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Enhancing Peer Learning in STEM Blended Course: A Pilot Study on Chemical Equilibria

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ABSTRACT

The transition to emergency online education during the pandemic reaffirmed the importance of a sense of belonging among students. However, promoting effective collaboration fostering social belonging in STEM blended learning remains a challenge, especially when opportunities for in-person contact are limited. This pilot study explored the practical implementation of adaptable, easy-to-apply peer learning activities in a first-year Chemical Equilibria blended course. A mixed method design combined quantitative data from exam analysis and surveys with qualitative insights from a focus group interview to capture both student performance and learning experiences. The findings suggest that the structured peer learning activities used in this study may enhance students' sense of belonging and potentially support improved performance on related learning tasks. Key elements that appear to contribute to success include mandatory individual preparation supported by online materials, opportunities for students to assist each other first, and the important role of teaching presence in fostering higher-order thinking. Moreover, this study identified scientific uncertainty as a potential source of stress for first-year students. This exploratory, practice-oriented pilot study demonstrates how low-threshold peer learning activities can be integrated into courses. It offers practical insights and inspiration for educators seeking to strengthen STEM teaching in blended learning environments.

Keywords: first-year undergraduate, peer learning, chemical education, STEM, blended learning

INTRODUCTION

Spring 2020 will long be remembered as the moment when Dutch education had to shift to emergency online delivery. This transition led to the creation of a substantial number of online resources for STEM subjects, providing valuable insights for the future development of blended learning (BL) in these disciplines. Earlier research had already identified that the online components of blended or distance learning could contribute to student isolation, stress, and reduced motivation, issues later intensified under pandemic conditions (Arslan, 2021; Elmer et al., 2020; Pei et al., 2023). This shows that even though the online part of BL has the potential to support individual learning, the face-to-face (F2F) social dimension cannot be ignored (Moore, 2014). This aspect becomes even more crucial considering that the majority of university students are between the ages of 18 and 25, a developmental stage marked by a strong need for social connection and a preference for peer interactions over those with parents. These social interactions are essential for building the collaborative and problem-solving skills necessary for success in STEM subjects, as well as for supporting students' personal and emotional development (Rogers et al., 2021).

From early life, humans naturally develop a sense of belonging, which is essential for well-being (Over, 2016). Belongingness has been linked to emotional and cognitive processes (Baumeister & Leary, 2017) and may play a role in enhancing learning, satisfaction, and academic engagement (Polat & Karabatak, 2022). Peer learning, defined as "the acquisition of knowledge and skill through active helping and supporting among status equals or matched companions" (Topping & Ehly, 1998), provides students with opportunities to review, explain, and discuss complex concepts, as well as collaborate on problem-solving, which are important skills in fields like chemistry. This collaborative process not only strengthens individual understanding but also fosters mutual learning, enabling students to support each other and achieve their learning goals (Cavallaro & Tan, 2006; Liaw et al., 2008; Razak & See, 2010). Furthermore, collaborative interaction has the potential to motivate learners, promote social connections, and enrich the learning experience (O'Donnell & King, 1999). Thus, this study explores the integration of simple, easily implemented peer learning activities in a blended course, focusing on Chemical Equilibria, a fundamental topic in university chemistry education.

THEORETICAL BACKGROUND

Blended learning involves a thoughtful integration of traditional classroom experiences with online learning activities (Garrison & Kanuka, 2004; Isnawan et al., 2025). In higher education, rotation mode (Staker H. & Horn, 2012) is reorganized as a method to encourage active student participation. This entails a structured rotation process "on a fixed schedule or at the teacher's discretion among classroom-based learning modalities" (Staker H. & Horn, 2012). Specifically, the flipped classroom strategy (Bergmann & Sams, 2012) can serve as a tool within this model, enabling students to engage with foundational chemical concepts through online resources at home, while in F2F classroom sessions, teachers focus on clarifying misconceptions, tackling complex problems and providing feedback and guidance to students (Bergmann & Sams, 2012).

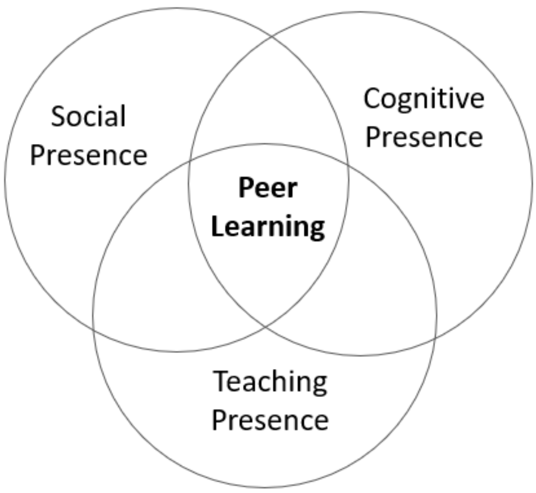


Figure 1. Community of Inquiry framework and peer learning

At the heart of effective BL lies the aim of facilitating meaningful and deep learning experiences (Garrison & Kanuka, 2004). To achieve this, our Chemical Equilibria course utilizes the Community of Inquiry (CoI) (Garrison & Kanuka, 2004) framework (**Figure 1**) and guides the development of peer-learning strategies that integrate cognitive, social, and teaching presence. Cognitive presence fosters higher-order learning, as it involves the development of critical thinking, analysis, and synthesis skills. This is particularly crucial in chemistry, where students must be equipped to apply abstract concepts to real-world chemical reactions. Cognitive presence unfolds through a four-stage process (Garrison & Vaughan, 2008). It starts with students engaging with a question or task (*triggering event*). Following this, they start to search for relevant information individually and collaboratively with peers through discussions and collaborative efforts (*exploration*). Subsequently, this process enables them to construct and affirm meaning by formulating solutions (*integration*). Finally, students can demonstrate proficiency in applying these solutions to new situations (*resolution*). In this process, social presence is vital for a supportive learning environment, wherein students exchange ideas, offer feedback and receive support. This sense of belonging, fostered through social presence, motivates deeper engagement and strengthens connections with peers (Pei et al., 2023). Teaching presence guides and facilitates the social and cognitive presence of students. By designing and implementing learning and teaching activities, teachers can create opportunities for students to develop higher-order thinking skills, resulting in deeper, more meaningful experiences.

Grounded in social constructivism, peer learning involves active exchanges of ideas and engaging discussions aimed at collectively building knowledge and comprehending concepts that can be challenging for individual students (Daniels, 2001). The co-construction of knowledge through peer learning can be thought of as a scaffolding process for students (Topping, 2005). Moreover, peer learning strengthens students' social connections by fostering meaningful interactions among students, creating a supportive environment that enhances learning outcomes and promotes a strong sense of belonging.

RESEARCH AIM AND RESEARCH QUESTION

This pilot study aims to integrate peer learning activities into a blended learning course on Chemical Equilibria. The study seeks to answer the research question: *How does the incorporation of peer learning activities impact students' learning outcomes and their sense of belonging in a blended Chemical Equilibria course?*

Research context

This study was conducted within the Chemical Science and Engineering program at a Dutch university. The program is conducted in English and has a diverse student background, with half of the students holding Dutch nationality and the other half originating from other countries. The program places a strong emphasis on teamwork, with students actively engaging with and learning about intercultural differences while collaborating within teams. The Chemical Equilibria course was chosen for this study due to its fundamental importance in chemistry education. Additionally, with an average participation of 40–50 students in this course, it serves as a suitable sample size for a pilot study before extending the experiences to other STEM courses.

INTERVENTION: PEER LEARNING IN CHEMICAL EQUILIBRIA BLENDED COURSE

Prior to peer learning

The course began with a brief introduction outlining the blended learning approach, followed by an online self-study phase aimed at helping students build a solid foundational understanding of Chemical Equilibria concepts. This preparation ensured students were confident and well-prepared for active engagement in the subsequent peer learning activities. The self-study materials included video pencasts [Figure 2] guiding students through formula derivations, concise mini-lectures covering key topics and formulas, and digital quizzes for practice and self-assessment. For a complete list of pencasts and mini-lectures, please refer to Supplementary Information (SI) 3.

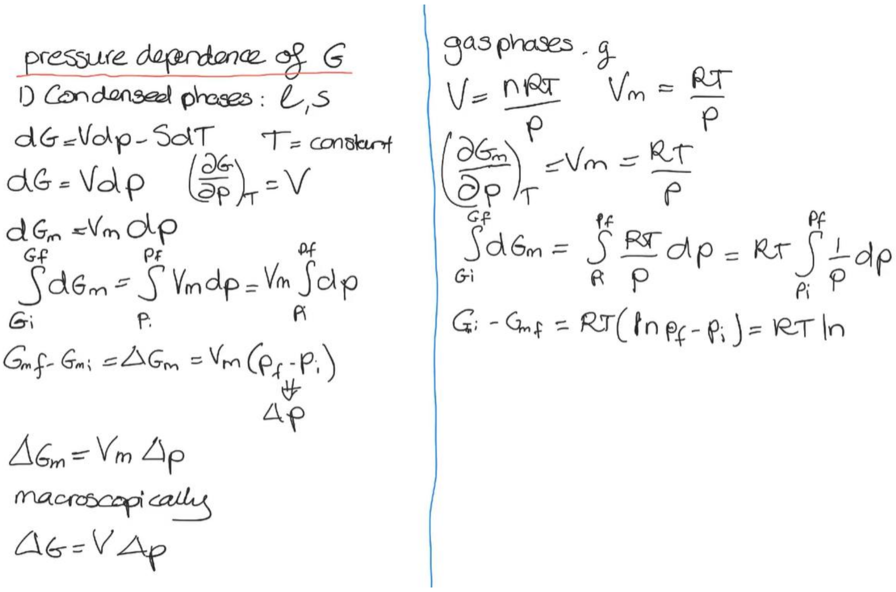
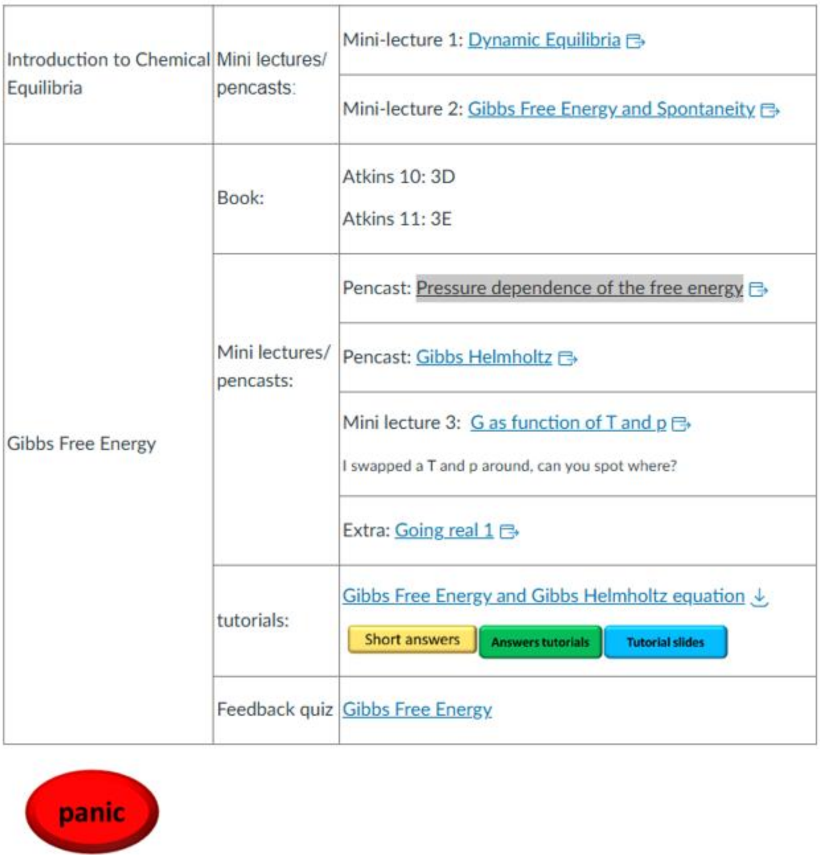


Figure 2. An Example of Pencast about Pressure Dependence

Atkins' Physical Chemistry (Atkins & De Paula, 2006), was recommended as a supplementary reading, offering similar content but presenting the underlying theory from an alternative perspective. In case of difficulties, students had the option to use the 'panic' button to contact the teacher for assistance (Figure 3).



Introduction to Chemical Equilibria	Mini lectures/ pencasts:	Mini-lecture 1: Dynamic Equilibria
		Mini-lecture 2: Gibbs Free Energy and Spontaneity
Gibbs Free Energy	Book:	Atkins 10: 3D Atkins 11: 3E
	Mini lectures/ pencasts:	Pencast: Pressure dependence of the free energy
		Pencast: Gibbs Helmholtz
		Mini lecture 3: G as function of T and p I swapped a T and p around, can you spot where?
		Extra: Going real 1
	tutorials:	Gibbs Free Energy and Gibbs Helmholtz equation Short answers / Answers tutorials / Tutorial slides
	Feedback quiz	Gibbs Free Energy

Figure 3. An example of an online unit

Peer learning activities

Building upon the insights gathered from the literature review, three types of easily implementable and adaptable peer learning activities were incorporated at various stages throughout the course:

- **Tutorial Sessions**: Following their initial exploration of the theory, students were asked to apply the acquired knowledge to practice with the theory and solve practical problems for given assignments during tutorial sessions (see SI 1). Collaborative work was encouraged but not mandatory, granting students the freedom to choose their own partners based on preferences rather than formal group assignments. The teacher was available for guidance and support throughout the tutorial sessions. Comprehensive explanations, including calculations, were provided post-session. This approach aimed to cultivate problem-solving skills and promote peer learning by allowing students to engage with problems before immediate exposure to solutions.
- **Group Discussions**: The second type of peer learning aimed to enhance students' understanding through mutual explanation in group discussions. Midway through the course, all students were asked to prepare an assignment at home (see SI 1 for this assignment). Subsequently, students worked together on this assignment during a group discussion session. Unlike voluntary peer learning in tutorial sessions, here, collaborative group work was compulsory. The teacher formed the discussion groups (3-4 groups, each with an average of 13 students). In the teacher's presence, each group discussed how to solve the assignment. No answers were provided at the end of the session; however, to encourage in-depth discussion, students were allowed to bring their discussion answers to the exam as reference material.
- **Exam Preparation**: The third peer learning activity took place during the exam preparation. Students were asked to solve three exam questions at home and submit their answers at the beginning of the lecture. Each student then received answers from a peer, and while the teacher explained the correct solutions, students reviewed and corrected their peer's answers. The goal of this activity was to encourage students to learn not only from their own mistakes but also from those of their peers. To promote active participation, students who had not attempted the questions beforehand were excluded from the session.

METHODOLOGY

This study spanned two consecutive years, observing two cohorts to examine the impact of peer learning on students' learning outcomes and perceived sense of belonging. To triangulate findings (Creswell & Creswell, 2017), we employed a mixed-methods approach, initially utilizing quantitative data from exam results and qualitative data from focus group interviews. To further enhance the reliability and depth of our findings, an additional embedded research design step was incorporated, which involved gathering supplementary survey data (Yin, 2014). The survey questions were specifically designed to complement and align with the insights gained from the exam results and interviews. Based on the preliminary results from 2022, adjustments were made to the 2023 peer learning activities. Following these adjustments, the same data collection and analysis process was repeated for 2023. Prior to data collection, all students provided informed consent, indicating their voluntary participation in the research study.

Data collection instruments

- Exam results: First, the exam results were used as quantitative data to assess the impact of peer learning activities on students' learning performance. The exam questions were designed to assess students' ability to apply their knowledge in both familiar and new situations. To assess the impact of the peer learning activities, the exam questions associated with the topics covered in peer -learning activities were analyzed. For example, students were asked to linearize the Clausius-Clapeyron equation during group discussion, and in the exam, they were required to answer questions based on the linearized equation (see SI 1 for the assignment).
- Focus group interview: Secondly, we conducted two focus group interviews, each comprising seven students from the 2022 and 2023 cohorts. The aim was to collect qualitative data on how the peer learning activities impact their sense of belonging throughout the learning process.
- Survey: Based on the outcomes of the exam and the focus group interviews, we distributed an anonymous survey among the students via the Learning Management System (Canvas). The survey, containing questions and students' responses, is available in the supplementary information (SI 2). The same survey process with an additional question was replicated in 2023.
- Supplementary data from learning analytics: The online learning behavior of the 2022 students was tracked using learning analytics integrated into Canvas. Our observations from this data (see SI 3) revealed that the majority of students in this cohort dedicated their self-study time for online mini-lectures and pencasts. Due to the constraints imposed by the privacy policy at our university, the utilization of learning analytics was discontinued for 2023.

RESULTS AND DISCUSSION

Exam results 2022

Data about the learning outcomes were obtained by evaluating the exam results and are presented in [**Table 1**]. To our surprise, not all students brought their group discussion answers to the exam as reference material. This led to an opportunity to analyze and compare the exam results between students who brought their discussion answers and those who did not (**Table 1**). Questions a-c on the exam closely mirrored the assignments addressed during the tutorial sessions and group discussion, i.e., linearization of the Clausius Clapeyron equation. Students were asked to calculate the sublimation enthalpy using a figure in which ln(p) data were plotted as function of 1/T for a sublimation process and the formula of the trendline was displayed. In the assignment students had to make their own figure using the given data (see SI 1). Exam questions d-f necessitated the application of the group discussion outcomes to new situations, i.e., a figure displaying the linearization of the Van't Hoff equation was presented where ln(K) data were plotted as function of 1/T and the formula of the trendline was displayed. Students were asked to calculate the enthalpy of reaction for this process. Upon comparing the exam performances of both student groups regarding questions a-c, it showed that those who utilized their group discussion references achieved higher scores compared to those who did not. However, in relation to questions linked to a new context (questions d-f), no significant difference in performance was observed between the two groups.

Table 1: Exam questions related to group discussions, question a-c concerned the linearization of the Clausius Clapeyron Equation, in question d-f students were asked about a linearized Van't Hoff equation.

		Students with reference (total=21)		Students without reference (total=23)	
Question number	Max number of points	Average points	Average/ max points	Average points	Average/ max points
a	3	**2.76**	0.92	2.65	0.88
b	4	**3.05**	0.76	2.50	0.63
c	4	**3.62**	0.90	3.28	0.82
d	4	3.29	0.82	**3.37**	0.84
e	2	1.50	0.75	**1.52**	0.76
f	3	**2.36**	0.79	2.35	0.78

Note: Presented here are the maximum points achievable, the average points and the average points divided by the maximum points. A value closer to 1 indicates better performance in answering the questions.

Focus group interview results 2022

The interviewed students in 2022 expressed appreciation for the benefits of online individual learning, highlighting how materials like videos facilitated *"streamlining the input and allowing information flow at their own pace*." This is in accordance with the data observed from learning analytics (see SI 3). According to the students, the self-study phase prepares them for engaging and productive peer learning activities.

Moreover, the students expressed a strong sense of belonging in this blended course. They highlighted the encouragement they experienced from their peers as well as the positive impact peer learning had on their overall learning process. Specifically, they mentioned that the presence of peers increased their motivation for group discussions. When asked about preferred activities to achieve better results and to increase the sense of belonging, student mentioned the exam preparation with peers, followed closely by group discussions and tutorial sessions. The importance of F2F was stressed as an enabler for complex in-depth conversations almost impossible to achieve in an online setting. They also recommended a dedicated space on campus for group work, accessible beyond regular class hours and a smaller group size for more effective communication.

The interviewed students experienced frustration when they did not receive a definitive answer from the teacher during group discussions or while preparing exam with peers. Some students felt a lack of confidence due to what they perceived as "*ambiguous*" or "*insufficient*" confirmation from the teacher. They expressed a strong desire for enhanced guidance and clearer direction from the teacher.

Survey results 2022

Based on the initial findings from the exam results and interviews, we incorporated an additional anonymous survey (see SI 2) to further validate and complement our results. From the interview, the students expressed their dislike for the uncertainty about whether their discussion outcomes were correct or not. The survey questions 4, 5 and 6 addressed this issue, questions 8 and 9 were open questions where the students could give their opinion about peer learning and suggest improvements to the course. Participation in the survey was voluntary, with 12 students completing it (response rate: 27.3%). Just as the interview, the survey indicated students' dissatisfaction with the absence of definitive answers from teachers. Specifically, 25% of respondents agreed with the statement "*It bothered me that I did not get the right answers for the group discussion,*" while 41.7% marked it as '*Somewhat True*.' In response to open-ended questions for suggestions, two students recommended improving the group discussions with more guidance and direction from the teacher. These results again echoed with the findings from the interviews and indicated the necessity to adapt teaching practices for peer learning activities.

33% of the survey respondents indicated that they did not bring their group discussion answers to the exam. Some of them clarified in the open-ended questions that their uncertainty about the answers was the reason. This was an interesting finding that sparked a philosophical consideration of the nature of truth. It suggested that first-year chemistry students believe all questions have an answer and that the answers should be found in answer sheets. This observation showed their struggle in handling scientific uncertainty.

Adjustments made for peer learning activities in 2023

Based on the results from 2022, it became apparent that improving the practice of teaching presence, a fundamental pillar within the Community of Inquiry, was essential. Subsequently, several adjustments were implemented:

First, a proactive approach was adopted during tutorial sessions; instead of waiting for student questions, teachers actively walked among students, asking about their understanding and offering assistance when needed.

Second, considering the feedback from students in 2022, the group sizes for discussions were reduced to 10 or 11. Third, in 2023 the teacher moderated discussions instead of the observing approach taken in 2022. This also encouraged active student participation. For instance, the teacher started by inviting a student to come forward and work out a question on the whiteboard. This student then would invite another student to work out the next question. In addition, the teacher and students engaged in discussions about scientific uncertainty,

Furthermore, after the group discussions, students were not given definitive answers, but instead, they received the article containing the utilized p, T data, which held information related to the answer. This aimed to cultivate critical thinking and analytical skills, crucial in dealing with scientific uncertainty. To gather insights on students' experiences obtaining answers from scientific papers, an additional question related to this matter was included in the 2023 survey (see SI 2).

Evaluation of the improvements in 2023

Similar to 2022, more than half of the students chose not to bring the answers from the group discussion to the exam. Once again, the exam results of students who brought their assignment answers were compared with those who did not. This comparison is presented in (**Table 2**). In this table, not only the exam results of 2023 are presented, but also the exam results of 2022 and previous years in which similar exam questions were asked to the students. To clarify, it is important to note that in 2018 and 2021, the linearization of the Clausius-Clapeyron equation was discussed during lectures, and p, T data were provided for practice. However, completing this task was not a mandatory learning activity, and students were not allowed to bring any related information to the exam. Additionally, linearization of equations was not tested during the 2019 exam, and due to the pandemic, exams in 2020 were conducted differently. Thus, the results from 2019 and 2020 were excluded from the comparative analysis.

In 2018, 32% of students, and in 2021, 27% of students correctly answered the exam questions on linearization. In 2022, this percentage increased slightly to 38%. The most significant improvement was observed in 2023, with 69% of students answering the questions correctly, likely due to adjustments made in the peer learning activities, with a stronger emphasis on explicit and active teaching presence during the peer learning process. We added an extra question to the 2023 exam, asking students to identify other formulas that could be linearized, thus assessing their *resolution* abilities. Of the 42 students, 37 (88%) completed the task successfully. Further, 89% of students (16 out of 18) who brought their group discussion answers to the exam successfully answered the linearization questions, compared to 54% of those who did not (13 out of 24). This suggests that students who participated in group discussions and brought their answers to the exam performed significantly better than those who did not.

Table 2: Exam result comparison on linearization questions for four different years.

Year	Number of students	with (+)/ without (-) answers	Correct answered	Sub%	%
2018	44	-	14	-	32%
2021	41	-	11	-	27%
2022	44	(+) 21	11	52%	38%
		(-) 23	6	26%	
2023	42	(+) 18	16	89%	69%
		(-) 24	13	54%	

Note: In 2018 and 2021 the linearization was discussed during non-mandatory tutorials. In 2022 and 2023 students participated in the group discussion and were allowed to bring their answers to the exam. Students who brought their answers (with (+)) can be compared to students who didn't (without (-)). Absolute and relative student numbers are presented.

Focus group interview results 2023

Similarly to 2022, the interviewed students in 2023 mentioned that the online learning materials gave them flexibility and also helped them to understand the subject better, especially with the chemical equations: "*I watched it over and over again until I understood it*." Moreover, engaging in all three forms of peer learning activities—tutorials, group discussions, and preparing exam with peers—led to a strong sense of belonging among the students and motivated them in the learning process.

Students emphasized the essential role of the teacher in achieving a deeper understanding of complex topics, noting that relying solely on videos or peer discussions was insufficient for thorough mastery. They stated the need for the teacher's support and guidance, especially when facing challenging issues. Students also mentioned that the teacher from this course was more *'approachable'*, which encouraged them to openly discuss their struggles and seek help when needed. In contrast to 2022, none of the students mentioned experiencing frustration due to not receiving definitive answers from the teacher.

Survey results 2023

The survey in 2023 utilized the same questions as in 2022, supplemented by an inquiry about utilizing the scientific paper to explore answers. Fourteen students participated in the survey, yielding a response rate of 33% (SI 2). Students from 2023 appeared to be less concerned about not receiving answers from teachers (as per survey question 4). In 2022, about 67% of the students were bothered by not receiving the answers, while this proportion decreased to 36% among students in 2023. This indicates that giving the students indirect access to the answers by giving them the opportunity to read and explore an article to check whether they obtained the same results appears effective: this approach may reinforce students' understanding using a broader range of scientific resources. However, one student, in response to open question 8 (SI 2), still expressed concern about the absence of answers provided.

In questions 1 and 2 of the survey, the students were asked about their motivation to work on the group discussion and whether they enjoyed the group discussion. Comparing the student cohorts of 2022 and 2023, students in 2023 demonstrated higher motivation and enjoyment, indicating the success of the improvements. These enhancements, including additional context explanation, smaller group sizes, the teacher's active role as a moderator, and indirect provision of answers, contributed to increased student satisfaction.

DISCUSSION

This study examined how peer learning activities impact learning outcomes and belongingness in a blended Chemical Equilibria course. The findings indicate that careful instructional design may play an important role in peer learning: students appeared to value self-paced, individualized online content, which supported flexibility, autonomy, and a stronger understanding of chemistry concepts. This individual learning phase prepared students for subsequent peer learning activities (Pei et al., 2023). The results further indicate that thoughtfully designed peer learning can enhance students' cognitive presence in which they discuss ideas, collaborate in constructing knowledge, and validate their understanding (Garrison & Kanuka, 2004). As reported by the students, peer learning activities particularly those took place in the F2F classroom were not only necessary for in-depth dialogs, but also encouraged them to attend campus activities for social belonging. However, to help students reach the resolution level of cognitive development (Garrison & Kanuka, 2004), additional guidance and facilitation from the teaching presence during the peer learning process were necessary (Garrison & Vaughan, 2008). Merely providing opportunities for group discussions and taking on the role of an observer was not sufficient, active moderation was required for students to achieve higher learning outcomes.

Teacher's role extended beyond delivering knowledge; it involved guiding students through complex topics and offering support and reassurance as they navigated challenges and uncertainties. This guidance helped students consolidate their understanding and engage more confidently with scientific uncertainties. Although first-year chemistry students generally appreciated the peer learning approach, they also faced difficulties when dealing with uncertainty in scientific reasoning. Encouraging students to explore and experiment, while emphasizing that uncertainty is an inherent part of scientific inquiry, can help reduce frustration and anxiety among STEM students.

Although designing high-quality chemistry education can be time-consuming, our experience showed that the peer learning activities implemented in this course could be achieved with relatively modest time investment, though this requires strategic reallocation rather than simple reduction of effort. For example, discussion of exam questions are already part of many courses; adapting the course by adding the exam practice is therefore expected to be a relatively light burden for the teachers. The creation of pencasts and mini-lectures required an initial one-time investment but subsequently reduced the need for repeated in-class explanations. This saved lecturing time can be strategically redirected toward a recurring commitment: the facilitation of in-class peer discussions. The time saved from traditional lecturing was redirected toward facilitating peer discussions, allowing the teacher to engage in more interactive forms of instruction. Ultimately, this redistribution of teacher effort represented a deliberate pedagogical trade-off: less time spent on content delivery and more time invested in supporting meaningful engagement. That said, our results warrant caution about overgeneralizing the efficiency of this approach. The localized nature of the improvements suggests that meaningful learning gains may require targeted peer learning activities for specific context. Teachers considering this approach should balance its demonstrated advantages against the potential for increased facilitation demands.

LIMITATIONS

This pilot study offers practical insights into implementing peer learning within a blended Chemical Equilibria course; however, several limitations should be acknowledged. First, the blended course had been established before the pandemic and evolved organically during the transition to emergency online education. Consequently, conducting a controlled comparison with the pre-pandemic version of the course was neither feasible nor intended. Furthermore, the original course design was not explicitly guided by the Community of Inquiry framework, and its social, cognitive, and teaching presences were not systematically conceptualized or documented. As a result, a detailed baseline analysis of these presences prior to the introduction of peer learning was not possible. Second, the quantitative findings were based on a subset of exam questions directly related to the peer learning intervention. While these results indicate potential benefits for learning outcomes, they do not allow firm conclusions about overall course performance. Additionally, the data were collected from student examinations across different cohorts, which may have been influenced by variations in student populations or external circumstances. Due to ethical considerations and GDPR restrictions, an experimental research design was not adopted in order to preserve the integrity and quality of the educational experience. Overall, this study does not aim to establish causal relationships but rather to document and reflect on practical adaptations in a blended STEM course. Future research could build on this work by employing larger sample sizes and exploring diverse chemical education contexts to enhance the generalizability of the results.

CONCLUSIONS

While this pilot study has several limitations, it provides useful empirical and practice-oriented insights into ways of enhancing chemistry education in blended learning environments. By integrating three types of peer learning activities into a first-year Chemical Equilibria course, the study illustrates how peer learning may be encouraged through relatively simple and adaptable instructional design choices. The findings indicate that peer learning, when supported by clear teacher facilitation and structured individual preparation, may contribute to improved learning outcomes and a stronger sense of belonging among students. Effective implementation, however, depends on students developing greater learning autonomy, which may differ from their previous educational experiences. Teachers play a key role in supporting this transition by designing well-structured learning activities, facilitating peer discussions, and providing ongoing guidance as students navigate their exploration of STEM subjects. In addition, the study points to the potential impact of scientific uncertainty as a stress factor for first-year STEM students, offering further insight into aspects of student well-being in higher education.

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Ethical Statement

All data used in this study were completely anonymised and cannot be reversed engineered to identify specific individuals.

Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contributions

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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