.

For the Challenger role, noteworthy positive correlations were observed with Extraversion ($r = 0.38$) and Openness ($r = 0.41$). Most of the correlations were significant and relatively large for the underlying facets (i.e., Leading, Communicative, Persuasive, Innovative, Change oriented, Open minded) and some of the Professionalism facets (i.e., Critical, Strategic). Additionally, significant correlations were found with the facets Decisive and Meticulous, which were positive and negative, respectively.

Regarding the Innovator role, a significant and relatively large correlation emerged with Openness ($r = 0.41$). Most of the correlations were also significant for the underlying facets (i.e., Abstract, Innovative, and Open minded). For Conscientiousness, a significant negative correlation was found with the Innovator role, though the coefficient was weaker ($r = -0.27$). The correlation with its facet Meticulous was relatively large and negative.

For the Team builder, strong positive correlations were found with Extraversion ($r = 0.42$) and Altruism ($r = 0.41$). For each of these domains, three of the underlying facets correlated significantly (i.e., Leading, Persuasive, Motivating, People-oriented, Cooperating, and Socially confident). An additional significant negative correlation was found with the facet Rational.

Lastly, the Connector role correlated significantly with Emotional stability (r = 0.27), Extraversion (r = 0.49), and Altruism (r = 0.37). For Emotional stability, only one significant correlation was found with the facet Decisive. For Extraversion, all facets correlated significantly (i.e., Leading, Communicative, Persuasive, and Motivating). Two out of four facets underlying the domain Altruism correlated significantly with the Connector role (i.e., Cooperating and Socially confident). Additionally, a significant negative correlation was found with the facet Rational.

4.2 Relationships between team role behavior and verbal behavior

Table 4 presents the results of the multilevel regression models examining the relationship between the TREO roles and the CPS categories. Table 5 presents the relationship between the TREO roles and the LIWC categories.

First, for the role of Organizer, significant positive relationships were found with the sub-categories "responding to others' ideas or proposed solutions" and "monitoring execution." In terms of linguistic inquiry, a significant negative relationship was observed with the

TABLE 3 Correlations between the BAQ (domains and facets) and the TREO roles.

	Task-Oriented		Change-Oriented		Socio-Emotional	
	Organizer	Doer	Challenger	Innovator	Team builder	Connector
Emotionals stability	**−0.01**	**0.01**	**0.12**	**0.08**	**0.18**	**0.27*****
Relaxed	−0.21	−0.16	−0.05	−0.04	0.03	0.08
Optimistic	−0.04	0.13	0.03	0	0.17	0.20
Stress resistant	0.05	−0.05	0.15	0.07	0.18	0.24
Decisive	0.21	0.12	0.28*	0.24	0.15	0.28*
Extraversion	**0.45*******	**0.21**	**0.38*****	**0.22**	**0.42*****	**0.49******
Leading	0.50***	0.16	0.40**	0.26	0.48***	0.49***
Communicative	0.38**	0.07	0.36**	0.20	0.21	0.32*
Persuasive	0.34**	0.26	0.33*	0.24	0.37**	0.38**
Motivating	0.30*	0.23	0.15	0.02	0.39**	0.44***
Openness	**−0.11**	**−0.03**	**0.41*****	**0.41*****	**−0.03**	**0.19**
Abstract	−0.13	0.04	0.28*	0.32*	−0.13	−0.03
Innovative	0.06	0.05	0.40**	0.41**	0.03	0.29*
Change oriented	−0.12	−0.15	0.30*	0.26	0.10	0.26
Open minded	−0.15	−0.08	0.35**	0.34**	−0.02	0.21
Altruism	**0.40*****	**0.27***	**0.14**	**0.09**	**0.41*****	**0.37*****
People oriented	0.27*	0.18	0	−0.01	0.29*	0.20
Cooperating	0.47***	0.30*	0.16	0.16	0.51***	0.38**
Helpful	0.30*	0.08	0.13	0.03	0.17	0.20
Socially Confident	0.23	0.24	0.16	0.09	0.29*	0.34*
Conscientiousness	**−0.07**	**−0.09**	**−0.25**	**−0.27***	**−0.19**	**−0.21**
Organized	0.07	0.11	−0.22	−0.25	0.08	0.02
Meticulous	−0.02	−0.09	−0.30*	−0.30*	−0.17	−0.20
Rational	−0.21	−0.27*	−0.03	−0.05	−0.37**	−0.31*
Persevering	−0.05	−0.01	−0.15	−0.12	−0.09	−0.13
Professionalism						
Ambitious	0.15	−0.01	0.20	0.04	0.11	0.15
Critical	−0.08	−0.10	0.34**	0.18	−0.18	−0.05
Result oriented	0.12	−0.02	0.27*	0.22	0.24	0.11
Strategic	0.07	−0.06	0.42***	0.23	0.04	0.14
Autonomous	0.05	−0.03	0.27*	0.16	−0.10	0

Personality domains are marked in bold. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

category We-pronoun and a positive relationship was found with the word category Negative emotions.

Second, for the Doer, a significant positive relationship was found with "establishing common ground." Additionally, significant negative relationships were observed with Word count and Time.

Third, for the Challenger role, no significant relationships were found with the CPS categories. However, a significant negative relationship was observed with Word count in terms of word use.

Fourth, no significant relationships were found between the Innovator role and the CPS categories. However, significant positive relationships were found with Word count and the LIWC category Time.

Lastly, for the Team builder role, the observed relationships with CPS categories were not significant. In terms of LIWC, a significant negative relationship was found with Words per sentence.

5 Discussion and concluding remarks

5.1 Unravelling the link between personality and team roles

The first objective of this study was to explore the relationships between personality traits and typical team role behavior as observed

TABLE 4 Results of the multilevel regression analysis showing the relationship between TREO dimensions and the relative frequencies of CPS categories.

	A. knowledge & understanding	A1. sharing knowledge	A2. establishing common ground	B. negotiating & coordinating	B1. responding	B2. monitoring execution	B3. time management	B4. technical coordination	B5. Discussing strategies	C. team functioning	C1. advancing collaboration
(Intercept)	49.34 (4.66)***	21.43 (3.87)***	27.91 (3.61)***	43.78 (4.66)***	7.75 (1.88)***	5.81 (2.57)*	4.92 (1.50)**	11.46 (2.93)***	8.64 (2.75)**	1.77 (0.93)	6.86 (2.66)**
Organizer	−1.77 (1.61)	−1.77 (1.36)	0.02 (1.24)	1.63 (1.61)	1.39 (0.65)*	2.58 (0.89)**	−0.86 (0.59)	−0.68 (1.01)	−0.62 (0.95)	0.14 (0.35)	−0.78 (0.92)
Doer	3.38 (2.31)	−0.20 (1.94)	3.59 (1.78)*	−2.13 (2.30)	−0.17 (0.93)	0.16 (1.27)	−0.51 (0.82)	−1.20 (1.44)	−1.67 (1.36)	−0.35 (0.50)	−1.20 (1.31)
Challenger	1.58 (3.20)	−1.85 (2.69)	3.45 (2.47)	−3.82 (3.19)	−0.55 (1.28)	0.89 (1.76)	−1.09 (1.14)	−3.50 (2.00)	−0.37 (1.88)	0.34 (0.69)	−0.45 (1.82)
Innovator	1.97 (3.75)	5.48 (3.15)	−3.54 (2.89)	1.40 (3.73)	0.12 (1.51)	−3.15 (2.06)	0.68 (1.31)	4.21 (2.34)	0.22 (2.21)	−0.32 (0.80)	0.25 (2.13)
Team builder	−2.79 (1.95)	−3.00 (1.64)	0.21 (1.50)	−0.27 (1.94)	−0.19 (0.78)	−0.51 (1.07)	0.82 (0.71)	0.56 (1.22)	1.35 (1.15)	0.53 (0.43)	0.79 (1.11)
AIC	1958.59	1868.21	1850.11	1961.41	1567.01	1703.22	1368.68	1759.14	1733.03	1188.66	1717.94
BIC	2038.46	1948.07	1929.97	2041.27	1646.87	1783.08	1448.54	1839.00	1812.89	1268.52	1797.80
LL	−956.30	−911.10	−902.05	−957.70	−760.51	−828.61	−661.34	−856.57	−843.51	−571.33	−835.97
Between-person variance	0.94	2.93	0.00	0.00	0.00	0.00	2.82	0.00	0.00	0.84	0.00
Within-person variance	282.55	184.87	171.75	286.85	46.59	87.28	17.40	112.94	100.14	7.73	93.41

Regression coefficient estimates are shown, along with the standard errors and the indicator of the corresponding p-value. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. A full overview of the categories (i.e., A, B, C) and sub-categories (i.e., A1, A2, etc.) is presented in Table 2.

TABLE 5 Results of the multilevel regression analysis showing the relationship between TREO dimensions and the relative frequencies of the selected LIWC categories.

	Words per sentence	Word count	I-pronoun	We-pronoun	Negations	Interrogatives	Positive emotion words	Negative emotion words	Cognitive process words	Time
Intercept	6.19 (0.42)***	218.04 (25.49)***	2.89 (0.80)***	3.94 (0.55)***	1.59 (0.68)*	0.77 (0.42)	0.82 (0.49)	0.05 (0.23)	15.57 (1.55)***	7.21 (0.94)***
Organizer	−0.18 (0.17)	−7.88 (9.82)	0.24 (0.29)	−0.40 (0.20)*	0.24 (0.23)	0.21 (0.15)	0.10 (0.18)	0.18 (0.08) *	−0.75 (0.58)	−0.45 (0.32)
Doer	−0.18 (0.23)	−28.84 (13.76)*	0.75 (0.41)	−0.18 (0.29)	−0.38 (0.33)	−0.15 (0.21)	−0.47 (0.25)	0.07 (0.11)	−0.77 (0.81)	−1.48 (0.46)**
Challenger	−0.27 (0.32)	−38.72 (19.11)*	0.33 (0.57)	−0.40 (0.40)	0.71 (0.46)	0.27 (0.29)	−0.54 (0.35)	0.29 (0.16)	−0.59 (1.13)	−1.19 (0.64)
Innovator	0.48 (0.37)	68.38 (22.03)**	−0.87 (0.67)	0.70 (0.46)	−0.60 (0.54)	−0.34 (0.34)	0.68 (0.41)	−0.24 (0.18)	1.13 (1.31)	2.31 (0.75)**
Team builder	−0.42 (0.20)*	−4.73 (11.82)	−0.15 (0.35)	0.40 (0.25)	0.25 (0.28)	0.13 (0.18)	0.15 (0.21)	0.11 (0.09)	0.31 (0.69)	0.65 (0.39)
AIC	792.26	2619.23	1166.73	992.68	1124.43	896.82	968.78	650.95	1436.19	1267.48
BIC	872.13	2699.09	1246.59	1072.54	1204.29	976.68	1048.64	730.81	1516.05	1347.34
LL	−373.13	−1286.62	−560.36	−473.34	−539.22	−425.41	−461.39	−302.47	−695.09	−610.74
Between-person variance	0.25	689.07	0.30	0.19	0.00	0.04	0.07	0.00	1.65	0.00
Within-person variance	1.21	5609.95	7.19	3.20	6.06	2.10	2.91	0.68	24.60	11.72

Regression coefficient estimates are shown, along with the corresponding standard error in parentheses and the p-value. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

and rated by close, long-term collaborators. Building on prior research (i.e., Mathieu et al., 2015), the current study provides additional insights into how personality characteristics may influence one's predisposition to take up specific roles within a team. A summarized overview of the findings is presented in Supplementary Appendix C.

Various relationships identified in this study align with research by Mathieu et al. (2015), who studied links between the Big Five and TREO team roles using a self-report questionnaire. Particularly, Organizers displayed relatively strong positive correlations with Extraversion, Challengers and Innovators had strong correlations with Openness, the roles of Team builder and Connector positively correlated with Extraversion, and Team builders correlated positively with Altruism. Additionally, our study revealed numerous interesting connections that were not yet revealed in Mathieu et al. (2015) research. Particularly, our work includes a deeper, facet-level examination of personality, and the relationship with observed, peer-rated team role behavior. The following section provides a thorough interpretation of the identified patterns.

An individual assuming the role of Organizer within a team, is characterized by their ability to establish structural frameworks for the team's activities, delineating the essential tasks to be executed (Mathieu et al., 2015). Consequently, our study shows that Organizer behavior exhibits a significant correlation with Leading, a personality facet encompassing leadership qualities, delegation proficiency, and instructional competence. Next, individuals perceived by their team members as adopting the organizer role also tend to demonstrate higher scores on Communicative, indicating their proclivity for extensive and articulate verbal interactions, as well as Persuasive, suggesting their perceived effectiveness in persuading others of their ideas and viewpoints. In the context of structuring tasks and monitoring past activities, one might naturally assume a positive correlation between Organizer and Conscientiousness, and with the Organized facet in particular. However, our research did not confirm this assumption. The Organized facet primarily reflects the capacity to plan and structure one's own work, with individuals excelling in this facet often displaying a degree of inflexibility. Contrarily, Organizer, within a team, entails taking the lead in structuring and shaping the group's work, placing a strong emphasis on the social aspect of team collaboration.

Interestingly, we found that the Doer role exhibited no robust correlations with any of the personality domains and facets. However, one relationship of smaller magnitude was found with Cooperating. This suggests that the Doer can be described as the dependable individual who takes on tasks and may not possess distinct characteristics but excels as a reliable executor.

When examining the definition of Challenger role (Mathieu et al., 2015), several aspects emerge, that correspond with various facets of the BAQ. Encouraging and motivating the team aligns with Leading. The disposition to consider alternative assumptions, explanations, and solutions, is associated with Open-minded and Innovative. Consistently, questioning and offering constructive criticism mirrors the facet Critical. Additionally, engaging in debates resonates with Communicative. All these BAQ facets exhibit strong, positive correlations with being perceived as a Challenger by team members. For this role, the findings underscore the link between individual's self-perceptions of their personality and how they are perceived by their colleagues. Intriguingly, Strategic also demonstrates a strong positive correlation with the Challenger role. This connection may be attributed to the underlying motivations for assuming this role. Strategic signifies a heightened emphasis on long-term planning and adopting a more expansive viewpoint, as opposed to fixating solely on immediate tasks and ongoing projects. Individuals possessing a stronger proclivity for long-term orientation are likely to display a greater inclination toward challenging the status quo, thus assuming the challenger role.

The definition of the Innovator role shares certain similarities with that of the Challenger role, albeit within more constrained boundaries. While a Challenger encourages the team to explore alternative and innovative explanations and solutions, an Innovator primarily stands out as an individual who consistently generates fresh, creative, and original ideas independently. This role displays the most robust correlations with Innovative and Open-minded. Nevertheless, what is noteworthy is the extent to which these dimensions of an individual's self-perception are accurately perceived by their colleagues during team collaboration.

A Team builder actively contributes to setting group norms and fostering a positive work environment (Mathieu et al., 2015). This aligns with the positive correlation observed with Leading. Individuals scoring high on Leading are more inclined, in comparison to those with lower scores on this facet, to take on a prominent role within the team. This may involve activities like establishing norms and fostering a positive work environment that garners attention and respect from their peers. The Team builder role also entails the ability to motivate team members, a characteristic substantiated by the strong correlation with Motivating. Furthermore, the Team builder role exhibits a significant positive correlation with Persuasive, indicating that these individuals perceive themselves as skilled at articulating and convincing others of their ideas. To attain the esteemed status of Team builder, one must project themselves as a genuine 'people person'. Conversely, a negative relationship was observed with Rational. Team members who mostly base their decisions on empirical data, prioritize rational arguments, and exercise discernment in their interactions, as prescribed by Rational, may not typically be seen by their team mates as dedicated to fostering a positive work atmosphere or offering support, as is the case with the Team builder.

The correlations with the BAQ facets exhibit remarkable similarity between the Connector and Team builder roles. However, the distinction lies in that the Connector role involves establishing connections with stakeholders beyond the team, rather than focusing on fostering relationships within the team. Consequently, those who take on the role of connectors tend to excel as adept networkers. Notably, among all team roles, the Connector displays the strongest correlation with Socially Confident, emphasizes characteristics such as amiability, spontaneity, and proficiency in networking.

5.2 Unravelling the link between team roles and verbal behavior

As a second research objective, our study investigated the relationship between typical team role behavior rated by colleagues, and verbal behavior, including the relative frequencies of types of utterances and LIWC measures, during CPS.

Team members identified as Organizers exhibited a higher relative frequency of utterances related to "responding to others' ideas or proposed solutions" and "monitoring execution." These findings align with previous research by Griggs et al. (2021), which suggests that Organizers often engage in coordinating team actions, summarizing team members' contributions, and setting goals. Additionally, team members rated as Organizers incorporated fewer we-pronouns, which may be an indication of a less collective orientation in verbal interaction. Furthermore, this role was associated with a higher use of negative emotion words. This particular finding warrants further exploration.

According to Griggs et al. (2021), the role of Doer is generally associated with supporting group memory, task execution, and maintaining task focus. The significant higher involvement of Doers in establishing common ground identified in the current study aligns with this description. By fostering an environment where information is clearly communicated and understood by the group, Doers enhance their ability to execute tasks effectively and maintain focus. Additionally, we observed that Doers had a lower word count and exhibited a less frequent use of time-related words in their conversations during CPS tasks. This may suggest that Doers prioritize a more action-oriented approach over engaging in extended team interactions. Further research is needed to verify this explorative finding.

Similarly to the Doer, team members identified as Challengers had a lower word count, indicative of less verbal interaction. Aligning with Griggs et al. (2021), this could be attributed to their focus on concise, targeted contributions aimed at questioning and critiquing ideas rather than engaging in extended dialogues. However, this concise communication style was not significantly observed in terms of average words per sentence.

Griggs et al. (2021) demonstrated that Innovators engage in behaviors such as generating ideas, sharing information, and working independently. Furthermore, we observed that individuals embodying the Innovator role had a higher word count and used more time-related words. This higher verbal interaction could be attributed to the nature of their activities, which involve extensive idea generation and detailed information sharing. However, the increased use of time-related words does not align directly with the typical role description of Innovators, suggesting that further exploration is needed.

Lastly, the Team Builder role, which typically involves managing conflicts, fostering a positive environment, and supporting consensus (Griggs et al., 2021; Mathieu et al., 2015), was associated in our study with a lower number of words per sentence (i.e., shorter sentences). This communication style may align with the nature of their role, which generally focuses on building consensus and maintaining a harmonious team environment instead of engaging in argumentation processes, which requires longer sentences.

5.3 Limitations of the current study

It is important to acknowledge certain limitations of this study. First, this study relies on intrinsically subjective self-report personality measures and peer ratings for the evaluation of typical team role behaviors, as well as non-automated human coding for content analysis. Although validated instruments were used, and inter-rater reliability was ensured, this could still introduce biases.

Second, the study was conducted within a specific context and with a limited sample size, which may affect the generalizability of the findings. Additionally, participants were not required to rate all their team members, resulting in some team members not receiving a full set of ratings for certain roles. However, this flexibility was necessary to ensure the validity of the ratings provided.

Third, it is important to note that the roles were assessed before the participants engaged in the CPS tasks. Therefore, the role evaluations were based on general impressions and long-term collaboration rather than the specific CPS tasks performed during the study. This approach was chosen to minimize the potential influence of the specific task characteristics on the role ratings. Nevertheless, this might have affected the findings.

Fourth, this study did not consider the team compositions and the distribution of personality traits within teams. Instead, we controlled for the overall group effect in our regression analyses to account for any potential influence of team characteristics.

Fifth, since team members had been working together for a longer time and the tasks they needed to perform for our research study were rather short, we could not assess how the verbal behavior in relation to the roles evolved over time.

5.4 Strengths of the current study

As stated in the title of our study, we aimed to peer into the kaleidoscopic view of team roles in the context of CPS, which is known as a complex context to investigate, by incorporating various measures and frameworks. Our research on the relationship between (a) personality domains and team role behaviors and (b) team role behaviors and verbal interactions is distinct from previous research in several ways.

To assess the relationship between personality domains and team role behavior, our study integrates additional facets labelled under Professionalism, alongside the traditional Big Five facets, providing a more comprehensive exploration. The simplicity of the Big Five serves as a valuable tool for establishing a shared vocabulary among researchers. However, it is increasingly accepted that a greater number of personality constructs offer significant benefits for both theoretical and practical applications (e.g., Stanek and Ones, 2018).

Additionally, we provide an overview of the correlations not only for each role and personality domain but also on the level of the personality facets, offering a more in-depth analysis. Merely making a conceptual distinction between facets within the Big Five domains is insufficient unless it holds empirical significance. When looking at our results, focusing on the relationships between the facets and domains of the BAQ and the TREO team roles, it proves useful to delve into the different facets of the BAQ, rather than solely concentrating on the broader Big Five domains. For instance, when considering the Conscientiousness domain, it appears unrelated to the Team builder role. Nevertheless, at the facet-level, a robust negative correlation emerges with the Rational facet. Evidently, team members who base their decisions on facts and figures, prioritize rational arguments, and exercise discretion in their interactions are not commonly perceived as Team builders. Such individuals may not

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typically invest effort in fostering a positive working atmosphere within the team, offering solace to stressed teammates, or providing motivation to those facing challenges. This principle also operates the other way around, as altruism displays a robust correlation with both being perceived as a Team builder and a Connector. When considering the distinct facets comprising the Altruism domain, neither of these team roles correlates significantly with the Helpful facet. Hence, it becomes apparent that demonstrating consideration and willingness to assist and help others does not contribute significantly to Team builder or Connector behaviors, as perceived by colleagues. The domain-level correlation predominantly arises from the strong positive association with the Cooperating facet, which primarily reflects a propensity to involve others and prefer teamwork over solitary work, rather than a focus on being helpful. The Helpful and Cooperating facets represent two distinct aspects within Altruism, both of conceptual and empirical importance in the context of team collaboration, as shown by our research.

Another strength, compared to similar research, is that our participants occupied diverse job roles across various sectors and were drawn from authentic teams characterized by longstanding collaborations. Despite the diverse nature of their job roles and sectors, we identified strong correlations, emphasizing the relevance of our findings across a broad spectrum of real-world team dynamics.

To examine the relationship between team role behavior and CPS processes, our study employed innovative methods not previously utilized for this purpose. Specifically, we used measures obtained through (a) content analysis, based on a CPS coding scheme and (b) LIWC. The identification of types of CPS utterances associated with each role enriches our comprehension of team dynamics. Our study, for instance, showed that organizers exhibited a higher relative frequency of utterances related to responding to others' ideas or proposed solutions and monitoring execution. This aligns with prior research by Griggs et al. (2021). Second, the integration of LIWC analysis provided an additional layer of insight into CPS processes. Whereas the coded CPS categories solely focus on what is being communicated, LIWC provides insights into the nuances of how communication unfolds such as the amount of communication (i.e., word count). However, it is important to recognize that the correlations observed between specific verbal behaviors and team roles are exploratory and descriptive.

5.5 Implications for team-learning in professional contexts

The outcomes of this study hold significant implications for understanding the interplay between personality self-perceptions, peer-rated team role behavior, and verbal behaviors in the context of computer-supported CPS.

First, our findings underscore the importance of considering individual self-perceptions of personality as critical drivers of team role behaviors. Hogan and Roberts (2000) posit that personality self-perceptions shape individuals' identities, interactions, and the roles they are willing to undertake. The convergence with other-ratings of team role behaviors highlights the robustness of these self-perceptions of personality. Understanding how individuals perceive their own personalities contributes to unravelling the dynamics of role allocation within teams. The successful demonstration that self-report personality measurements not only predict individual behavior but also correlate with typical team role behavior, provides a bridge between individual and team-level assessments. This suggests that personality assessments can offer valuable insights into team dynamics, aiding coaches and trainers in developing teams and their members. Furthermore, the robust correlation between individual self-perceptions of personality and how individuals are perceived by others in a team context adds validity to personality assessments, emphasizing their utility in predicting not only individual but also team-related behaviors.

Second, the study provides a unique contribution by demonstrating the applicability of peer-rated team role measurements for predicting individuals' behavior in teams. Employers, coaches and trainers seeking to understand how candidates or employees are likely to behave within a team context can leverage these insights.

Third, as shown by Mathieu et al. (2015), self-report team role questionnaires often exhibit rather low correlations with peer-rated team role behavior. This raises doubts about the effectiveness of self-report team role questionnaires as reliable predictors. Our study suggests that personality assessments provide an alternative indicator for typical team role behavior instead of self-report team role questionnaires. Future research could compare the predictive ability of self-reported team role questionnaires compared to personality assessments for typical team role behavior.

5.6 Future research opportunities

This research opens avenues for further exploration of the behaviors associated with specific team roles in various contexts. Future research could also examine the relationship between team roles and both individual and team performance measures. In addition to the methods used in this study, researchers should explore additional methods for analyzing both verbal-and non-verbal behaviors. This includes using additional variables, such as analytical thinking and clout, available in newer versions of LIWC (Pennebaker et al., 2022), which were not accessible in the Dutch language at the time of this study.

To address the aforementioned limitations, future research should expand the sample size and include diverse contexts to enhance the generalizability of the findings. A larger sample size would allow the inclusion of the team as a higher-order structure in hierarchal regression analysis. Additionally, this would enable the exploration of other analysis methods, such as latent profile analysis.

Future studies should also consider examining the impact of different assessment timings on role evaluations and task performance. Investigating whether assessing team roles before or after specific tasks yields different insights and could help to refine our understanding of role dynamics in collaborative settings.

Moreover, future research could explore the causal effect of team composition and the distribution of personality traits within teams on verbal and non-verbal interactions during CPS. Understanding how the collective personality profile of a team affects its functioning, and effectiveness could offer deeper insights into team dynamics.

Furthermore, previous research has examined the associations between personality traits and team performance in a curvilinear manner. For instance, Curşeu et al. (2019) identified an inverted U-shaped association between Openness and contributions to teamwork in some studied samples. Therefore, future research could explore the relationships studied here using a curvilinear approach.

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 Social and Societal Ethics Committee of KU Leuven. 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

SB: Conceptualization, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. AV: Conceptualization, Investigation, Writing – original draft, Writing – review & editing. SS-M: Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing. TD: Writing – review & editing. JH: Writing – review & editing. FD: Conceptualization, Funding acquisition, Investigation, Supervision, Writing – original draft, Writing – review & editing. AR: Conceptualization, Funding acquisition, Investigation, 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.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2024.1345892/full#supplementary-material

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Can we foster pre-service teachers' competences for digital collaboration?

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Digital collaboration in schools is becoming increasingly important in educational processes—for teachers as well as for students. Teachers' competences, including professional knowledge (e.g., technological-pedagogical content knowledge; TPCK), attitudes (e.g., regarding the usefulness of digital collaboration), and their motivational orientations (e.g., intrinsic motivation and self-efficacy beliefs), are essential prerequisites for digital collaboration within the teaching staff and for teaching students how to learn collaboratively using digital media. Teacher education at universities plays a crucial role in the development of teachers' professional competences, yet little is known about how teachers' digital collaboration competences can be fostered effectively. Hence, the research aim was to investigate (a) the development of pre-service teachers' TPCK, attitudes, and motivational orientations toward digital collaboration in general, (b) analyze the development of their intentions to use digital collaboration in the future, and (c) evaluate the effectiveness of interventions focused on digitally collaborative learning. In this multi-cohort quasi-experimental study with pre-post design, $N = 439$ students participated either in intervention group (IG) courses ($n_{IG} = 351$) explicitly fostering digital collaboration or in regular university courses without explicit fostering of digital collaboration, who served as a control group (CG; $n_{CG} = 88$). Results of conditional latent three-level growth models indicate a positive development of pre-service teachers' TPCK and their intentions to use digital collaboration. This research contributes to the highly relevant question of how to prepare teachers for increasingly digitalized teaching and learning settings in school.

KEYWORDS

teacher competences, digitalization, digital collaboration, professional knowledge, teacher attitudes, teacher motivation, TPACK

1 Introduction

Digital competence is a key competence for the 21st century (Vuorikari et al., 2022). Digital teaching and learning have become more and more relevant, not only due to the COVID-19 pandemic, resulting in new teaching methods and new ways of communication within the classroom as well as within the teaching staff. Systematic reviews show an increasing body of research on teachers' digital competences and the need for fostering (pre-service) teacher's competences to deal with and teach with digital media (Basilotta-Gómez-Pablos et al., 2022; Gutiérrez-Ángel et al., 2022). Digital technologies, including computers and digital platforms, provide various possibilities for collaboration in the school context. Also, digital collaboration is widely considered an important aspect of digital competence in general (van Laar et al., 2017) and of teachers' professional digital competence in particular (Skantz-Åberg et al., 2022). Furthermore, digital collaboration has potential for teachers in several areas, such as professionalization (Redecker and Punie, 2017), synchronous and asynchronous problem-solving (Vuorikari and Brečko, 2013), or joint development of lesson plans (Hrastinski, 2021). Consequently, teachers need to be prepared to work together digitally in effective ways in order to improve teaching and learning processes. According to established and empirically tested models of teachers' professional competence (professional competence in general: Baumert and Kunter, 2013; digital competences: Mishra and Koehler, 2006; Skantz-Åberg et al., 2022), teachers' professional knowledge (here: Technological Pedagogical Content Knowledge, TPCK), attitudes (e.g., regarding the usefulness of digital collaboration), and their motivational orientations (e.g., intrinsic motivation and self-efficacy to collaborate digitally) are vital components of teachers' competence, which in turn is predictive for teachers' intentions to use digital collaboration. A broad body of evidence indicates that the first phase of teacher education at universities is essential for the development of (pre-service) teachers' professional competences (Blömeke et al., 2008; Lachner et al., 2021; Tatto, 2021). Consequently, university courses provide an ideal opportunity to promote pre-service teachers' competences for digital collaboration. The present study evaluates interventions to foster pre-service teachers' digital collaboration in different subject didactics courses at a German university, investigating the development of pre-service teachers' competences and their intentions to engage in digital collaboration in the future.

2 Theoretical background

2.1 Digital collaboration among teachers

The importance of digital collaboration is increasingly recognized across various sectors of society in general and educational systems specifically. Especially since the COVID-19 pandemic, the opportunities and challenges of digital teaching and learning processes have been discussed and empirically investigated worldwide. Within the European Framework for the Digital Competence of Educators (DigCompEdu), digital collaboration is identified as a crucial component of teachers' digital competencies (Redecker and Punie, 2017). This emphasis on digital collaboration underscores its significance for addressing the demands and complexities of professional educational practice. Distinct from teacher cooperation, collaboration is defined as "a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a sheared conception of a problem" (Roschelle and Teasley, 1995, p.70). Teacher collaboration can be regarded as a continuum from working individually on the one end and intense deep levels of collaboration such as co-construction on the other (Fussangel and Gräsel, 2010; Vangrieken et al., 2015). There is sound empirical evidence that teacher collaboration is positively associated with instructional quality and student achievement (e.g., Goddard et al., 2007; Ronfeldt et al., 2015).

Digital technologies offer significant potential to enhance the quality of collaboration among teachers, e.g., by providing for synchronous and asynchronous communication, sharing resources or engaging in joint tasks, collaborative learning processes, or co-construction (Jeong and Hmelo-Silver, 2016). Studies indicate that digital collaboration is associated with higher learning performance, more positive attitudes toward learning and more productive collaboration—for students as well as teachers (Sung et al., 2017). Moreover, it can be a powerful tool for teacher professionalization and teaching itself, as digital teacher collaboration bears the potential to improve teachers' professional performance by, e.g., sharing best-practice examples not only within schools but within a broader professional network (García-Martínez et al., 2022). However, effective digital collaboration requires specific competencies, underscoring the need to integrate digital technology skills into university teacher training programs (Caena and Redecker, 2019). As such, fostering pre-service teachers' competences for digital collaboration is essential for leveraging the potential of digital technologies in education.

2.2 Teachers' professional competences for digital collaboration and their relevance for teachers' actions

According to established models of teachers' professionalism, competences for digital collaboration include cognitive and motivational components (Baumert and Kunter, 2013; Skantz-Åberg et al., 2022). One core component of teachers' competence is their professional knowledge. In the context of teaching with digital technologies, the widely established TPACK model describes *Technological Pedagogical Content Knowledge (TPCK)* as a special form of knowledge that goes beyond content knowledge, pedagogical knowledge, and technology knowledge (Mishra and Koehler, 2006). Being subject-independent, TPCK includes knowledge about using technologies, instructional techniques using digital technology and knowledge about student learning (Mishra and Koehler, 2006). Research has repeatedly shown positive relations between teachers' TPCK and student achievement in different subjects and grades (e.g., Akturk and Ozturk, 2019; Duan et al., 2022) and it is therefore an important objective for university teacher training. TPCK can be an important prerequisite for using digital technologies for collaboration in later professional life (Maor, 2017).

Besides professional knowledge, teachers' attitudes play an important role for their professional behavior, as they influence the subjective perception of situations and impact teachers' actions on an unconscious level (Staub and Stern, 2002). Attitudes can also moderate the use of professional knowledge and skills (Gess-Newsome, 2015). According to the (situated) expectancy-value-model, the utility value, as a component of the subjective task value, is one factor that impacts individuals' choices and actions (Eccles and Wigfield, 2020; Wigfield and Eccles, 2000). When a specific task or goal is considered valuable or useful, individuals are more likely to engage in it. Concerning digital collaboration, teachers' *attitude toward the usefulness* of digital technology positively predicts their intentions to participate in technology-related professional development and collaboration (Fütterer et al., 2023; Vangrieken et al., 2015).

Alongside cognitive components of professional competences, affective-motivational aspects are equally important for teachers' professional performance. Motivational orientations such as intrinsic motivation and self-efficacy beliefs are vital motivational components of teachers' professional competences (Baumert and Kunter, 2013). Following Ryan's and Deci's self-determination theory, *intrinsic motivation*, i.e., the joy of performing an activity itself, goes hand in hand with self-determined action (Ryan and Deci, 2017, 2020). Consequently, intrinsic motivation is considered an important prerequisite for multiple aspects of professional success, e.g., for the quality of teachers' professional actions, their well-being, and student outcomes (Keller et al., 2016). Studies on teachers' intrinsic motivation with regard to digital collaboration are scarce. Yeung et al. (2014) found that mastery goal orientation positively related to (pre-service) teachers' use of digital technologies, while Kolleck (2019) investigated teacher collaboration in general and discovered a bidirectional association between teachers' motivation and teacher collaboration. Another motivational orientation, teachers' *self-efficacy beliefs*, as a conviction that one is able to successfully master tasks and a further component of motivational orientations, also correlates with teacher performance, teacher well-being and student performance (Bandura, 1978; Zee and Koomen, 2016). There is empirical evidence that teachers with higher self-efficacy beliefs are more likely to share information in digital collaboration settings than teachers with low self-efficacy beliefs (Richter et al., 2022).

To the best of our knowledge, no empirical studies to date simultaneously investigate all of the aforementioned aspects of teacher professionalism with regard to digital collaboration, meaning that the question of the associations between (pre-service) teachers' competences and their performance remains unanswered. In their model of teacher competence as a continuum, Blömeke et al. (2015) argue that the aforementioned cognitive and affective-motivational dispositions are prerequisites of teachers' situation-specific skills (e.g., making decisions on how to act in a certain situation) and performance. Furthermore, the theory of planned behavior states that individuals' background factors, such as knowledge, attitudes and emotions, predict a person's intentions, which in turn precede actual behavior (Ajzen and Albarracin, 2007; Dierendonck et al., 2024). Hence, referring back to digital collaboration, there is strong theoretical and empirical evidence for the importance of teachers' aforementioned competences for their *intentions to use digital collaboration* in their professional life and for actually engaging in digital collaboration.

2.3 Relevance of teacher education and interventions for pre-service teachers

Teacher education at universities plays a crucial role in the development of teachers' professional competences (Blömeke et al., 2008). A curriculum of subject-specific courses, subject-didactic courses and general pedagogical components—the proportions vary across teacher training programs (e.g., for future elementary school teachers or future upper secondary school teachers)—provides learning opportunities to foster pre-service teachers' cognitive and non-cognitive competences. A range of intervention studies demonstrate the effectiveness of measures to promote digital competences among pre-service teachers within this first phase of teacher education. In their qualitative study, Reisoğlu and Çebi (2020) showed that pre-service teachers attending a 70-h training on digital competences rooted in the DigComp framework (Redecker and Punie, 2017) reported higher knowledge and skills regarding communication and collaboration via digital technologies. It should be critically noted that there was no control group in the study design and the effects can therefore not be attributed to the intervention alone. However, Lachner et al. (2021) evaluated the effectiveness of a 3-week TPACK intervention in a quasi-experimental study and found positive effects on pre-service teachers' TPACK (here: Technological Pedagogical Content Knowledge) and their technology-related self-efficacy. However, a quasi-experimental study by Bertram et al. (2023) indicated that a 2-day workshop with pre-service and in-service teachers could increase self-efficacy in teaching with digital technology in all participants, but no effects were found for technological-pedagogical knowledge and attitudes. Summarizing, empirical evidence on the effectiveness of interventions to foster pre-service teachers' digital competences mostly focuses on isolated aspects of competencies rather than comprehensively addressing both cognitive and motivational components, does not always specifically address digital collaboration, and findings are not consistent. Consequently, the present study aims to evaluate the effects of interventions developed and implemented within subject-didactic courses on pre-service teachers' digital collaboration.

3 Research questions and hypotheses

Given the importance of teacher education for the development of pre-service teachers' professional competences and the growing relevance of digital competences, the present study aims to investigate (a) the development of pre-service teachers' TPCK, attitudes, and motivational orientations toward digital collaboration as core aspects of their professional competence as well as (b) their intentions to use digital collaboration as in-service teachers. Furthermore, we evaluate the effectiveness of interventions promoting pre-service teachers' digital collaboration. Concretely, three research questions guided the present study:

RQ1: How do pre-service teachers' competences for digital collaboration develop over the course of a semester?

H1: We expect a positive development of (a) technological-pedagogical content knowledge, (b) attitudes toward the use of digital collaboration, and (c) motivational orientations toward digital collaboration among all pre-service teachers.

RQ2: Is there a change in pre-service teachers' intentions to use digital collaboration (idealistic and realistic) in the course of one semester?

H2: Analog to hypothesis H1, we also expect a positive development in pre-service teachers' intentions to collaborate digitally in the future.

RQ3: What differences in competence development and intentions to use digital collaboration can be seen between pre-service teachers who attend courses that explicitly promote digitally collaborative work (intervention group, IG) and pre-service teachers attending regular courses (control group, CG)?

H3: It is assumed that the pre-service teachers' competences and intentions to use digital collaboration develop more positively in the IG than in the CG.

4 Methods

4.1 Sample and design

Data originated from the project "Collaborative teaching and learning with digital media in teacher education: mobile—professional—inclusive" (K4D, funded by the German Federal Ministry of Education and Research). Altogether, $N = 439$ pre-service

TABLE 1 Overview of samples in intervention group (IG) and control group (CG).

	n	Age *M* (*SD*)	% Female	% Bachelor studies	% aspired teaching degree: university-preparatory secondary school
IG	351	23.6 (4.48)	72.36	80.01	29.06
CG	88	23.0 (3.42)	62.50	73.86	28.41

None of the differences between IG and CG are statistically significant.

TABLE 2 Overview constructs used for assessment.

Construct	Source	No. of Items	Sum score range	Cronbach's alpha (t1/t2)
TPCK[1]	Lorenz et al. (2017)	5	5–20	0.88/0.88
Attitude toward the usefulness of digital technology[2]	Vogelsang et al. (2019)	8	8–32	0.84/0.88
Intrinsic motivation for digital collaboration[2]	Mullis et al. (2016)	5	5–20	0.88/0.90
Self-efficacy for digital collaboration	Adapted from Gebauer et al. (2013)	5	5–20	0.81/0.83
Intention to use digital collaboration (idealistic)[3]	Own development	6	6–24	0.72/0.82
Intention to use digital collaboration (realistic)[4]	Own development	6	6–24	0.81/0.86

[1]Likert scale ranging from 1 = "not applicable at all" to 4 = "totally applicable"; [2]Likert scale ranging from 1 = "totally disagree" to 4 = "totally agree"; [3]Likert scale ranging from 1 = "very reluctant" to 4 = "very gladly"; [4]Likert scale ranging from 1 = "very unlikely" to 4 = "very likely".

teachers participated voluntarily at both measurement points, giving informed consent as required by the local data protection law. The interventions and thus also the survey took place in the context of the according courses. 81.05% of the courses (lectures and seminars) were compulsory for the students; accordingly, this was an opportunity sample. Participants differed regarding their degree program (bachelor vs. master studies) as well as the type of teaching degree they were set to attain (elementary school vs. non-university preparatory secondary school vs. university-preparatory secondary school). Sample information is provided in Table 1.

Data assessment took place between 2020 and 2023 at TU Dortmund University, Germany, with five cohorts of pre-service teachers. In a pre-post-control group design, pre-service teachers attended either didactic courses that used and explicitly fostered digital collaboration (intervention group, IG) or regular didactic courses without digital collaboration (control group, CG). The interventions were developed in different subject didactic courses (Chemistry, English, Mathematics, Music, Social Science, and Physical Education) on the basis of a common definition of digital collaboration:

> "Digitally collaborative work is an interactive and discursive form of collaboration using digital media in which the group members…
> …feel individually responsible for the joint result,
> …are dependent on each other to achieve the goal,
> …enter into discussion and exchange in order to negotiate different perspectives and meanings or to negotiate common perspectives and meanings,
> …help and support each other in their work in the best possible way,
> …not only work alone, but together as a team,
> …make joint decisions on their goals and on the work process meeting (jointly agree, exchange, coordinate and reflect)" (Hußmann et al., 2020).

Hence, in the IG courses, students worked together on joint problems using digital technologies such as Moodle, Padlet, or video conferencing. While the focus in Mathematics courses was on collaboratively solving mathematical problems, for example, joint movement analyses were carried out in Physical Education courses and soundscapes were created together in Music courses. The interventions in the IG courses differed in duration and intensity across subjects (minimum: two sessions with intervention per semester, maximum: several weeks of intervention) as well as in terms of the form of collaboration (synchronous vs. asynchronous). Pre-service teachers in the control group did not receive tasks, specially designed to collaborate digitally. Nevertheless, also regular seminars include a certain degree of collaboration. In comparison to the IG, such collaboration is not specially designed to foster pre-service teacher's competences for digital collaboration. To evaluate the effectiveness of the interventions, data was collected via online questionnaires at the beginning of the semester (t1) and at the end (t2) in both IG and CG courses.

4.2 Instruments

Pre-service teachers' competences for digital collaboration and their (idealistic and realistic) intentions to use digital collaboration in their future profession as teachers were assessed using established questionnaires and self-developed scales. Table 2 provides an overview of the assessed constructs, original sources, sum score range, and internal consistency, measured by Cronbach's Alpha, for t1 and t2.

Altogether, internal consistency was good for all constructs at both measurement points.

4.3 Analyses

To answer the research questions, a hierarchical linear modeling approach was employed, utilizing a multilevel latent Rasch model as delineated by Doran et al. (2007), to evaluate changes in pre-service teachers' competences for digital collaboration. The analysis was conducted using the "lme4" package within the R statistical software environment. The quasi-experimental study design incorporated a hierarchical structure, introducing a random intercept to account for variability at the course level and a random slope to capture the development (pre-intervention vs. post-intervention) within each course. Further, the model included three fixed effects: (1) a group effect, quantifying the initial discrepancy between the intervention and control groups as assessed during the pre-measurement; (2) a time effect, measuring the development observed between the pre-and the post-measurement in the IG and CG together; and (3) a treatment effect, articulating the interaction between the development (pre vs. post) and the intervention group (courses with digitally collaborative teaching intervention vs. regular didactic courses without digital collaboration). The magnitude of the treatment effect delineates the degree to which the intervention group yielded a stronger development relative to the control group. The results are reported in terms of standardized regression coefficients.

Additionally, the robustness of the effects was assessed by integrating control variables into the analysis. These control variables incorporate characteristics inherent to the courses under investigation. Specifically, the variables included (1) the level of certification, distinguishing between bachelor's (reference category) and master's level courses; (2) the obligatory nature of the course, differentiating between compulsory (reference category) and elective courses; (3) the type of teaching degree in which participants were enrolled, contrasting primary education (reference category) with other educational specializations; and (4) the instructional format, comparing seminars (reference category) with lectures. The most frequently observed category within each variable was designated as the reference category. Within the analysis, the regression coefficients, adjusted for these control variables, elucidate the effects attributable to students enrolled in compulsory bachelor-level seminars within a primary school teacher education program.

TABLE 3 Descriptive results for each construct.

Constructs	Measurement	Group	*M*	*SD*
TPCK	pre	Control	13.2	2.5
		Intervention	12.5	2.8
	post	Control	13.8	2.8
		Intervention	13.8	2.5
Attitudes toward digital collaboration	pre	Control	23.9	4.2
		Intervention	24.0	3.9
	post	Control	24.1	4.2
		Intervention	24.6	4.0
Intrinsic motivation for digital collaboration	pre	Control	14.0	3.1
		Intervention	14.4	3.0
	post	Control	13.8	3.2
		Intervention	14.3	3.1
Self-efficacy for digital collaboration	pre	Control	14.3	2.6
		Intervention	14.4	2.4
	post	Control	14.6	2.8
		Intervention	14.8	2.3
Intention to use digital collaboration (idealistic)	pre	Control	17.6	3.4
		Intervention	18.1	3.3
	post	Control	18.4	3.9
		Intervention	18.2	3.6
Intention to use digital collaboration (realistic)	pre	Control	15.8	3.2
		Intervention	16.5	3.2
	post	Control	16.8	3.8
		Intervention	16.9	3.6

5 Results

5.1 Descriptive results

Descriptive analyses showed that students in the intervention group and the control group differed in their TPCK at the beginning of the semester and numeric results already indicate a more positive development in the intervention group (see results for research question 3). There were no differences between the two groups for the other competence constructs (attitudes and motivational orientations; see results for research question 1). Regarding pre-service teachers' intentions to use digital collaboration in the future, descriptive results indicate more positive intentions of students in the intervention group at the beginning of the semester. Means and standard deviations for each group and measurement point are displayed in Table 3.

5.2 RQ1: development of pre-service teachers' competences for digital collaboration during the semester

The analysis comparing overall pre-and post-measurements over the course of one semester revealed no statistically significant change in any of the competence constructs. This outcome suggests that, within the parameters of this study and the measurement interval employed, the intervention or the passage of time did not appreciably influence the pre-service teachers' TPCK, their attitudes toward digital collaboration, or their motivational orientations toward such collaboration (see Table 4).

5.3 RQ2: development of pre-service teachers' intentions to use digital collaboration in the future

An overall increase in idealistic and realistic intentions to engage in digitally collaborative instruction was observed, as seen in Table 4.

Statistically significant growth was recorded in the idealistic intention to engage in digitally collaborative instruction, as evidenced by a regression coefficient $\beta = 0.18$ (0.07). Similarly, the realistic intention to engage in digitally collaborative instruction demonstrated a significant rise, with $\beta = 0.20$ (0.08). These increments remained substantial and robust when adjusting for various course characteristics in the analysis. This suggests that, over time, there was not only a notable enhancement in the idealistic predisposition toward use of digitally collaborative tools in instructional settings but also an

TABLE 4 Results of the hierarchical latent Rasch model estimating the group, time, and treatment effect.

			Without control variables			With control variables		
RQ	Construct	Effect	β	*se*	*p*	β	*se*	*p*
1/3	TPCK	Group	**−0.21**	**0.10**	**0.031**	**−0.20**	**0.10**	**0.037**
		Time	0.17	0.09	0.061	0.16	0.10	0.098
		Treatment	**0.21**	**0.10**	**0.037**	**0.22**	**0.10**	**0.027**
	Attitudes toward digital collaboration	Group	0.02	0.08	0.803	0.03	0.08	0.709
		Time	0.04	0.07	0.618	−0.03	0.08	0.715
		Treatment	0.06	0.08	0.433	0.06	0.08	0.429
	Intrinsic motivation for digital collaboration	Group	0.10	0.10	0.293	0.13	0.10	0.186
		Time	−0.06	0.08	0.445	−0.13	0.09	0.157
		Treatment	0.04	0.09	0.689	0.03	0.09	0.758
2/3	Self-efficacy for digital collaboration	Group	0.04	0.09	0.620	0.04	0.09	0.685
		Time	0.09	0.08	0.265	0.07	0.09	0.444
		Treatment	0.04	0.09	0.661	0.07	0.09	0.466
	Intention to use digital collaboration (idealistic)	Group	0.11	0.08	0.189	0.12	0.08	0.142
		Time	**0.18**	**0.07**	**0.008**	**0.15**	**0.07**	**0.039**
		Treatment	**−0.15**	**0.07**	**0.044**	**−0.15**	**0.08**	**0.042**
	Intention to use digital collaboration (realistic)	Group	**0.15**	**0.08**	**0.049**	**0.15**	**0.08**	**0.045**
		Time	**0.20**	**0.08**	**0.011**	**0.23**	**0.09**	**0.009**
		Treatment	−0.12	0.09	0.167	−0.12	0.09	0.187

RQ, Research Question. Significant effects ($p < 0.05$) are printed in bold.

increase in the realistic intention to implement such tools, irrespective of the specific nature or type of course attended.

5.4 RQ 3: differences between intervention group and control group

Within the scope of research question 3, two statistically significant treatment effects were discerned (see Table 4). Firstly, an analysis pertaining to Technological Pedagogical Content Knowledge (TPCK) unveiled a treatment effect in the anticipated direction. This effect indicates that courses engaging in digitally collaborative practices yielded a more pronounced augmentation in TPCK relative to control courses. Nonetheless, it is imperative to acknowledge the presence of an equally significant difference between the intervention group and the control group prior to the intervention phase (t1). This discrepancy implies that, although the intervention courses saw an increase in TPCK over the course of the semester, this brought them in line with the TPCK levels of the control group, rather than surpassing them. Secondly, the analysis revealed a statistically significant treatment effect regarding the idealistic intention to use digitally collaborative tools; however, the direction of this effect was contrary to expectations. Participants in courses explicitly engaging in digitally collaborative practices exhibited a lower intention to use such practices in the future. This outcome suggests a paradoxical effect where exposure to and participation in digitally collaborative activities may have tempered participants' enthusiasm for or perceived utility of these practices for future teaching contexts.

Both the first (pertaining to TPCK) and the second (concerning the idealistic intention to use digitally collaborative practices) statistically significant treatment effects were robust to the adjustments made for course characteristics.

6 Discussion

In this study, we explored the impact of interventions aimed at enhancing pre-service teachers' competences for digital collaboration within subject didactics courses at a German university. In light of the increasing importance of digital competence as a key skill for the 21st century, and the growing relevance of digital teaching and learning methods post-COVID-19, our findings present a nuanced view of such interventions' effectiveness. It also adds to the growing body of research on pre-service teachers' digital competences (Basilotta-Gómez-Pablos et al., 2022). Particularly against the background of pre-service teachers perceiving their training in digital skills as rather inadequate (Instefjord and Munthe, 2017), the study presented here makes a contribution to improving these skills in university education.

6.1 Core findings

Focusing on cognitive as well as non-cognitive aspects of teachers' professional competences, our analysis revealed no statistically significant changes in pre-service teachers' technological-pedagogical content knowledge (TPCK), attitudes toward digital collaboration, or motivational orientations toward digital collaboration from pre-to post-measurement for the whole sample (research question 1). This suggests that the short-term intervention may not have been sufficient to effect noticeable changes in these complex constructs. A possible explanation for the stagnation in competence aspects during a semester could be the variety of individual and institutional factors (e.g., motivational orientations of technical support) that influence the development of digital competencies (Kholid et al., 2023; Lachner et al., 2021). In addition, data collection in the first cohorts took place during the COVID-19 pandemic, when university courses were largely held digitally. This forced pre-service teachers to use digital media for communication and to participate in university courses, potentially weakening the effect of interventions focused on fostering digital collaboration. However, there was a significant positive development in pre-service teachers' TPCK in the intervention group.

Regarding research question 2, we observed a statistically significant increase in both idealistic and realistic intentions to use digital collaboration over time for all participants, indicating a growing openness to digital collaboration methods among participants, independent of course characteristics. Accordingly, it would be important to create favorable conditions for digital collaboration in the second phase of teacher training (post-graduate student teaching). In addition to technical equipment, opportunities to practice digital collaboration are also important factors that influence teachers' willingness to collaborate (e.g., Chen et al., 2014).

Focusing on the effectiveness of the intervention (research question 3), two significant treatment effects were identified that were contrary to expectations. Firstly, while the intervention group showed an increase in TPCK, this was enough to bring their competencies in line with those of the control group, rather than surpass them. A possible explanation for this effect is that students who perceived greater improvement were more likely to participate in the post-measurement. Interpreted positively, this finding shows that the intervention potentially contributed to reducing the gap in pre-service teachers' TPCK. Differences in intervention types, intervention durations or learning environments are known to affect the effects of TPCK interventions (Ning et al., 2022), but course characteristics were controlled for in our analyses. Secondly, and more unexpectedly, the intervention group displayed a reduced intention to use digitally collaborative practices in the future. One explanation for this result could be the implementation of group work within the interventions. Underperforming team members are a not uncommon phenomenon in group work and they might have negative impacts on other group members (Jassawalla et al., 2009). Anyway, this paradoxical outcome suggests that while the interventions may enhance specific competences, they might simultaneously temper enthusiasm for future use of these digital practices, possibly due to unmet expectations or challenges encountered during implementation.

6.2 Limitations and implications

Despite the methodological strengths of the present study, there are some limitations to be discussed—especially in light of the effects not found in the intervention on important aspects of pre-service teachers' competences. First, participant drop-out from pre-to post-measurement must be viewed critically, even though the course instructors gave students class time to answer the questionnaire. On the positive side, there were no statistically significant differences between participants with and without drop-out in terms of age, gender distribution, educational stage or type of teaching degree. Secondly, the first data collection period took place in fall 2021. At that time, the majority of university courses had been held digitally for three semesters. For our study, this means that the students were already used to using digital media for communication or to participate in courses and we were therefore unable to create a control group without treatment in the strict sense. Thirdly, the interventions were very heterogeneous between courses. Although we controlled for course characteristics in our analyses, future analyses could focus on the effects of individual interventions. Unfortunately, the data collected as part of this project does not allow it, but it would be useful to investigate the effectiveness of the duration, intensity, method or software used on pre-service teachers' competence development. Furthermore, the results should be validated on a larger sample, including courses from different universities. Especially against the background that effects significant, but small (Lakens, 2021), the replicability of the findings should be checked, ideally in a randomized controlled field trial, allowing for causal interpretations. Thinking one step further, future research projects should focus on the effects of pre-service teachers' digital collaboration competences on actual collaboration during their later in-service teaching. Longitudinal studies could identify effective interventions to foster relevant competences and investigate the development of digital collaboration competences in all phases of teacher education. Ultimately, the question of the effect of digital collaboration on the quality of teaching and learning processes remains unanswered.

6.3 Conclusion

In conclusion, our findings underscore the complexity of integrating digitally collaborative practices into teacher education and highlight the need for more comprehensive and possibly longer-term strategies to effectively foster digital competences among pre-service teachers. The robustness of the results, even after controlling for course characteristics, suggests that these conclusions are not merely artifacts of specific contexts but indicate broader trends that warrant further investigation and consideration in the development of teacher education curricula.

Data availability statement

The datasets presented in this article are not readily available because the data are not accessible for data protection reasons. Requests to access the datasets should be directed to Annika.Ohle-Peters@tu-dortmund.de.

Ethics statement

Ethical approval was not required for the studies involving humans because the study did not include vulnerable participants. All participants gave informed consent before filling out the questionnaire. 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

AO-P: Investigation, Project administration, Writing – original draft. UL: Formal analysis, Writing – review & editing. NM:

Conceptualization, Funding acquisition, Supervision, 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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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2024.1455074/full#supplementary-material

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Collaborative online learning in higher education—quality of digital interaction and associations with individual and group-related factors

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Collaborative online learning became a necessity for universities during the COVID-19 pandemic. Even though it is known from research that online collaboration is an effective way of learning, digital interaction can be challenging for learners. Group members have to create a high-quality interaction to ensure the success of the collaborative learning process. Based on a theoretical model of collaborative learning, high-quality interaction can be determined with regard to cognitive group activities (prior knowledge activation, transactivity), meta-cognitive group activities (organization of the work process), and relational group activities (group climate, participation and task-related communication). Our study aims to examine how students manage a self-directed collaborative learning setting, how they perceive the process quality of digital interaction and how the interaction quality is related to self-reported outcomes (learning gain and satisfaction). We use a newly developed questionnaire to assess the quality of digital interaction in terms of the aforementioned dimensions. Furthermore, we focus on associations with the beliefs about web-based learning and the ability of perspective-taking at the individual level as well as the sense of community at the group level. We conducted a quantitative study within online university courses that were implemented asynchronously due to the COVID-19 pandemic. $N = 298$ undergraduate students in teacher education rated the quality of a digital collaborative learning settings (response rate of 72%). The students worked on collaborative tasks autonomously without any guidance from the teacher. We find differences between (meta-)cognitive and relational factors of interaction quality, and differences in the strength of the associations with outcomes and individual and group-related factors. Our study provides insights into students´ collaborative online learning and examines the relationships between different dimensions of group interaction quality and the input and outcome variables. Limitations and areas for further research are discussed.

KEYWORDS

collaborative learning, digital interaction, group interaction, collaborative online learning, group activities, cooperative learning

1 Introduction

Collaborative learning settings have been implemented worldwide for decades in educational contexts (Hmelo-Silver et al., 2013). Collaboration is anticipated to foster learners social competencies and motivation, as well as to promote deeper learning and understanding (Gillies, 2016; Ginsburg-Block et al., 2006; Hanson et al., 2016; Kyndt et al., 2013). Through knowledge co-construction, learners are expected to achieve more than they would individually achieve in a teacher-centered environment (Johnson and Johnson, 2009).

Along with innovations in educational technology over the last few years (Huang et al., 2019), collaborative online learning has gained importance since the early 2000s (Zawacki-Richter and Latchem, 2018) and has become particularly relevant during the COVID-19 pandemic. Due to the lockdown, universities and schools were forced to move into the digital space (García-Morales et al., 2021; Vahle et al., 2023) amid temporary restrictions on face-to-face teaching. Consequently, collaborative learning formats must be implemented online. *Collaborative online learning* is connected to specific affordances and challenges (Jeong and Hmelo-Silver, 2016) and can be realized in various forms (Jeong et al., 2019). High-quality interaction is one of the most important factors in determining the effectiveness of online learning (van Dorresteijn et al., 2024). There is a lack of empirical studies investigating the process characteristics of digital interactions in authentic learning situations (Vuopala et al., 2016).

In this study, we used a newly developed questionnaire to assess the quality of online collaborative learning among higher education students. The purpose of this study was to analyze the process quality of digital student interactions in a university setting. Students worked in groups during a university course that was implemented asynchronously due to the pandemic. Furthermore, the associations between interaction quality, individual and group-related factors, and outcomes were analyzed. This is essential for gaining a better understanding of how digital collaborative learning can be effectively implemented in higher education. The aim was to determine the factors that impact the success of collaborative learning to gain a better comprehension of the learning process.

This paper begins by presenting the theoretical framework, followed by a description of the research design and methods.

2 Theoretical background

2.1 Collaborative online learning

Collaborative learning is a widely used teaching format in higher education that allows students to share knowledge in self-directed learning environments. While some authors distinguish between *collaborative* and *cooperative* learning (Dillenbourg, 1999), others highlight their similarities (Kreijns et al., 2003). We follow the conclusions of Kirschner (2001), who emphasizes commonalities, and use the term *collaborative learning* as "an umbrella term for various instructional approaches to small group learning" (Yang, 2023, p. 718) throughout this study. In a collaborative learning setting, learners work in small groups to solve problems by exchanging and discussing ideas. They are stimulated to deal with others´ opinions, reflect on their own considerations, and take responsibility for their own and the group's learning (e.g., Johnson and Johnson, 2009).

Based on research conducted over the last few decades, there is sufficient empirical evidence that collaborative learning is effective in enabling the co-construction of knowledge and deep learning (Johnson et al., 2007). It offers socially shared learning experiences and promotes motivation, social competencies, and learning achievements (e.g., Kyndt et al., 2013). At its best, collaborative learning can foster skills that are essential for 21st-century learning needs and success in future employment (OECD, 2019; Robbins and Hoggan, 2019). Beyond randomized controlled trial evidence for its effectiveness, collaborative learning "is underused in practice" (Scager et al., 2016, p. 1). True collaborative learning is challenging, and high-quality productive group interactions rarely exist in practice. The cognitive level of questions and explanations is often low; learners try to minimize their amount of work and interact at a low cognitive level (e.g., Antil et al., 1998; Kreijns et al., 2003; Ross, 2008).

Shifting from collaborative learning formats to digital environments presents additional challenges to group interaction and communication. Before the pandemic, Computer-Supported Collaborative Learning (CSCL) research focused on the use of technology for collaborative learning in higher education and its effectiveness (Cress et al., 2021; Dillenbourg et al., 2009). During the pandemic, a shift to online collaborative learning became imperative for universities. Digital collaboration allows students to continue to interact remotely with their peers. Since the pandemic began, researchers have examined how universities have managed to transition to online teaching (e.g., Crawford et al., 2020). However, the implementation of collaborative learning formats resulting from this transition has been investigated less frequently to date (Kalmar et al., 2022).

Online learning environments offer a range of possibilities for interaction, allowing groups of learners to engage in collaborative learning (Ku et al., 2013). Various digital tools can be used to support digital communication. Synchronous real-time video conferencing, chats and emails, discussion forums, document collaboration, and visual representation tools are the most common (Jeong and Hmelo-Silver, 2016). Regarding framework conditions, one essential requirement for the successful implementation of online learning is the absence of technical issues. Technical difficulties in online learning have been discussed as important factors impeding the effectiveness of collaborative learning (Sitzmann et al., 2010).

In principle, digital collaborative learning can be expected to be as effective as face-to-face collaboration, as shown by previous studies in higher education contexts (e.g., Chen et al., 2018; Graham and Misanchuk, 2004; Jonassen and Kwon, 2001). Findings from meta-analyses indicate differences in group performance and the quality of group interaction depending on the digital tools and learning environments used by learners (Chen et al., 2018; Jeong et al., 2019). Research also reveals that for online forms, the quality of interaction is often inadequate in educational practice, especially in the absence of tutor-led guidance and the structuring of collaborative activities (Kreijns et al., 2003; van Leeuwen and Janssen, 2019).

High-level group interaction can be considered the core process in collaborative (online) learning (Janssen and Kirschner, 2020). This determines the presumed outcomes demonstrated in several meta-analyses (e.g., Pai et al., 2015). Whether a group succeeds in establishing a high-quality interaction depends on the different factors of individuals, groups, and contexts (Gillies, 2016; Scager et al., 2016). To illustrate the relationships between the dependent factors, processes, and outcomes of collaborative learning, a theoretical model of collaborative learning is presented in the following chapter.

2.2 Theoretical model of collaborative learning: an input-process-outcome-model

A theoretical model of collaborative learning processes is shown in Figure 1. The model refers to the *Implementing Collaborative*

Learning in the Classroom Framework (ICLC; Kaendler et al., 2015) and *Input-Process-Outcome-Frameworks*, which are established and empirically validated in team effectiveness research in work and organizational psychology (e.g., Dulebohn and Hoch, 2017). While Kaendler et al. (2015) focused on the teacher level, our study addressed the student level. The ICLC framework includes both teacher and student levels but primarily focuses on and specifies the teacher level. The student level is described in the interactive phase (with reference to Molenaar et al., 2011) by interaction quality, and more precisely, by collaborative, cognitive, and meta-cognitive group activities. We integrate these three factors into our model at the process stage. The quality of group interaction is conceptualized in our model as the key process variable at the student level, predicting the cognitive, motivational and social-communicative outcomes of individuals and groups.

The quality of the group process is impacted by the framework at the input stage. Early research on collaborative learning focused on contextual conditions such as collaborative tasks, resources, and communication media (Dillenbourg et al., 1996). Individual preconditions and group-level variables also influence whether a group succeeds in creating high-quality interactions. The following section focuses on the variables relevant to this study. In collaborative learning, social skills are essential for maintaining effective communication and interpersonal interactions (Johnson and Johnson, 2009; Prichard et al., 2006). Research also stresses the importance of individual motivational factors that are considered to be associated with students´ participation in collaborative interaction (Meyer and Turner, 2006). Individual motivational beliefs seem to affect group behavior in collaborative learning settings (Ahola et al., 2023). Furthermore, shared beliefs of the group as a social system predict the interaction behaviors of group members (van den Bossche et al., 2006).

Following our model, these different input variables directly affect the quality of the process stage, or more precisely, the group interaction quality. What factors constitute high-quality, productive group interactions? How can we describe high-quality group interactions? Social interaction is the key to collaborative learning. Grounded in social constructivist learning theory, studies have addressed how interactions in collaborative learning should be designed to ensure meaningful learning (Roschelle and Teasley, 1995; Vuopala et al., 2016). High-quality interaction between groups, representing the core condition for learning success, can be defined through *cognitive*, *metacognitive* and *relational group activities* (Kaendler et al., 2015; Molenaar et al., 2011).

Cognitive group activities refer to interactive learning processes and knowledge co-construction. The design of a co-constructive learning process (Webb, 2010) is integral to the success of group learning. Group interactions can only be productive if cognitive processes are stimulated in the learning process through exchange and collaborative reasoning in the sense of a learning talk (Alexander, 2017). This form of interaction challenges the activation of prior knowledge and stimulates mutual questioning, explanations, and the formulation and justification of hypotheses and opinions (Weinberger

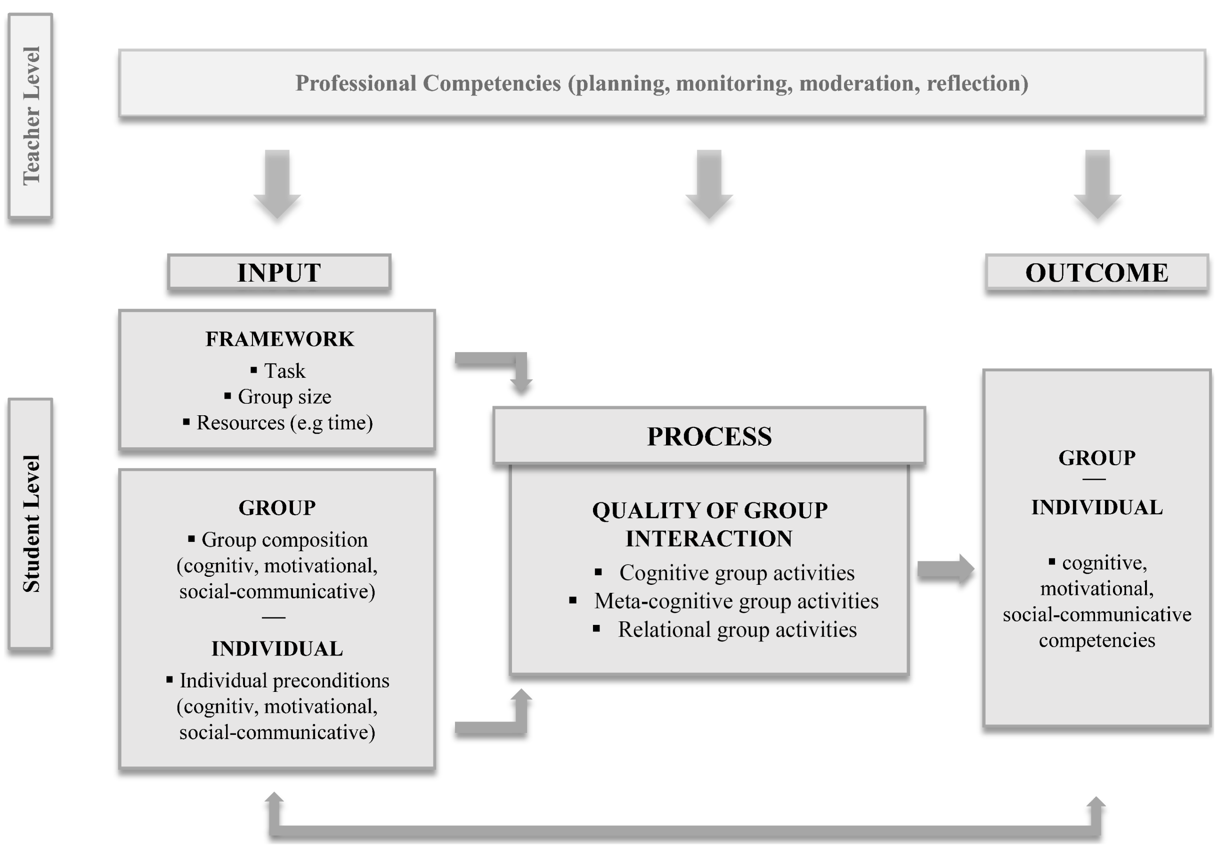


FIGURE 1
Theoretical model of collaborative learning.

and Fischer, 2006). Confronting differing arguments challenges learners to compare them and justify and elaborate on their own (Chi and Wylie, 2014). Through interrelated and coherent interactions between group members, a *transactive learning process* that is superior to individual learning can be established (e.g., King, 1998; Fischer et al., 2013). The *transactivity* of group member interactions is the centerpiece of co-constructive collaboration (Janssen and Kirschner, 2020).

Metacognitive group activities focus on the joint *organization* of the group work process. Effective work organization is highly important for the success of collaboration (Kwon et al., 2014). The extent to which a group succeeds in structuring the work process through planning, goal-setting, and appropriate time allocation for collaborative tasks guides collaborative discussions. These elements are in line with strategies that function as group-based metacognition (Hadwin and Oshige, 2011; Järvelä and Hadwin, 2013; Järvelä et al., 2015). The organization of work processes indicates whether socially shared regulated learning (De Backer et al., 2022a) occurs in the group.

Relational group activities involve interpersonal components of the interaction. The *participation of all group members* is an important prerequisite for productive learning processes of the whole group (Isohätälä et al., 2017). Beebe and Masterson (2003) described domination or lack of participation by individual group members (e.g., due to uncertainty or poor commitment) as central factors that can impede the collaborative learning process (Kirschner et al., 2015). Whether communication in the group is *task-related* (i.e., focused on the learning goal and content) is also relevant (Chinn et al., 2000). The more effectively a group succeeds in reducing dysfunctional and task-irrelevant topics, the greater the likelihood of fostering productive interaction (Kauffeld and Lehmann-Willenbrock, 2012). A respectful *group climate* is a key factor in effective collaboration (e.g., Johnson and Johnson, 1999). Mutual appreciation and support are indispensable (Huang and Lajoie, 2023). West (1990) introduced the term “participative safety” for a trusting climate and defined it as a prerequisite for group members to contribute their ideas and develop solutions to problems (Edmondson, 1999).

Collaborative learning processes involve *cognitive*, *metacognitive*, and *relational* group activities that promote learning. Although several studies, particularly in the field of CSCL, address specific aspects (e.g., socially shared regulation, Järvelä et al., 2015), empirical knowledge regarding these factors remains limited. Few studies have simultaneously analyzed group interactions with regard to different process characteristics (Vuopala et al., 2019). There is also still a lack of research investigating the process quality of digital interactions in authentic online collaborative learning settings (Vuopala et al., 2016).

To gain a more comprehensive insight into digital interaction in a higher education context, we conducted a quantitative study using a new questionnaire developed by our research group. The questionnaire assesses the quality of interaction from students’ perspectives along the aforementioned dimensions and has been validated in a study investigating face-to-face collaborative learning (Bach and Thiel, 2024). To our knowledge, there is no instrument available that simultaneously consider the different factors of group interaction from a learner’s perspective. There is a need for instruments that make group interaction quality visible in a differentiated way and with which collaborative learning can be evaluated in higher education practice. The results of the validation study show that it is possible to differentiate empirically between various factors and that there are differential correlations with input factors or outcomes. The questionnaire was used to investigate students´ digital collaborative learning to answer the following research questions.

2.3 Research questions

In this study, we focus on three research questions that empirically investigate the theoretically assumed relationships depicted in the theoretical model of collaborative learning, as shown in Figure 1.

The first research question (RQ-1) focuses on *framework conditions* at the input stage. As the framework conditions in our study are not regulated by teachers, the students are completely autonomous in organizing the collaborative learning phases. Against this background, it is necessary to investigate how students manage the collaborative learning setting. These questions aimed to gain insight into the context of the collaborative learning process. As the collaborative learning phases were black boxes due to the design, it was first necessary to clarify whether the students were collaborating appropriately.

(RQ-1) How do students organize collaborative learning processes? Specifically, the following subquestions were addressed: How much time do groups invest in collaborative learning tasks? Are technical difficulties impeding digital collaboration? How often do students use different online tools for collaborative tasks, and are there associations between the different types of online tools and group interaction quality? Research indicates that group processing depends on the digital tools chosen for collaboration (Jeong et al., 2019).

The second research question (RQ-2) examines the *quality of digital group interaction in association with outcomes* (i.e., self-reported learning gain and satisfaction with the group process). Collaborative learning can enhance the competence gain and motivation of learners (Johnson and Johnson, 2009; Kyndt et al., 2013). The impact of different group activities on outcomes has not yet been examined simultaneously.

(RQ-2) Is the quality of digital interaction in groups related to outcomes (i.e., self-reported learning gain and satisfaction with the group process)? From a theoretical perspective, cognitive and metacognitive group activities are presumably more strongly related to cognitive learning gains than to satisfaction, whereas relational group activities are more strongly related to satisfaction (Chi and Wylie, 2014; Johnson and Johnson, 1999).

The third research question (RQ-3) examines the associations of *group interaction quality and the outcomes with individual and group-level characteristics* of the input stage. We focused on three potential determinants of the quality and effectiveness of collaborative learning.

First, the associations with *cognitive perspective-taking ability* of group members were investigated. As outlined above, social competencies are essential for appropriate behaviors in collaborative settings. They enable individuals to achieve their own goals while considering the interests of their group members. Cognitive perspective-taking ability, defined as the ability to understand and empathize with another person’s perspective, is crucial for effective group communication (Mouw et al., 2020). A high level of perspective-taking increases the group’s problem-solving competence and leads to more productive group interactions (Webb and Mastergeorge, 2003). However, empirical evidence supporting the significance of perspective-taking ability is lacking. This may be due to the fact that previous studies often linked it to achievement-related factors and did not investigate the association in relation to process characteristics of group interaction.

Second, associations within the context of digital learning relevant individual motivational variables were examined. Collaborative work is generally considered a highly motivating instructional approach. By integrating technology into collaborative learning, personal *beliefs about online learning* become increasingly relevant. Computer-related motivational attitudes have been a research topic since the 1980s (Coffin and MacIntyre, 1999). There is evidence that beliefs about online learning influence individual behavior and engagement in digital learning environments (Yang and Tsai, 2008).

Third, we focus on the groups´ shared beliefs about the group as a functioning social system (van den Bossche et al., 2006). With the *sense of community*, we consider an important motivational factor at group level that can predict how learners engage in collaborative learning (Delahunty et al., 2014). McMillan and Chavis (1986, p. 9) established a conceptual definition of the sense of community as "a feeling that members have of belonging, a feeling that members matter to one another and to the group, and a shared faith that members' needs will be met through their commitment to be together." Particularly in digital collaborative settings, a strong sense of community helps mitigate the isolation and absence of face-to-face interactions (Lowenthal et al., 2023). A strong sense of community increases the probability of engaging in collaborative learning (Reeves and Gomm, 2015), leads to a more positive perception of online courses (Baker and Moyer, 2019), and contributes to student learning outcomes (Battistich et al., 1995). Empirical studies are lacking to examine the relationships between a group's sense of community, group interaction quality, and outcomes (Han et al., 2022).

(RQ-3) Are individual and group-related factors associated with the quality of digital interactions? It is assumed that high level of the *ability of perspective-taking*, *beliefs about online learning*, and a *sense of community* within the group are positively related to the quality of digital interaction in the groups and outcomes.

3 Methods

3.1 Research design

In the summer term of 2020, a quantitative standardized survey was conducted to examine the online collaborative learning of teacher education students in 13 undergraduate courses. In their second semester, the students attended an asynchronous course that was delivered online in the Blackboard learning management system due to the university's closure during the COVID-19 pandemic. Every week, the students had access to recorded PowerPoint slides with inputs about the principles of teaching and learning and individual tasks that had to be completed autonomously. Furthermore, students were randomly assigned to fixed learning groups consisting of three or four persons. Eight collaborative learning tasks were conducted over a 12-week semester. The students decided which collaborative online tools they had used to complete the tasks. The students worked on collaborative tasks autonomously without any guidance from the teacher. An example of a collaborative learning task is shown in Figure 2. The collaborative task was embedded in a session on teaching quality and support for student knowledge acquisition in the classroom. After theoretical and audio-recorded input on the theories of memory, information processing, and text comprehensibility, a text vignette was provided to the students. A classroom scenario was described in the vignette. In preparation for the collaborative tasks, the students read the vignette independently. They were then instructed to make individual notes on how the teacher in the vignette could have better supported the students in their knowledge acquisition. They should refer to the previously presented theoretical content. After completing the individual pre-work, the students were instructed to organize group meetings online. They discussed their suggestions in their group and agreed on five measures. The measures were written in a template, justified in detail, and with reference to theoretically gained knowledge. After completing the collaborative task, the jointly created documents are uploaded to the learning management platform.

The other seven collaborative tasks were similarly structured; after the theoretical input, the students had to apply the newly acquired knowledge to a collaborative task. The tasks were explained using audio-recorded slides by a lecturer. Additional materials, such as templates or written work instructions, were provided. Other tasks included motivating students in the classroom, developing ethical standards for teaching, discussing classroom videos, and providing collaborative ratings of teaching quality. Approximately 60–90 min were scheduled for each collaborative task.

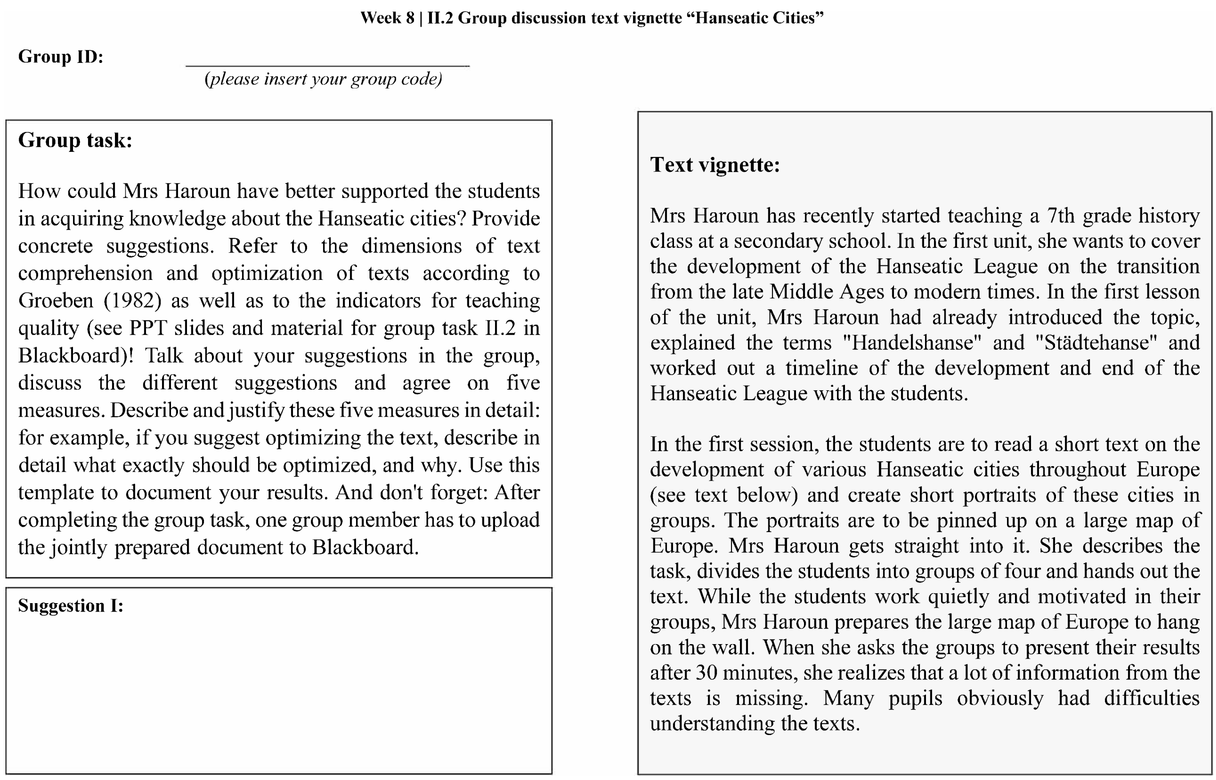
At the end of the semester, the students were asked to complete a standardized questionnaire on collaborative learning activities. The survey was conducted online using the Unizensus software supplied by Blubbsoft GmbH. The students were given 3 weeks to complete the online questionnaire and were reminded twice via email to participate. Participation was voluntary and anonymous.

3.2 Sample

The sample consists of $N = 413$ students nested in 129 groups. The mean group size was 3.3 persons: 60% of the groups consisted of three members, 34% of four members, and 6% of only two persons. We achieved a response rate of 72% at the individual level and included $N = 298$ students nested in 119 groups in our study (average cluster size was 2.3 group members). The mean age of the participants was 22.47 years ($SD = 5.59$, $Mdn = 21$ years), and 78% were female. Participants in the sample represented a broad range of academic subjects (e.g., mathematics/science, German/foreign languages). Forty-six percent were primary school students, and 54 % were secondary school students. Most students had worked together in groups for the first time; only 11% of respondents self-reported that they had "previously worked with one or more persons in a group."

3.3 Measures

To address RQ-1 (framework conditions of collaborative learning settings), one question about the online tools that have been used for digital collaboration and one question regarding the extent of technical problems that have occurred during the collaborative activities (4-point Likert scale, 1: "Never," 2: "Rarely, "3: "Often," 4: "Always") were included in our questionnaire. We also added one question to assess the time invested in the collaborative learning tasks


Week 8 | II.2 Group discussion text vignette "Hanseatic Cities"

Group ID: ______________________
(please insert your group code)

Group task:

How could Mrs Haroun have better supported the students in acquiring knowledge about the Hanseatic cities? Provide concrete suggestions. Refer to the dimensions of text comprehension and optimization of texts according to Groeben (1982) as well as to the indicators for teaching quality (see PPT slides and material for group task II.2 in Blackboard)! Talk about your suggestions in the group, discuss the different suggestions and agree on five measures. Describe and justify these five measures in detail: for example, if you suggest optimizing the text, describe in detail what exactly should be optimized, and why. Use this template to document your results. And don't forget: After completing the group task, one group member has to upload the jointly prepared document to Blackboard.

Suggestion I:

Text vignette:

Mrs Haroun has recently started teaching a 7th grade history class at a secondary school. In the first unit, she wants to cover the development of the Hanseatic League on the transition from the late Middle Ages to modern times. In the first lesson of the unit, Mrs Haroun had already introduced the topic, explained the terms "Handelshanse" and "Städtehanse" and worked out a timeline of the development and end of the Hanseatic League with the students.

In the first session, the students are to read a short text on the development of various Hanseatic cities throughout Europe (see text below) and create short portraits of these cities in groups. The portraits are to be pinned up on a large map of Europe. Mrs Haroun gets straight into it. She describes the task, divides the students into groups of four and hands out the text. While the students work quietly and motivated in their groups, Mrs Haroun prepares the large map of Europe to hang on the wall. When she asks the groups to present their results after 30 minutes, she realizes that a lot of information from the texts is missing. Many pupils obviously had difficulties understanding the texts.

FIGURE 2
Example of a collaborative learning task.

("How much time did you invest on average per week in the collaborative learning tasks?," 8-point Likert scale, 1: "30 min" to 8: "240 min").

To answer RQ-2 and RQ-3, group interaction quality and outcomes were assessed using a newly developed questionnaire for collaborative learning settings (Bach and Thiel, 2024). The first version of the questionnaire, designed to assess the quality of interaction, originally consisted of 48 items. It was pretested and validated on several samples of students in secondary schools ($N=932$ students) and higher education ($N=333$) to investigate its psychometric properties. The final questionnaire used in the current study contains a total of 31 items in German language. For this article, the authors translated all items into English. The questionnaire measured the collaborative learning processes along the dimensions of the groups´ cognitive, metacognitive, and relational activities. It includes six dimensions that are relevant for collaborative learning processes: *Joint activation of prior knowledge* (three items) and *transactivity* (six items) as cognitive group activities; *organization* (four items) as metacognitive; *group climate* (six items), *participation* (three items), and *task-related communication* (three items) as relational group activities. Regarding the outcomes, we examined the *learning gain* (three items) and overall *satisfaction* of learners with digital collaboration (three items).

To address RQ-3, the following additional scales were included in the survey. The *ability of perspective-taking* was assessed using the German subscale of the Interpersonal Reactivity Index (Davis, 1996; Paulus, 2009). *Beliefs about online learning* were captured using six items (with reference to Yang and Tsai, 2008). To capture the groups´ *sense of community*, we used three items to measure social entities (with reference to Jason et al., 2015). This subscale captures the experience of having performed in a well-functioning and effective group while having developed a strong sense of belonging within the group. All items were measured on a 6-point Likert scale (1: "Does not apply at all" to 6: "Fully applies").

Finally, 5-digit group codes that were given to the groups *a priori* were asked in an open question to allow the assignment of individual ratings to the group level.

Example items are reported in Table 1.

3.4 Data analysis

The data were analyzed using quantitative methods in SPSS Statistics 28 (IBM Corp, 2021) and Mplus (Muthén and Muthén 1998–2017). Because of the nested data structure (individuals at Level 1 clustered in groups at Level 2), intraclass correlation coefficients, ICC(1), for the dimensions were calculated based on the null model within multilevel analyses. These values indicate the proportion of the total variance accounted for by the clustering of individuals into groups.

For RQ-1, descriptive results are presented. To answer RQ-2, we report the results of a multivariate path analysis with two dependent variables. Although the number of clusters is relatively high at Level 2, the average cluster size is very small, resulting in overestimated standard errors; thus, using multilevel analysis would lead to problems by underestimating the *p*-values. Applying the

TABLE 1 Example items.

Dimension	No. of items	Example item
Organization	4	We first summarized our prior knowledge about the topic.
Prior knowledge	3	We have defined concrete goals.
Transactivity	6	In the group discussion, we referred to each other's arguments.
Group climate	6	The group members treated each other with respect.
Participation	3	Some members did not take part in the group discussions. (−)
Task-related communication	3	We often drifted off-topic in the group discussions. (−)
Learning gain	3	The collaborative work has broadened my understanding of the subjects.
Satisfaction	3	I enjoyed working in the group very much.
Perspective-taking	4	I try to look at everybody's side of a disagreement before I make a decision.
Sense of community	3	In my opinion, we fit together well as a group.
Beliefs about online learning	6	Compared to traditional face-to-face seminars, I find it easier to learn in online courses.

The original items were in German and translated into English for this paper.

TABLE 2 Descriptive statistics.

Quality of interaction	M_{L1}	SD_{L1}	α	M_{L2}	SD_{L2}	$ICC(1)$
Organization	4.18	1.18	0.82	4.11	0.88	0.10
Prior knowledge	3.89	1.40	0.90	3.78	1.17	0.19
Transactivity	4.73	1.11	0.92	4.69	0.92	0.16
Group climate	5.71	0.69	0.93	5.68	0.56	0.29
Participation	4.82	1.46	0.86	4.81	1.18	0.20
Task-related communication	5.40	1.60	0.68	5.41	0.55	0.27

L1, individual level 1; L2, group level 2; 6-point Likert scale 1: "Does not apply at all" to 6: "Fully applies".

Mplus command "type is complex" ensures that the estimations are corrected for the standard errors considering the multilevel data structure and between-class variance. To address RQ-3, the results of the correlation analysis (Pearson's coefficients) at Levels 1 and 2 are presented.

4 Results

4.1 RQ-1: framework conditions

The first research question aimed to determine the framework conditions for digital collaboration. On average, the groups invested about 1.5 to 2 h per week in digital collaborative tasks ($M = 98.14$ min, $SD = 34.20$, $Mdn = 90$ min). Regarding the digital tools the groups used to complete the collaborative tasks, the results showed that the groups in our sample mainly used video conferences ($M = 2.72$, $SD = 1.21$, $N = 119$) and messenger services ($M = 3.66$, $SD = 0.51$, $N = 119$). Emails ($M = 2.09$, $SD = 0.69$, $N = 119$), shared online documents ($M = 1.59$, $SD = 0.81$, $N = 119$), and online tools integrated into the learning management platform ($M = 1.27$, $SD = 0.53$, $N = 119$) were rarely applied to collaborative tasks. Technical difficulties did not occur often in the groups; 95% of the students reported that group communication was *never* or *seldom* impeded by technical issues ($M = 1.67$, $SD = 0.48$, $N = 119$).

At the group level, significant correlations with *self-reported group interaction quality* were found in relation to the online tools used by groups. The more frequently video conferencing was used for working on group tasks, the more likely the groups were able to establish elaborate and in-depth discussions. The results showed positive, small-to-medium (Cohen, 1988) correlations for *transactivity* ($r = 0.38$, $p < 0.001$), *prior knowledge activation* ($r = 0.27$, $p = 0.003$), and *organization* ($r = 0.24$, $p = 0.009$). No significant associations were found with *group climate* ($r = 0.15$, $p = 0.106$), *participation* ($r = -0.14$, $p = 0.126$), or *task-related communication* ($r = 0.13$, $p = 0.152$).

4.2 RQ-2: associations of interaction quality with learning gain and satisfaction

To determine whether the digital collaborative learning sessions were conducted effectively, the second research question focused on the quality of interaction and its associations with outcomes.

Descriptive statistics for all dimensions assessing the quality of digital interactions are shown in Table 2. While most groups succeeded in establishing a positive group climate, working focused on the tasks, and integrating all group members in the discussion, we found lower mean values for the cognitive and metacognitive group activities, that is, the joint activation of prior knowledge, transactivity, and organization of collaborative work. The ICC(1) values indicate that a substantial part of the variance (10–29%) was explained by group membership. We found higher values for the group climate, participation, and task-related communication than for (meta-) cognitive group activities.

We investigated whether the quality of group interactions led to better outcomes. Self-reported learning gain ($M_{L1} = 4.23$, $SD_{L1} = 1.24$, $\alpha = 0.89$, $M_{L2} = 4.22$, $SD_{L2} = 0.93$, $ICC(1) = 0.12$) and overall satisfaction with the group process ($M_{L1} = 4.65$, $SD_{L1} = 1.35$, $\alpha = 0.93$, $M_{L2} = 4.58$, $SD_{L2} = 1.16$, $ICC(1) = 0.36$) are considered cognitive and motivational outcomes.

Results of multivariate path analyses (see Figure 3) reveal that learning gain is greater for groups who systematically activate their prior knowledge ($b = 0.16$, $SE = 0.06$, $\beta = 0.19$, $p = 0.005$), and structure their learning process through meta-cognitive strategies ($b = 0.29$, $SE = 0.07$, $\beta = 0.28$, $p < 0.001$). If the group succeeds in establishing transactive group discussions, we find significant, positive associations with the satisfaction ($b = 0.22$, $SE = 0.18$, $\beta = 0.20$, $p = 0.006$), but not with the learning gain.

A positive group climate ($b = 0.47$, $SE = 0.11$, $\beta = 0.26$, $p < 0.001$) and the involvement of all group members ($b = 0.13$, $SE = 0.06$, $\beta = 0.16$, $p = 0.018$) also significantly predict the extent of the learning gain. Both variables have, in line with the expectations, a greater effect on the satisfaction with the group process (group climate: $b = 0.79$, $SE = 0.13$, $\beta = 0.39$, $p < 0.001$; participation: $b = 0.19$, $SE = 0.05$, $\beta = 0.20$, $p < 0.001$). No significant paths were found for the sub-dimensions of task-related communication. The independent variables accounted for 40% of the variance in predicting learning gains and 55% of the variance in predicting satisfaction. Model fit indices are not reported because the estimated path model was saturated (i.e., df = 0, perfect fit to data), as we expected associations between all variables.

4.3 RQ-3: associations between interaction quality and the ability of perspective-taking, beliefs about online learning, and the group's sense of community

The third research question concerns how individual and group-related factors were associated with the quality of interaction in the groups. Table 3 presents the correlation coefficients at individual and aggregate group levels.

Concerning the ability of perspective-taking ($M_{L1} = 5.00$, $SD_{L1} = 0.76$, $\alpha = 0.70$, $ICC(1) = 0.06$), we find moderate positive and significant correlations with the (meta-)cognitive subdimensions and small positive values for group climate participation and task-related communication. Except for the small positive correlations with the outcomes, mostly no significant correlations were observed between beliefs about online learning ($M_{L1} = 3.55$, $SD_{L1} = 1.53$, $\alpha = 0.93$, $ICC(1) = 0.11$) and dimensions of interaction quality, which is contrary to expectations. At the group level, the sense of community ($M_{L1} = 5.16$, $SD_{L1} = 1.21$, $\alpha = 0.92$, $M_{L2} = 5.10$, $SD_{L2} = 1.01$, $ICC(1) = 0.30$) is highly positively correlated, especially with group climate, participation, and overall satisfaction with the digital collaborative learning process.

5 Discussion

This study investigated online collaborative learning based on the perceptions of students attending an asynchronous university course. Groups of three or four students worked collaboratively throughout one semester. Lecturers introduced group tasks on recorded slides, and collaborative learning phases were conducted without teacher guidance. The groups decided autonomously how to complete the collaborative tasks. At the end of the semester, students rated the collaborative learning process. A new student questionnaire was used to assess the quality of collaborative learning (Bach and Thiel, 2024). Group interaction was operationalized via cognitive, metacognitive, and relational group activities relevant to the productivity of collaborative learning settings. Furthermore, questions about framework conditions, as well as individual and group characteristics, were included in the survey. Our study aimed to gain insight into self-directed collaborative online learning and empirically investigate the different pathways that contribute to the success of collaborative learning.

The results revealed that the groups, according to their self-reports, spent the expected amount of time on the collaborative learning tasks; on average, the groups invested slightly more than 1.5 h per week over the 12-week semester on the collaborative tasks. Video conferencing and messenger services were primarily used.

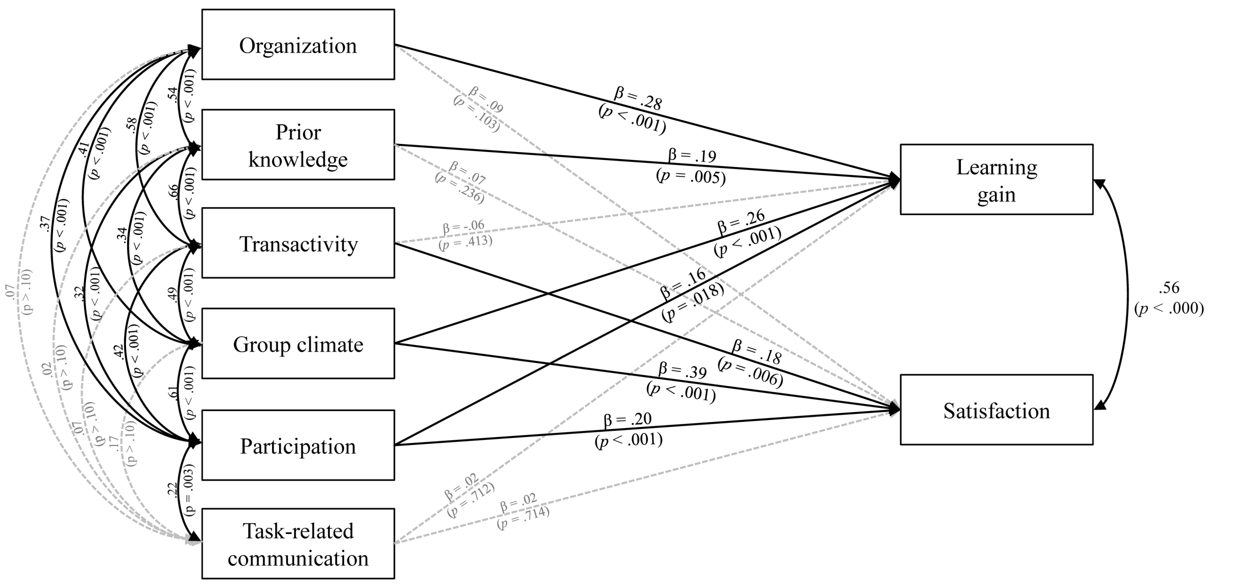


FIGURE 3
Results of path analysis with two dependent variables, learning gain and satisfaction, predicted by the six dimensions of interaction quality. Reported values are standarized coefficients with p-values in parantheses. Significant paths are depicted by solid lines, while non-significant lines are depicted by dotted lines (in grey). R^2 (learning gain)= .40 ($p < 0.001$); R^2 (satisfaction) =.55 ($p < 0.001$).

TABLE 3 Correlations between interaction quality and individual and group-related predictors.

	Perspective-taking	Beliefs of web-based learning	Sense of community
Organization	0.32*** / 0.23*	0.011# / 0.19*	0.45*** / 0.49***
Prior knowledge	0.31*** / 0.11ns	0.07ns / 0.12ns	0.38*** / 0.54***
Transactivity	0.31*** / 0.20*	0.08ns / 0.13ns	0.54*** / 0.62***
Group climate	0.16** / 0.13ns	0.07ns / 0.17#	0.78*** / 0.74***
Participation	0.12# / 0.07ns	0.01ns / 0.12ns	0.68*** / 0.73***
Task-related communication	0.14* / 0.13ns	0.01ns / 0.12ns	0.22*** / 0.21*
Learning gain	0.22*** / 0.18#	0.17** / 0.19*	0.59*** / 0.62***
Satisfaction	0.16** / 0.07ns	0.12* / 0.12ns	0.81*** / 0.86***

Values on the left side of the slash represent the coefficients at individual level 1 ($N = 282$), on the right side at group level 2 ($N = 119$). *$p < 0.05$, **$p < 0.01$, *$p < 0.001$, #$p < 0.10$, ns, non-significant, i.e., $p > 0.10$.

Considering that videoconferencing is associated with more in-depth group interactions, it may be beneficial to specify in advance which tools should be used for collaborative learning. Technical difficulties identified in previous studies as the main barriers to digital collaboration (Sitzmann et al., 2010) were rare in our study. Consequently, the interaction quality ratings are consequently not affected by technical limitations.

Regarding the digital interaction quality, we found higher mean values for relational group activities than for cognitive or metacognitive activities. Establishing a respectful group climate, the participation of all group members, and task-related communication showed comparatively high averages, which is in line with findings from empirical instructional research (Fauth et al., 2014). According to our findings, relational group activities were also unaffected by the digital tools that the groups used to work on collaborative tasks. However, the use of video conferencing can stimulate the (meta-)cognitive learning process in a group. The quality of interaction with regard to the joint activation of prior knowledge, organization, and transactivity is associated with the increasing use of video conferencing. In line with the findings of Jeong et al. (2019), we found that fully asynchronous formats may not achieve the intended level of in-depth exchange and should be supplemented by synchronous formats (Joksimović et al., 2015). Furthermore, ICC-1 also showed higher values for relational activities than for (meta-)cognitive activities. This implies that group members tend to be more consistent in their ratings and that the instrument differentiates better between groups.

According to our results, the group climate and participation of all group members positively impacted learning gains and satisfaction with the collaborative learning process. This emphasizes the importance of these characteristics in digital collaboration group processes. However, we found no significant impact of task-related communication on the outcomes, perhaps because a certain level of task-irrelevant conversation in groups could foster group cohesion and even effectiveness, as suggested in the literature (O'Keefe, 1995). In this respect, a non-linear relationship may exist, which should be examined in follow-up studies. Furthermore, the study was conducted during the COVID-related lockdown, strongly impacted social contacts (Long et al., 2022). Working in online groups may have had a buffering effect; therefore, conversations about topics unrelated to the tasks compensated for social isolation.

Our results show stronger associations between the organization and prior knowledge dimensions with learning gain than with satisfaction with the collaborative learning process, which is in line with expectations. Contrary to expectations, the impact of transactivity on satisfaction was greater than that on cognitive learning gain. While the intercorrelation between transactivity and learning gain was significant ($r = 0.45$, $p < 0.001$), it disappeared when all factors were included in the model. This could indicate mediation effects, which need to be further investigated using with larger sample size.

Furthermore, only a limited number of factors associated with group interaction quality and outcomes could be empirically included. According to previous findings, an important factor could be the individual's prior knowledge, which impacts the success of the learning process (Slof et al., 2021). Differences in group composition were also not considered (e.g., collective efficacy that could have a positive impact on group discussion and performance, see Wang and Lin, 2007).

According to our results, the ability of perspective-taking is also a precondition for the success of collaborative learning processes in digital interactions. At the individual level, there were consistently positive correlations of medium size between the ability of perspective-taking and the (meta-)cognitive group activities. This finding is also evident at the group level: groups with a higher average level of perspective-taking ability are also more effective in transactive communication and organization of group processes with regard to metacognitive group activities. This is a reasonable finding because the ability to empathize with others' thoughts is a genuine aspect of transactive communication. With the ability of perspective-taking, we captured the cognitive part of the multidimensional construct of empathy rather than the emotional aspect (Davis, 1996), which may correlate more strongly with the motivation factors of the group process.

Our findings confirmed that creating a sense of community in digital interactions significantly affects the quality of digital interactions and outcomes. In line with expectations, there were strong associations with relational group activities, such as group climate, participation, and satisfaction. We found lower values for task-related communication only. This result confirms the aforementioned conclusion and is consistent with the assumption that a certain amount of private communication can positively affect group cohesion, particularly in digital collaborative learning processes.

According to our findings, beliefs about web-based learning do not seem meaningfully related to the quality of group interactions. The strongest association was observed with learning gains. However, a reciprocal relationship is also possible here; groups that have worked virtually successfully may also have improved their attitudes toward online learning as an outcome. Causal direction can only be ascertained using experimental and longitudinal studies. In addition, item formulations may lack specificity because they generally refer to learning through digital courses. In this respect, it is a distal factor in the collaborative learning process, which could explain the weaker relationship.

Overall, our study provides insights into digital collaborative learning in higher education during the COVID-19 pandemic. Using the new student questionnaire, group interaction quality can be assessed in a differentiated manner. The consideration of different group activities allows for the examination of specific, theoretically assumed relationships. However, this brings up an important limitation: the questionnaire is being used for the first time for the assessment of *digital* collaborative learning; thus far, it has only been validated in face-to-face settings (Bach and Thiel, 2024). The empirical findings can be considered as evidence of the construct validity of the questionnaire for digital collaborative learning. Nevertheless, follow-up studies should include further validation of this questionnaire. Objective data (e.g., student or group achievement) could be used for validation as well as observational studies to assess the quality of group interaction for comparison with self-ratings. Also, in terms of construct operationalization, it should be reflected that the questionnaire could be improved regarding the metacognitive group activities. The organization sub-dimension in our questionnaire could be expanded to include additional factors, such as collaborative reflection on the group process (De Backer et al., 2022b).

Further limitations include this study's cross-sectional design with only a single measurement, which does not allow for the derivation of causal relationships. High-quality group interaction can also enhance the social competencies and the ability of perspective-taking of group members. Longitudinal studies are required to investigate the direction of these associations. Future studies could address this problem by adopting a longitudinal approach to enhance our understanding of the underlying mechanisms. Additionally, the study was conducted with only one cohort of students at a single university and, therefore, has restrictions in terms of the generalizability of the findings.

Furthermore, the limited sample size (particularly the average cluster size) poses an additional methodological challenge by restricting the use of latent multilevel analyses. This problem already occurred in the population because the group size was small in our collaborative learning setting. A low average cluster size in the sample was available for data analysis, resulting in statistical underpowering, which compromised the reliability of the group level. Increasing the sample size would also allow for multilevel confirmatory factor analyses and analyses of mediation effects.

In addition, a larger sample could also be used to analyze the gender differences identified in collaborative learning research (see Cai et al., 2017, for technology use; Costa et al., 2001, for social competencies). Our findings align with this perspective, showing different means in variance analyses (higher values for females in perspective-taking ability and for males regarding beliefs about web-based learning). However, due to the different group sizes in our sample (232 females and 66 males), the results should be validated in subsequent studies.

Finally, all analyses relied on self-reported data, which could have included response bias. Despite these limitations, our study provides insights into students´ collaborative online learning and examines the relationships between different dimensions of group interaction quality and the input and outcome variables.

Data availability statement

The data are available upon request to the authors. Requests to access the datasets should be directed to anabel.bach@fu-berlin.de.

Ethics statement

Ethical approval was not required for the studies involving humans because criteria requiring an ethical approval were not given in accordance with the institutional requirements (no examination of patients, no risks, harm or discomfort to the participants, no vulnerable groups, use only non-identifiable data etc.). 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

AB: Conceptualization, Software, Writing – original draft, Writing – review & editing, Data curation, Formal analysis, Investigation, Methodology, Project administration. FT: Conceptualization, Writing – review & editing, Project administration, Resources, 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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Analyzing first-semester chemistry students' transactive talk and problem-solving activities in an intervention study through a quantitative coding manual

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Introduction: During the COVID-19 pandemic, digital video conferencing formats temporarily became the new norm at universities. Due to social distancing, these environments were often the only way for students to work together. In the present study, we investigated how first-semester chemistry students dealt with new, challenging content, i.e., quantum theories of chemical bonding such as molecular orbital (MO) theory, in such an unfamiliar collaboration environment. Studies in the field of Computer-Supported Collaborative Learning (CSCL) suggest that small groups working on complex tasks are particularly effective when students actively build on the ideas and reasoning of their peers, i.e., when they engage in transactive talk and when they structure their work on a metacognitive level by following typical problem-solving patterns.

Methods: To operationalize these constructs, we developed a coding manual through quantitative content analysis, that we used to analyze a total of $N = 77$ students working together in 21 small groups on two consecutive tasks: the creation of glossaries and the construction of concept maps on MO theory. Our manual showed very good characteristics in terms of internal consistency and inter-coder reliability. Based on the data obtained, it was possible to not only describe the student's transactive communication and problem-solving activities, but to correlate it with other variables such as knowledge development in MO theory, which allowed us to compare the two different collaborative phases as well as different treatment groups.

Results and discussion: Students showed a higher proportion of transactivity and problem-solving activities when constructing the concept maps than when creating glossaries. In terms of knowledge gains, a multiple linear regression analysis revealed that students in groups that derived consequences from their collaborative work showed greater improvements than students who did not, although the students' prior knowledge remained the most influential factor. As for the different treatments, our data did not reveal any noticeable difference when students from a small group worked with either complementary or identical material before collaboration, neither in terms of transactive talk nor problem-solving patterns. All in all, we were able to develop and test a powerful tool to quantify transactive communication and problem-solving activities in a collaborative context.

KEYWORDS
computer-supported collaborative learning, transactive talk, problem-solving, quantitative content analysis, molecular orbital theory

1 Introduction

In general, digital-collaborative approaches have proven to be well suited for learning difficult scientific content (Kyndt et al., 2013). Such difficult content may, for example, include quantum mechanical theories of the chemical bond such as molecular orbital (MO) theory (Brundage et al., 2023). From a socio-constructivist point of view, the aim of collaborative learning scenarios is to engage learners in joint discourse and knowledge co-construction in order to achieve beneficial learning outcomes for each participating individual (Mercer and Howe, 2012; Roschelle and Teasley, 1995). In theory, activity within a pair or group can be considered as co-constructive when learners share and discuss the ideas which they have constructed individually before: Throughout this process, they may develop their understanding of the topics at hand, create new ideas, negotiate meanings of existing ones and integrate new information into already existing knowledge structures (Gätje and Jurkowski, 2021; Webb, 2009; Webb et al., 2014). A central characteristic of knowledge co-construction is that students may potentially construct knowledge they would not have been able to on their own (Deiglmayr and Spada, 2011).

1.1 Transactivity in collaborative learning scenarios

According to Gätje and Jurkowski (2021), one essential mechanism behind the effectiveness of collaboration is that it allows students to engage with each other's understandings of the matter at hand, a process that Mercer and Howe (2012) call *interthinking*, i.e., a coordinated activity centered around establishing, maintaining and developing *intersubjectivity*. The latter refers to a form of cognitive agreement on the meaning of concepts within a group (Berger and Luckmann, 2011; Cooper-White, 2014; Mercer and Howe, 2012). Building on this thought, transactive communication, or dialogs in which learners build upon and develop previous contributions from group discussion, serves this purpose of co-constructing a joint solution to the task at hand from collaboration (Berkowitz and Gibbs, 1983; Vogel et al., 2023). Vogel et al. (2017) summarize multiple benefits of transactive communication in small groups: In accordance with Chi and Wylie's (2014) ICAP framework, they argue that transactive communication has two benefits on a socio-cognitive level: First, contributions that add new ideas to the contributions of others may increase the amount of knowledge and perspectives in the group discussion. Furthermore, transactive activities can evoke socio-cognitive conflicts between learners. Resolving these conflicts can lead to a further increase in subject knowledge (Schwarz and Linchevski, 2007).

Gätje and Jurkowski (2021) also report multiple instances, in which transactivity was reported to positively relate to the results in group processes, e. g., in young adults' discussions of moral dilemmas (Berkowitz and Gibbs, 1983), scientific problem-solving (Azmitia and Montgomery, 1993), or test performance after partner work in educational psychology (Jurkowski and Hänze, 2015). In a study conducted by Jurkowski and Hänze (2015), students who were trained in producing transactive statements outperformed their peers who did not receive such a training in a subsequent test on the topic. For that reason, the degree of transactivity within a collaborative problem-solving scenario might influence both the quality of the resulting product as well as the learning progress that individual learners make within this scenario (Gätje and Jurkowski, 2021; Vogel et al., 2023; Webb et al., 2021).

When investigating transactive talk, three distinct forms can be distinguished: self-references, low-transactive communication and high-transactive communication (Gätje and Jurkowski, 2021; Noroozi et al., 2013; Teasley, 1997; Vogel et al., 2023).

1.1.1 Self-references

Students engage in transactive self-talk when they provide a substantive justification or illustration for the ideas they put forward or the progress they make. Although several authors (e. g. Gätje and Jurkowski, 2021) argue that transactivity can only occur when students refer to the ideas that others make, we decided to follow along Berkowitz' and Gibbs' (1983) as well as Teasley's (1997) broader definition of the term which includes self-referential statements into the transactive category. Bisra et al. (2018) were able to show that this form of communication might also be beneficial for the further development of learners' conceptual understanding when working together in pairs or small groups.

1.1.2 Low-level transactivity

In low-level transactive speech acts, students ensure that they have correctly understood the thought process behind utterances from group members by paraphrasing statements or asking direct questions that aim at missing or more detailed explanations. Although, on the group level, no new knowledge is constructed in this way, these acts serve as a mechanism to integrate group knowledge into individual cognitive structures. Thus, they can be beneficial to individual learning (Gätje and Jurkowski, 2021; Zoethout et al., 2017).

1.1.3 High-level Transactivity

In contrast to low-level transactivity, students add new ideas when they execute high-level transactive speech acts and thus progress the co-construction of knowledge on the group level. Such acts include expanding on ideas, asking critical questions or pointing out mistakes, contrasting several multiple and joining together separate concepts from the group discourse (Gätje and Jurkowski, 2021; Vogel et al., 2023; Weinberger and Fischer, 2006).

1.2 Problem-solving processes in co-constructive activities

Aside from transactive argumentation, the students' problem-solving skills also need to be considered when describing co-constructive processes (Engelmann et al., 2009; Priemer et al., 2020; Webb et al., 2021). According to Funke (2012), problem-solving requires learners to construct a mental representation of the problem, which they then try to solve by integrating their prior knowledge (Priemer et al., 2020). In this context, problems can be defined as situations in which learners need to overcome an obstacle (= problem) to achieve a goal state from a given state (Funke, 2012). This requires both subject-specific knowledge as well as metacognitive strategies (Priemer et al., 2020). According to Pólya (1957, p. 5), problem-solving in its simplest form consists of the following four steps:

1. Understanding the problem
2. Devising a plan
3. Carrying out the plan
4. Looking back

Priemer et al. (2020) document that similar steps can be found in other established problem-solving models. According to the OECD's (2013, p. 126) widely accepted (Priemer et al., 2020) operationalization in the 2012 PISA study, problem-solving processes should start with exploring and understanding the problem. The goal here is for learners to build a mental representation of the information given to them in the problem context. In a collaborative learning situation, it is important for learners not only to understand the problem individually, but to achieve a common understanding of the problem situation at the group level (Vogel et al., 2023).

The second step in the PISA framework is the creation of a situation or problem model from the problem situation (OECD, 2013, p. 126). If necessary, the problem needs to be translated into a different representational format, e. g., by constructing tables, drawing graphics or converting the problem into a symbolic or verbal representation.

The third phase of a problem-solving process should include the planning and execution of a solution (OECD, 2013, p. 126). The planning phase involves defining or clarifying the goal, which is also reflected in our first two categories. Furthermore, students should divide the goal into sub-goals, devise a strategy to reach the goal state, and execute it.

In the fourth phase of problem-solving, learners should monitor their progress toward their (sub-)goal, detect possible obstacles and react accordingly. The final phase includes a critical reflection of the work process and product.

1.3 Research questions and hypotheses

Literature suggests that there should be a positive relation between the development of students' learning success and the quality of their collaboration in small groups (Gätje and Jurkowski, 2021; Noroozi et al., 2013; Priemer et al., 2020; Vogel et al., 2023). However, these results should be critically examined for their applicability to our study, as many positive correlations were measured not in small groups, but in paired work (e. g., Jurkowski and Hänze, 2010; Jurkowski and Hänze, 2015). Furthermore, at the time of writing this paper, we were not aware of any studies investigating this in the context of the collaborative construction of glossaries and concept maps on quantum chemistry.

For that reason, we try to answer the following research questions throughout this paper:

> RQ1 How well do university students in each small group collaborate when they create glossaries and concept maps on molecular orbital theory together?
>
> a To what extent do students engage in transactive talk, i.e., refer to their own or each other's ideas in their argumentation?
>
> b To what extent do students structure the work process on a metacognitive level, i.e., follow established problem-solving patterns?
>
> RQ2 How is the quality of the collaboration in small groups (as operationalized in question 1) related to the development of the individual students' content knowledge, taking into account their prior knowledge before they start to collaborate?

Following along the literature discussed above, we hypothesize there to be a positive relation between the development of students' learning success and the quality of the students' collaboration in small groups.

Similar to the idea underlying the jigsaw method (*cf.* Aronson and Patnoe, 2011), we hypothesize that an increase in positive interdependence among students might also lead to an increase in transactivity and meta-communication, when the students realize that they need their peers to succeed in solving the problem presented to them, i.e., to create a glossary or a concept map (Johnson and Johnson, 1999).

One way to achieve this is by distributing the information needed to address the problem among various group members, so that no one person alone, but only the group as a whole, should be able to solve the problem. We will investigate whether this division of information positively impacts collaboration in the presented context in the following research question:

> RQ3 To what extent does collaboration differ between students who work with identical or complementary material before the group process in terms of
>
> a … transactive talk and problem-solving activities in general?
>
> b … the influence of transactive talk and problem-solving activities on the development of their concept knowledge?

2 Materials and methods

First, we present the intervention study in which we conducted our analyses (section 2.1). In the second subsection 2.2, we describe the development of a coding manual through quantitative content analysis according to Döring and Bortz (2016, pp. 555–559), before we finish with a principal component analysis (PCA) of our two scales in subsection 2.3.

2.1 Design of the Intervention

The research questions were addressed within the framework of a larger intervention study focused on molecular orbital theory, which we conducted in early 2022 in Germany (Hauck et al., 2023a). Before the intervention, students attended the introductory first-semester lecture (*General and Inorganic Chemistry*, held by the second author of this paper). The lecture followed an *Atoms-First* approach, meaning that students were confronted with quantum chemical content from the beginning of their studies, starting with basic quantum mechanical principles and finishing with molecular orbital (MO) theory (Chitiyo et al., 2018; Esterling and Bartels, 2013) around December. Over the Christmas break, the students could register to participate in our intervention, which started right after the holidays. Students could withdraw at any time or object to the processing of their data without negative consequences. Prior to participation, each of them filled out a declaration of informed consent, which contained important information on data protection, data security, and the further processing of data.

In January, the students took part in five seminar sessions (see Figure 1). Due to the circumstances caused by the COVID-19 pandemic, all seminar sessions had to be held online. Accordingly, the students did not work together face-to-face, but via video conference: Although the presentations were given digitally in the first half of the semester, the students had not yet collaborated with their peers in this lecture. Furthermore, there were only few, if any, opportunities for students to get to know their fellow students before the intervention (Werner et al., 2021). For this reason, we carried out two team-building activities in the first session of the study: To get to know each other, students entered a Zoom breakout session with other members of their small group and played a question game called "3 truths, 1 lie," where they had to make three true and one false statement about themselves. The others had to guess which statement was the false one. Whenever the students got together in small groups, they were supervised by a moderator, e. g., a student assistant or a lecturer.

In this particular phase, the moderator led the students through the question game, so that all of them were equally included. Later on, the moderator's tasks were to record phases in which the students worked in small group, to help them with technical problems, and to answer questions regarding the organization of the intervention. At the end of this ice breaking activity, the students had to decide for a team name and return to the meeting from their breakout session. In the second step, the students participated in a quiz competition against other small groups: The students took turns to answer chemistry-related questions with the help of their group members.

After the students visited the regular introductory chemistry lecture, they participated in the intervention: First, they worked with interactive learning videos by themselves and then created glossaries and concept maps on MO theory to apply and structure their knowledge. During that second phase, $N = 77$ students were separated into small groups of 3–5 students (see Figure 1 for a detailed overview of the intervention structure) which form the sample for the research presented in this paper.

In the first session ("pre"), we assessed the students' prior knowledge of general quantum chemistry and molecular orbital theory with a self-developed questionnaire consisting of 29 closed-ended (single-choice) and eight open-ended questions (Hauck et al., 2023b).

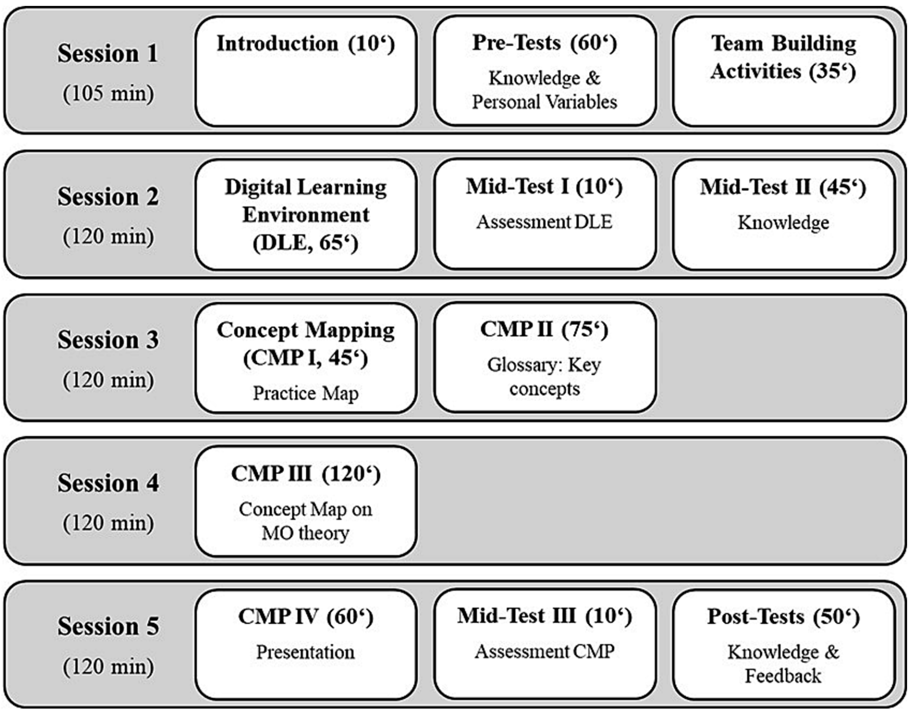

FIGURE 1
Structure of the five seminar sessions. In the first session, students receive an introduction, complete pre-tests, and participate in team-building activities. In the second session, they work with a digital learning environment (DLE), assess it in Mid-Test I, and answer subject knowledge questions for the second time in mid-test II. Sessions 3 to 5 are dedicated to the concept mapping process (CMP). In session 3, students first create a practice map, then select and explain key concepts of molecular orbital theory in a glossary. In session 4, they transfer, structure, and link these concepts into a concept map, which they present in session 5. Afterwards, students assess the CMP, complete a final subject knowledge questionnaire in the post-test, and provide feedback on the entire intervention.

As learners need to have at least some amount of prior knowledge in order to effectively collaborate on complex tasks (Zambrano et al., 2019), the co-constructive phase was preceded by an individual constructive phase (Olsen et al., 2019). For that reason, the students worked on a Digital Learning Environment (DLE) by themselves in session 2. The DLE consisted of interactive learning videos which covered fundamental quantum chemical principles of MO theory (focus A), as well as the practical application of the theory (focus B), i.e., the creation and interpretation of so-called MO diagrams. The learning videos were developed based on the principles of the Cognitive Theory of Multimedia Learning (Mayer, 2014) and enriched with interactive elements to engage learners more actively and provide immediate feedback, which has shown positive effects on learning outcomes in numerous studies (Hattie, 2023). For a detailed description of the videos and their development, see Hauck et al. (2023a).

Afterwards, their knowledge on the topic was tested once again through the same questionnaire ("mid"). In the following three sessions, the students created glossaries and concept maps on MO theory to apply their knowledge and link existing concepts. Finally, they were tested a final time ("post").

As summarized in Table 1, our sample consists of 41 female, 35 male, and one non-binary student ($N = 77$). The overall majority of them were first-semester students which graduated at a German upper secondary school. About half of them were from a Chemical Biology program, 20 studied Chemistry, and 14 aspired to become chemistry teachers for upper secondary school. The remaining students studied chemistry as a subsidiary subject, e. g. for a degree in mathematics (B. Sc.).

In our investigation, we compared students who worked in two different treatment groups (TGs):

> TG1 About half of the students ($n = 39$) worked together in 10 small groups of three to five students each to create glossaries and concept maps. Every one of them watched identical interactive videos beforehand.
>
> TG2 The other half ($n = 38$) also created glossaries and concept maps in 11 small groups of three to five students each. However, in the preceding phase, these students viewed two complementary subsets of videos that corresponded to the two different foci of the learning environment (A, quantum chemical basics vs. B, application of MO theory). When combined, video variants A and B contained the same content as the videos that treatment group TG1 worked with. On their own, students who watched videos corresponding to focus A were lacking the information on the application of MO theory, which only their other group members who worked with video variant B had, and vice versa for the quantum chemical basics.

TABLE 1 Description of the sample ($N = 77$).

Item	Distribution
Gender	41 female, 35 male, 1 non-binary
Semester	72 first-semester students, 5 third-to sixth-semester students
Country of graduation and self-reported German language proficiency	75 students graduated upper secondary school in Germany 2 students graduated abroad (language proficiency C1 and C2)
Field of study	20 students of Chemistry (B. Sc.), 38 students of Chemical Biology (B. Sc.), 14 students of Chemistry Teaching for the upper secondary level (B. Sc./B. A.), 5 others with Chemistry as a subsidiary subject

Within this paper, the separation of the students into these intervention groups allows us to address research question RQ3 by comparing TG1 (identical videos before the start of collaboration) and TG2 (complementary videos).

We have previously published an in-depth investigation of the students' conceptual knowledge throughout the intervention (Hauck et al., 2023b). There, we could show that the learning videos have been very effective in influencing their knowledge of MO theory. However, creating concept maps did not lead to a significant change in conceptual knowledge when comparing mean knowledge test scores for the entire sample. Furthermore, there seemed to be no difference between the treatment groups on a macroscopic level. However, should there be a difference between the groups concerning research question RQ3a, then this would suggest that the development of each student's subject knowledge should be investigated in more detail, which would be a further discussion point of this paper.

In the collaborative work phases, students returned to the same small groups from session 1. Once again, we created Zoom breakout sessions and assigned moderators to each of them. In contrast to the team building activity, the moderators took a more passive role: To guarantee standardized conditions, they did not answer any questions regarding the method of concept mapping or the content. For that reason, we showed a pre-recorded presentation to the students at the beginning of each seminar session. These presentations contained information on the organization of the session, methodological and technical tutorials to create glossaries in Moodle (phase "CMP II" in Figure 1) or Concept Maps via CmapTools (phase "CMP III" in Figure 1), as well as an explanation of the tasks the students had to work on during the session. After the introduction, the students had the opportunity to ask questions in plenary, before working in their breakout sessions. In each work phase, the moderator posted the task in the Zoom chat, before the students chose a group member to share their screen with and began working.

For our subsequent analyses, the moderators recorded the audio and video of the creation of the glossary (phase "CMP II" in Figure 1, 75 min) and the construction of the concept map (phase "CMP III" in Figure 1, 120 min), using the capture function in Zoom. The final data set contains 42 videos, 21 from each phase. Each of these videos will be investigated separately in its entirety, so that in the end, we will obtain 42 ratings for each of our items, i.e., two ratings per group.

2.2 Development of the coding manual through quantitative content analysis

Since the goal of this article is to relate both transactivity and problem-solving behavior to students' subject knowledge, a quantified variable, we have chosen to investigate these constructs using quantitative content analysis (Coe and Scacco, 2017; Döring et al., 2016; Riffe et al., 2019, pp. 148–167) of the screen and audio recordings of the collaborative phases from the intervention study presented in section 2.1. We chose this method because it allows us to systematically categorize and score our qualitative material through a coding process. These quantified data can then be further processed using quantitative statistical analysis methods and integrated with other variables such as the students' subject knowledge (Coe and Scacco, 2017; Döring et al., 2016).

In accordance with Coe and Scacco (2017), this process can generate either low-or high-inference data. The latter are produced when the objective is to make non-observable deep structures accessible for quantitative analysis, e. g. in the case of analyzing transactivity in a collaborative learning situation, as we have done. In our analysis, we followed the 12 steps of this method according to Döring and Bortz (2016, pp. 555–559).

The first four steps, the development of research questions and hypotheses; the design of the study; the sampling; and the preparation of the data for analysis have already been covered in section 2.1 as well as within this subsection.

2.2.1 Generation of categories from theory

The fifth step is to deductively design the coding manual, which we originally created in German. Following research question RQ1, we decided to develop two distinct scales: The first set of categories consists of the three transactivity categories described in section 1.1: self-references (category 1.1), low-level transactivity (1.2) and high-level transactivity (1.3). The second set contains seven categories to analyze the students' problem-solving behavior in small groups as described in section 1.2.

We want to distinguish between groups that plan carefully in advance and those that start working without a plan and only realize during the process that some of them might have a different understanding of the task than other group members. The latter would still be better than not establishing a common understanding at all. However, this runs the risk of students working independently instead of together. For this reason, we derive the following two categories from the first problem-solving step, the exploration and understanding of the problem, i.e., the creation of a glossary or a concept map:

Students establish a common understanding of the task…

1 Before they start working on it,
2 While they are working on it.

The second step, the creation of a situation or problem mode, corresponds to the tasks the students were given ("create a glossary from the information in the interactive learning videos"; "transfer your glossary into a concept map"). Therefore, we did not include a category for this step in our coding manual.

Given that the creation of concept maps is quite difficult due to it requiring both profound conceptual as well as metacognitive knowledge (Haugwitz et al., 2010; Nesbit and Adesope, 2006), we scaffolded the third problem-solving step, i.e., the planning and execution of a solution, by including sub-goals. First, students should transfer all terms from the glossary to the concept map. Second, they were tasked to look for a way to arrange the concepts on the map and third, link them with arrows. To represent this third phase, we derived the following category:

3 Students pre-structure their work process or discuss their strategic approach before they start working on the task. On the highest level, students discuss how to proceed before beginning with a new work phase.

Category 4 operationalizes the fourth problem-solving activity, monitoring of the work process:

4 Students structure their work process or discuss their strategic approach while they are working on the task. On the highest level, students actively monitor their work process and, if necessary, react accordingly.

Finally, we included three items to investigate whether the students followed the fifth step of problem-solving, a critical reflection of their work process and product. We separated these two reflections in categories 5 and 6. In category 7, we examine the extent to which students not only reflect on their work but also draw conclusions for their future actions.

5 Students reflect their work process or their strategic approach after they have finished working on the task. On the highest level, this reflection is done in an extensive and self-critical way.
6 Students reflect on the product they created, i.e., their glossary or concept map while they are working on the task or after they have finished working on it. The criteria from the preceding item also apply for the highest level in this one.
7 Students derive consequences for future learning processes from their reflections or discussions. On the highest level, this reflection is not limited to the contents of MO theory or to the creation of glossaries and concept maps.

For each item, we derived a fundamental idea of what it should measure as well as possible positive and negative indicators from the literature presented in this article. Each item is rated on a 3-point ordinal scale from 1 (students do not exhibit the described behavior) to 3 (students fully exhibit the described behavior).

2.2.2 Inductive revision and pre-testing

During the development process, the manual was revised and tested several times, corresponding to steps 6 and 7 of the quantitative content analysis. A revision cycle always proceeded as follows: The manual was applied to 2–4 videos by several raters. These videos were recorded in a similar intervention we conducted in early 2021, in which students who had attended the same lecture a year earlier also created concept maps in small groups (*cf.* Hauck et al., 2021). Afterwards, the raters came together, revised ambiguous wordings, and replaced any indicators from the literature with actual student statements that fitted the item, thus creating anchor examples.

2.2.3 Rater training; analysis of reliability and finalization of the coding manual; coding of the entire sample

In the 8th and 9th step of the analysis process, we double coded a random selection of eight videos (four videos which showed the creation of a glossary and four that depicted the construction of a concept map), corresponding to 19% of our total sample to check the reliability of the manual. Using IBM's SPSS software (version 29), we calculated Cronbach's Alpha to assess internal consistency between the transactivity and problem-solving items. Analysis of the double coding resulted in an excellent correlation between the two coders ($ICC_{unjust} = 0.952$, *cf.* Koo and Li, 2016). In terms of internal consistency, we obtained a good alpha-value for the transactivity scale (items 1.1 to 1.3 for both phases, $\alpha = 0.736$) and an acceptable one for the problem-solving scale (items 2.1 to 2.7 for both phases, $\alpha = 0.664$) according to Cortina (1993). Due to these satisfactory results, no more changes were made to the manual. Nonetheless, we discussed and eliminated the differences in the ratings of these eight videos so that they could be included in the subsequent overall sample. This was necessary to obtain a sufficiently large sample for the subsequent analyses.

Tenthly, we analyzed all remaining 34 videos, and we conducted statistical analysis using SPSS. The final two steps, i.e., the statistical analysis and the interpretation of data, will be described in the results section of this article.

An English translation of the German manual can be found in the Supplementary material of this article, including a comprehensive description of our categories as well as explanations on how to score them.

2.3 Principal component analysis of the two scales

Before we analyzed our data against the background questions of the research questions, we conducted a principal component analysis to extract common factors and to look for possible dimensional reductions. Our PCA reveals that all three transactivity items load on a singular factor (see Table 2 for the corresponding correlation matrix), so that no rotation or normalization is needed, and we can assume there to be a common underlying latent construct (Osborne, 2015).

Regarding the problem-solving items, two different factors can be uncovered. The varimax rotated component matrix with Kaiser normalization (Kaiser, 1958, see Table 3) illustrates that the items 2.5, 2.6, and 2.7 heavily load on the first factor; items 2.1 and 2.3 load on the second one; and 2.2 and 2.4 correlate with both. This result is interesting insofar as these three sets of items correspond to the three different phases investigated: Items 2.1 and 2.3 refer to students' activities before beginning to create their glossaries or concept maps; items 2.5 to 2.7 relate to the students' reflections after finishing; items 2.2 and 2.4, which load on both factors, pertain to strategies while working. Although a reduction to two problem-solving factors would be possible in principle, we refrain from doing so in view of the ambiguous results for these two items, so that we retain seven separate problem-solving factors. Another reason for our decision is the potential loss of information if we reduce all seven items to two factors.

TABLE 2 Correlation matrix for the transactivity scale.

Item	Correlation with component 1
1.1 Self-references	0.77
1.2 Low-level transactivity	0.81
1.3 High-level transactivity	0.89

Extraction through PCA via SPSS.

3 Results

In this section we will answer the research questions underlying this paper. Subsection 3.1 contains the descriptive results for our transactivity-and problem-solving items to subsequently address research question RQ1. The necessary data basis for RQ2 is formed by a multiple linear regression analysis in section 3.2. Finally, the chapter closes with a quantitative comparison of transactive talk and problem-solving patterns between students in treatment groups TG1 and TG2 in order to answer research questions RQ3a and RQ3b.

3.1 Descriptive statistics

The data presented here correspond to research question RQ1: Through a descriptive analysis of our ratings on the transactivity (section 3.1.1) and problem-solving (section 3.1.2) scales, we operationalize the quality of the students' collaboration while they worked in small groups to create glossaries (CMP II phase in Figure 1) and concept maps (CMP III phase in Figure 1).

3.1.1 Transactivity scale

Table 4 illustrates the transactivity ratings for the phase in which the students created glossaries.

Table 5 refers to the creation of concept maps in the CMP III phase.

In both work phases, the student's level of transactive communication was assessed as high, which can be deduced from the high mean scores: Not a single one is below 2.5 out of a maximum of 3 points and in no category in any of the two phases did fewer than two thirds of all groups receive the highest score. Furthermore, the amount of low-level transactive communication (item 1.2) was rated as low for only one group in each of the two phases. No group showed a low amount of self-referential (item 1.1) or high-level transactive (item 1.3) speech acts in either phase. For the creation of the concept map, all but one group's high-level transactive communication was rated at the highest level.

3.1.2 Problem-solving scale

Table 6 contains the ratings for the 7 problem-solving items for the phase in which students created glossaries in small groups.

Table 7 shows the respective ratings for the concept-mapping phase, CMP III.

Compared to the results on the transactivity scale, the ratings on the problem-solving scale were more heterogeneous.

While working together to create a glossary, more than half of the students frequently discussed the strategy they wanted to approach the work process with before they started (item 2.3) or during the work process (item 2.4); only one group did not do so at all. Beyond the strategic approach, scores are much lower:

About one quarter of the groups took the time to establish a common understanding of the task before they started working on it (item 2.1); one quarter only partly did so; the remaining half of all groups immediately began their work. If we take a look at the same activity during the work process, the mean values are even lower with only one group frequently negotiating their understanding of the task while working on it (item 2.2). The same could be observed for the reflection of the work process which only 3 student groups did in an extensive and

TABLE 3 Rotated correlation matrix for the problem-solving scale.

Item	Correlation with component 1	Correlation with component 2
2.1. Discuss common understanding of task before starting to work		0.70
2.2. Discuss common understanding of task after starting to work	0.44	0.53
2.3. Structure work process before starting to work		0.79
2.4. Structure work process after starting to work	0.57	0.34
2.5. Reflect on work process	0.84	
2.6. Reflect on product	0.76	
2.7. Derive consequences for future learning	0.71	

Extraction through PCA; varimax rotation with Kaiser normalization via SPSS. Coefficients below 0.30 are suppressed.

TABLE 4 Descriptive statistics for the transactivity scale (3-point ordinal scale), glossary creation (CMP II phase).

Item	Total amount of ratings	Ratings on level 1	Ratings on level 2	Ratings on level 3	*M*	*SD*
1.1. Self-references	21	0	5	16	2.76	0.44
1.2. Low-level transactivity	21	1	6	14	2.62	0.59
1.3. High-level transactivity	21	0	6	15	2.71	0.46
Overall transactivity	63	1	17	45	2.70	0.49

M is the mean value across all ratings of the item; *SD* is the respective standard deviation.

TABLE 5 Descriptive statistics for the transactivity scale (3-point ordinal scale), Concept Map creation (CMP III phase).

Item	Total amount of ratings	Ratings on level 1	Ratings on level 2	Ratings on level 3	*M*	*SD*
1.1. Self-references	21	0	4	17	2.81	0.39
1.2. Low-level transactivity	21	1	5	15	2.67	0.56
1.3. High-level transactivity	21	0	1	20	2.95	0.21
Overall transactivity	63	1	10	52	2.81	0.43

M is the mean value across all ratings of the item; *SD* is the respective standard deviation.

TABLE 6 Descriptive statistics for the problem-solving scale, glossary creation (CMP II phase).

Item	Total amount of ratings	Ratings on level 1	Ratings on level 2	Ratings on level 3	*M*	*SD*
2.1. Discuss common understanding of task before starting to work	21	10	5	6	1.81	0.87
2.2. Discuss common understanding of task after starting to work	21	15	5	1	1.33	0.58
2.3. Structure work process before starting to work	21	1	8	12	2.52	0.60
2.4. Structure work process after starting to work	21	1	7	13	2.57	0.60
2.5. Reflect on work process	21	14	4	3	1.45	0.75
2.6. Reflect on product	21	3	17	1	1.91	0.44
2.7. Derive consequences for future learning	21	12	8	1	1.48	0.60

M is the mean value across all ratings of the item; *SD* is the respective standard deviation.

self-critical way. Similar effects were shown for the in-depth reflection of the glossaries (item 2.6) and the discussion of consequences for future learning processes beyond the scope of MO theory and the creation of glossaries itself (item 2.7), which only one group did.

Apart from item 2.1 (establishing a common understanding of the task before beginning to work on it), all item's mean values increase by about half a point on the respective scale when creating the concept maps, which means that students show a larger frequency of problem-solving strategies compared to the creation of the glossaries beforehand. Once again, the highest mean ratings were given for items 2.3 and 2.4, covering the discussion of the strategic approach to the task before and during the work process.

3.2 Regression analysis

With the analyses presented in this subsection, we aim at answering research question RQ2: Following up on the results from sections 3.1

TABLE 7 Descriptive statistics for the problem-solving scale, concept map creation (CMP III phase).

Item	Total amount of ratings	Ratings on level 1	Ratings on level 2	Ratings on level 3	*M*	*SD*
2.1. Discuss common understanding of task before starting to work	21	14	4	3	1.48	0.75
2.2. Discuss common understanding of task after starting to work	21	6	10	5	1.95	0.74
2.3. Structure work process before starting to work	21	1	9	11	2.48	0.60
2.4. Structure work process after starting to work	21	1	1	19	2.86	0.48
2.5. Reflect on work process	21	9	5	7	1.91	0.89
2.6. Reflect on product	21	2	10	9	2.33	0.66
2.7. Derive consequences for future learning	21	7	10	4	1.86	0.73

M is the mean value across all ratings of the item; *SD* is the respective standard deviation.

and 3.2, we investigate whether the quality of collaboration within their small groups influences the individual students' knowledge development throughout the creation of glossaries and concept maps.

For that reason, we conducted a multiple linear regression (MLR) analysis: Independent variables consisted of the students' content knowledge prior to collaboration ("mid"-knowledge, MK, *cf.* Figure 1), the averaged transactivity scores (TS) across all three items and both collaborative work phases as well as all seven respective problem-solving scores, which we also averaged across both phases to reduce the complexity of our model against the background of the rather small sample size of only 21 groups. As the dependent variable, we chose the students' content knowledge at the end of the intervention ("post"-knowledge, PK).

After calculating the MLR, we checked our data set for possible outliers. All studentized residuals were within the acceptable range from −3 to 3 (Pope, 1976). None of the leverages exceeded the limit calculated with the formula given by Igo (2010). All Cook distances are smaller than 1 (Cook, 1979). Linear independency of residuals was indicated by a Durbin-Watson value of 2.086 (Durbin and Watson, 1951). Furthermore, our studentized residuals were normally distributed according to a non-significant Shapiro-Wilks test ($p = 0.660$). Using the variance inflation factor (VIF) criterion according to Kim (2019), none of our items exceeded a value of 10, so that we assume there to be no significant multicollinearity between factors which could limit the power of the regression analysis.

The R^2 for the overall model was 0.722 (adjusted $R^2 = 0.685$), indicating a high goodness-of-fit (Cohen, 1988). Furthermore, an analysis of variance [ANOVA, $F(9) = 19.329$, $p < 0.001$] shows that the independent variables we selected are able to statistically significantly predict the students' learning outcomes at the end of the intervention.

Table 8 shows an overview of the regression coefficients, showing that only the students 'mid'-knowledge and the scores for item 2.7 (groups discuss consequences for future learning) remain as significant influences in the model, whereas the 'mid'-knowledge is by far the stronger predictor of the two. Neither the transactivity score nor other problem-solving categories significantly predict the student's post-test results.

3.3 Comparison of treatment groups

In the third and final subchapter, we address the third research question RQ3a: By comparing two different treatment groups TG1 (which we designed in a way that all students work with identical learning videos in the preceding DLE phase) and TG2 (in which different students from the same small group watched different videos beforehand), we examine whether there are differences in transactive talk or problem-solving patterns whether students enter collaboration after watching identical (TG1) or complementary (TG2) videos before beginning to collaborate by calculating unpaired Welch-tests (*cf.* Rasch et al., 2011; Ruxton, 2006) for each variable for the creation of glossaries (Table 9), concept maps (Table 10), as well as for the average values between the two (Table 11). Although there are marginal differences between some variables on the descriptive level, our data indicates that none of them are statistically significant. Since there are no differences between the groups in any category that could explain possible differences in the influence of transactive communication or problem-solving activities on the development of expertise, research question RQ3b cannot be answered satisfactorily on the basis of the present data set.

4 Discussion

Throughout this paper, we described the successful development and implementation of a coding manual to quantify university students' transactive communication and problem-solving activities while they created glossaries and concept maps on a difficult chemistry topic, molecular orbital theory.

In section 2.2.3, we were able to demonstrate a sufficient degree of reliability through satisfactory values for the inter-coder correlation and the internal consistency of our two scales, so that we can conclude that the manual is suitable for use in practice and to answer the three research questions underlying the structure of this paper.

With research question RQ1, we wanted to investigate how well students in our intervention were able to engage in transactive talk (RQ1a) and to what extent they followed established problem-solving patterns to structure their work on a meta-cognitive level (RQ1b).

Regarding RQ1a, we were able to measure very high amounts of transactive talk across all phases. There was only one group in which low-level transactive talk was rated on the lowest level in both phases.

From our perspective as lecturers, this is a very desirable result, because students exhibit desired behavior when they justify their own viewpoints in group discussions, ask each other questions or paraphrase the ideas of group members and expand on the

TABLE 8 Results from multiple linear regression to explain students' "post"-knowledge (PK).

Variable	*B*	*SE*	*β*
Constant Term	0.05	0.14	
MK	0.87*	0.08	0.81*
TS	−0.01	0.09	−0.03
2.1. Discuss common understanding of task before starting to work	−0.04	0.03	−0.12
2.2. Discuss common understanding of task after starting to work	−0.02	0.03	−0.05
2.3. Structure work process before starting to work	−0.01	0.03	−0.03
2.4. Structure work process after starting to work	0.07	0.06	0.15
2.5. Reflect on work process	−0.03	0.04	−0.10
2.6. Reflect on product	−0.03	0.04	−0.08
2.7. Derive consequences for future learning	0.08*	0.03	0.20*

B, non-standardized regression coefficient; *SE*, standard error; β, standardized regression coefficient; *MK*, "mid"-knowledge; *TS*, averaged overall transactivity score. Significant effects are indicated via * for $p < 0.05$.

TABLE 9 Comparison of treatment groups TG1 and TG2 when creating glossaries (CMP II phase), unpaired Welch-tests.

Item	*TG*	*N*	*M*	*SD*	*T*	*df*	*p*
1.1. Self-references	1	10	2.70	0.48	−0.61	17.67	0.55
	3	11	2.82	0.40			
1.2. Low-level transactivity	1	10	2.50	0.71	−0.86	15.38	0.40
	3	11	2.73	0.47			
1.3. High-level transactivity	1	10	2.70	0.48	−0.13	18.67	0.90
	3	11	2.73	0.47			
2.1. Discuss common understanding of task before starting to work	1	10	1.60	0.84	−1.06	18.97	0.31
	3	11	2.00	0.89			
2.2. Discuss common understanding of task after starting to work	1	10	1.30	0.48	−0.25	18.08	0.81
	3	11	1.36	0.67			
2.3. Structure work process before starting to work	1	10	2.40	0.70	−0.88	16.26	0.39
	3	11	2.64	0.51			
2.4. Structure work process after starting to work	1	10	2.50	0.53	−0.52	18.62	0.61
	3	11	2.64	0.67			
2.5. Reflect on work process	1	10	1.20	0.42	−1.74	14.44	0.10
	3	11	1.73	0.91			
2.6. Reflect on product	1	10	1.90	0.32	−0.05	16.39	0.96
	3	11	1.91	0.54			
2.7. Derive consequences for future learning	1	10	1.50	0.71	0.17	16.49	0.87
	3	11	1.46	0.52			

contributions of their fellow students in a co-constructive manner. From our perspective as researchers, these results must be taken with a grain of salt, as the resulting ceiling effects could dilute further analyses due to an underestimation of variance within the sample (Jennings and Cribbie, 2016). To counteract this effect, several approaches are conceivable. Firstly, the 3-point scale could be refined to achieve better resolution in the higher rating range. Secondly, the analyzed material could be divided into shorter segments, allowing to better identify and differentiate phases with higher and lower degrees of transactive communication, for example. The quantitative data obtained from coding with the manual could subsequently be correlated with other data within the scope of research questions RQ2 and RQ3.

In relation to question 1b, the results indicated that students may have already learned or at least intuitively followed some problem-solving patterns, especially when it comes to strategizing before and during their work process (items 2.3 and 2.4). On the other hand, the participants in our study tended to start working on their problems immediately without clarifying the task.

Few groups actually took the time to conduct a comprehensive process-level reflection, which could have resulted from time constraints some students reported in their feedback to the

TABLE 10 Comparison of treatment groups TG1 and TG2 when creating concept maps (CMP III phase), unpaired Welch-tests.

Item	*TG*	*N*	*M*	*SD*	*T*	*df*	*p*
1.1. Self-references	1	10	2.80	0.42	−0.10	18.63	0.92
	3	11	2.82	0.41			
1.2. Low-level transactivity	1	10	2.50	0.71	−1.25	14.03	0.23
	3	11	2.82	0.41			
1.3. High-level transactivity	1	10	2.90	0.32	−1.00	9.00	0.34
	3	11	3.00	0.00			
2.1. Discuss common understanding of task before starting to work	1	10	1.30	0.68	−1.04	18.88	0.31
	3	11	1.64	0.81			
2.2. Discuss common understanding of task after starting to work	1	10	1.70	0.82	−1.52	16.41	0.15
	3	11	2.18	0.60			
2.3. Structure work process before starting to work	1	10	2.40	0.70	−0.54	16.60	0.60
	3	11	2.55	0.52			
2.4. Structure work process after starting to work	1	10	2.80	0.63	−0.50	12.62	0.63
	3	11	2.91	0.30			
2.5. Reflect on work process	1	10	1.90	0.88	−0.02	18.99	0.98
	3	11	1.91	0.94			
2.6. Reflect on product	1	10	2.40	0.70	0.43	18.42	0.67
	3	11	2.27	0.65			
2.7. Derive consequences for future learning	1	10	1.60	0.70	−1.61	18.82	0.13
	3	11	2.09	0.70			

TABLE 11 Comparison of treatment groups TG1 and TG2, mean values of the creation of glossaries (CMP II phase) and concept maps (CMP III phase), unpaired Welch-tests.

Item	*TG*	*N*	*M*	*SD*	*T*	*df*	*p*
1.1. Self-references	1	10	2.75	0.43	−0.41	17.18	0.69
	3	11	2.82	0.34			
1.2. Low-level transactivity	1	10	2.50	0.62	−1.22	13.72	0.24
	3	11	2.77	0.34			
1.3. High-level transactivity	1	10	2.80	0.35	−0.49	15.49	0.63
	3	11	2.86	0.23			
2.1. Discuss common understanding of task before starting to work	1	10	1.45	0.55	−1.41	18.94	0.17
	3	11	1.82	0.64			
2.2. Discuss common understanding of task after starting to work	1	10	1.50	0.58	−1.06	18.95	0.31
	3	11	1.77	0.61			
2.3. Structure work process before starting to work	1	10	2.40	0.62	−0.85	14.63	0.41
	3	11	2.59	0.38			
2.4. Structure work process after starting to work	1	10	2.65	0.47	−0.67	16.30	0.51
	3	11	2.77	0.34			
2.5. Reflect on work process	1	10	1.55	0.55	−0.94	18.24	0.36
	3	11	1.82	0.75			
2.6. Reflect on product	1	10	2.15	0.47	0.28	18.92	0.78
	3	11	2.09	0.49			
2.7. Derive consequences for future learning	1	10	1.55	0.55	−0.95	18.52	0.35
	3	11	1.77	0.52			

intervention (*cf.* Hauck et al., 2023a). With regard to the creation of glossaries, this came as a surprise to us regarding the fact that the students had to use them as a foundation to create their concept maps in the succeeding seminar session.

This underlines the importance of appropriate scaffolding in collaborative problem-solving, especially because students had to start their studies under COVID-19 conditions and thus had to work together on a very difficult topic in an unfamiliar online environment with peers they probably did not know well before (Weber et al., 2022; Werner et al., 2021). This argument is supported by the observation that our ratings for the second collaborative phase (CMP III), in which students created concept maps from their glossaries, improved in all categories that students had previously struggled with, except for the creation of a shared task understanding before starting the work (item 2.1). Another plausible explanation would be that the students perceived the creation of glossaries only as a preparatory task for the creation of concept maps and therefore considered it less important. It would therefore be helpful to more explicitly emphasize the importance of the glossary for the subsequent work.

The MLR we conducted to answer RQ2 resulted in two possible predictor variables from our set of items: The influence of the students' prior knowledge is not surprising, but a well-executed reflection on the collaboration process (item 2.7) as a predictor of the students' knowledge gain is a major finding of this paper. It appears that students, who learn a lot, are more likely to reflect at the end of the collaboration and derive consequences for their future actions. Vice versa, it could also mean that groups, in which reflection on the task is raised to an additional meta-level, gain more from the collaboration at the end. This is an important result, as in the context of digital learning, the question of how to precisely structure collaborative scenarios to maximize learning effectiveness often arises (Chen et al., 2018; Sung et al., 2017). If certain patterns were to prove predictive of the success of individual groups beyond this study, they could be encouraged through the use of targeted scaffolds.

Against the background of these results, some methodological limitations must be discussed. First, the mean differences in conceptual knowledge between the two points of measurement are very small to a level of statistical non-significance – especially when comparing the mean values (*cf.* Hauck et al., 2023b). This might hinder an analysis of possible moderators such as the amount of transactive talk or adequate problem-solving behaviour. Furthermore, this might have also affected the comparison of treatment groups (RQ3a and RQ3b) who did not show any significant difference in neither conceptual knowledge, conceptual knowledge development, amount of transactive talk on any level nor in any form of problem-solving activity we measured with our manual at any measurement point. Possible reasons for this could be that the students used the creation of glossaries and concept maps primarily to consolidate the large amount of knowledge they had acquired through the previously viewed interactive learning videos (*cf.* Hauck et al., 2023b).

This consolidation may have had a positive impact on their long-term knowledge retention, particularly as a result of creating concept maps (see also Haugwitz et al., 2010; Nesbit and Adesope, 2006). However, follow-up testing would be required to test this hypothesis. In our design, this was not possible as our intervention ended right before the students took the exam in the corresponding course.

Second, we coded transactive talk and problem-solving activities at the group level, whereas the students' subject knowledge was assessed for each individual participant. Although the higher resolution which could be achieved by investigating individual students' behavior might allow for a more detailed analysis, we refrained from doing so because of several reasons: On the one hand, our approach was sufficient to answer the research questions presented in this paper. On the other hand, it allowed us to bypass technological limitations resulting from the video conferencing environment: To protect the students' personal data, we did not record their faces in the conference. As they took part using their own devices, audio quality was poor for some students, so that not every statement could be attributed to the exact person who had made it. Furthermore, fixating on individual students might neglect the influence of their group members' behavior. Since we analyzed both the small groups and the individual students within these groups, we cannot ensure that the individual observations are independent of one another. This limitation could be addressed by using a multilevel regression model (instead of the uni-level model we utilized), which, however, would require a larger sample size than is available in our study (*cf.* Maas and Hox, 2004). Nevertheless, our linear regression model allows us to capture the overall dependencies between content knowledge and the influencing variables we proposed.

Third, our data set is limited to a single cohort of students at our university. To test the generalizability of our results, studies on other content, in higher semesters, and at other universities or schools would need to be conducted.

Apart from other forms of statistical techniques or follow-up studies, several approaches are conceivable to overcome the above-mentioned limitations of our study, especially with regard to the possible loss of information during our coding process. One possibility would be to increase the resolution by splitting the units of analysis into narrower segments, e.g., 5-min intervals. So far, we have only awarded one score per category for the creation of glossaries (75 min) and for the creation of concept maps (120 min). Even if this approach was practicable for us and efficient in terms of research economics, the coarser resolution is accompanied by a loss of information. The same point of criticism arises from our purely quantitative research approach. By bundling different speech acts into one category, it is no longer possible to recognize from the data in retrospect which group, for example, asked a particularly large number of critical questions. Similarly, interesting dialog patterns cannot be captured by a single score alone. We therefore suggest that the use of coding manuals such as this one should be accompanied by qualitative methods, for example in a mixed methods setting (*cf.* Tashakkori and Teddlie, 2016).

Nonetheless, most of these limitations can be attributed to external variables that are beyond the scope of the study presented in this paper. In the context of our quantitative study, the manual itself proved to be a powerful tool that allowed us to quantify several dimensions of computer-supported collaborative learning in two different forms of activity on an especially difficult chemistry topic.

By identifying new appropriate indicators and anchor examples, the manual could easily be applied to other topics, including non-chemistry ones, as it encompasses all the tools necessary to quantify transactive communication and problem-solving activities in collaborative settings. The integration into other methodological contexts, e. g. as part of a mixed-methods study, is also viable, as is the use of the manual in secondary schools or other contexts and age groups beyond the university level.

Data availability statement

The datasets presented in this article are not readily available because in the context of the written consent form, we assured the students that their data will only be stored on devices belonging to our university. Hence, we are not permitted to disclose the data publicly. Requests to access the datasets should be directed to IM, insa.melle@tu-dortmund.de.

Ethics statement

Ethical approval was not required for the studies involving humans because the study was developed in accordance to the European General Data Protection Regulation (GDPR) and conducted with university students: Each participant filled out a declaration of informed consent, which contained important information on data protection, data security, and the further processing of data. The participation in the study was voluntary for the students. Non-participation did not result in any disadvantages for them. 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

DH: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Validation, Visualization, Writing - original draft, Writing - review & editing. AS: Conceptualization, Resources, Supervision, Validation, Writing – review & editing. IM: Conceptualization, Formal analysis, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, 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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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2024.1423330/full#supplementary-material

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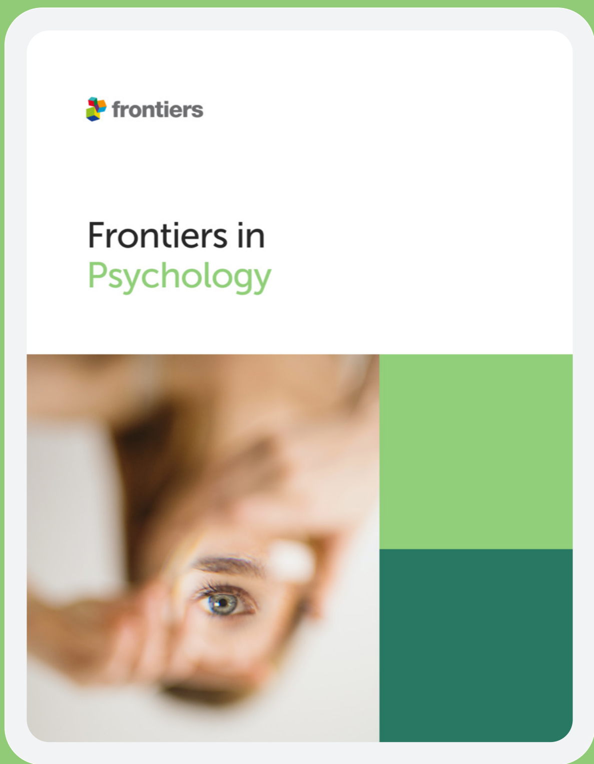

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