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Exploring peer facilitation and critical thinking in asynchronous online discussions: A lag sequential analysis approach

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Asynchronous online discussions (AODs) are increasingly prevalent in higher education to adapt to educational changes and promote critical thinking among learners. Past research has emphasized instructors' facilitation roles in encouraging learners' critical thinking in AODs, while fewer studies explored peer facilitation and peer participants' critical thinking from the students' perspective as facilitators. This study used a lag sequential analysis approach to examine peer facilitation techniques and critical thinking in a peer-facilitated AOD spanning six tasks over 12 weeks with 40 undergraduate participants. Results highlighted that the most frequently used peer facilitation techniques were *giving own opinions or experiences* and *questioning*, with the latter demonstrating the highest number of significant sequential patterns. Peer participants' critical thinking primarily involved *analyse* and *evaluate*, with significant sequential patterns observed in lower level and higher order critical thinking stages but not between them. Further investigation revealed the impact of peer facilitation techniques on critical thinking, and a new three-phase model was developed to describe their associations. These findings suggest that dynamic peer facilitation techniques effectively enhance critical thinking, with specific techniques targeting distinct phases of its development in AODs. The study provides actionable insights for educators, offering strategies to optimize facilitation approaches and foster critical thinking skills in higher education settings.

KEYWORDS
asynchronous online discussion, critical thinking, lag sequential analysis, peer facilitation techniques

Practitioner notes

What is already known about this topic

- Asynchronous online discussions are widely used in higher education to encourage learners' critical thinking.
- Instructors as facilitators play a positive role in encouraging learners' critical thinking in asynchronous online discussions, while the role of peer facilitators is less discussed.
- In peer-facilitated asynchronous online discussions, the facilitation techniques used by peer facilitators affect the development of critical thinking in peer participants.

What this paper adds

- Uses lag sequential analysis to examine the sequential patterns of peer facilitation techniques and critical thinking in peer-facilitated asynchronous online discussions.
- Reports common peer facilitation techniques used by peer facilitators and observed significant sequential patterns.
- Presents the distribution and developmental sequential patterns of critical thinking in peer participants.
- Examines the association between peer facilitation techniques and critical thinking, and develops a new three-phase model to describe this association.

Implications for practice and/or policy

- Dynamic peer facilitation techniques can effectively promote the development of critical thinking in peer participants, with specific relationships existing between different phases of critical thinking and different types of peer facilitation techniques.
- This study reveals the facilitation of critical thinking in asynchronous online discussions from the perspective of learners as facilitators, filling a research gap.
- The findings provide practical guidance for effectively encouraging critical thinking among college students in higher education.

INTRODUCTION

In the post-pandemic era, online learning has become the new norm in higher education, significantly changing the traditional pedagogical approaches (Azorín & Fullan, 2022; Salas Pilco et al., 2022; Sidi et al., 2023). Innovative approaches such as blended teaching, flipped classroom and adaptive teaching promote student-centred learning (Divjak et al., 2022; Gallagher et al., 2022; Yang et al., 2022). Asynchronous online discussions (AODs) are crucial in these approaches, enhancing student engagement and online interactions (Guo et al., 2022; Wu & Ouyang, 2024). Previous research showed that active AODs significantly enhance college students' online interaction and improve their knowledge construction ability from a social constructivist perspective (Koszalka et al., 2021). Moreover, AOD facilitates the creation of a collaborative learning environment without geographical location and time constraints, thus allowing learners to engage in meaningful exchanges and share diverse

perspectives (Hsu & Shiue, 2017). Given these characteristics of AODs, it has potential advantages in promoting students' implicit higher order thinking skills, such as critical thinking, which is becoming a topic of concern among researchers.

Critical thinking is a form of reflective thinking that establishes a clear logical relationship between facts and theories (Zhan, 2021). In the 21st century, critical thinking often refers to students' ability to reason, question assumptions and engage in reflective analysis, which has become a crucial skill for innovation in higher education and professional settings (González-Pérez & Ramírez-Montoya, 2022). Consequently, cultivating critical thinking is now a primary goal in higher education. Evidence shows that AODs effectively encourage critical thinking in college students (Afify, 2019; Jiang et al., 2023; Klisc et al., 2017). The two main advantages are as follows: (1) AODs provide a platform for social interaction among students without time and distance constraints; and (2) AODs encourage students to critically reflect on their ideas with their peers (Hew & Cheung, 2008; Jeong & Chiu, 2020).

Although AODs are used to encourage college students' critical thinking, their effectiveness has weakened due to the lack of guidance and feedback from instructors, uninspiring discussion tasks and monotonous content, resulting in low engagement and superficial discussion threads (Hew, 2015). To address these issues, researchers have advocated for instructors to act as facilitators in AODs, providing guidance and feedback to keep discussions on track (Ari et al., 2022; Lee, 2020; Oh et al., 2018). However, some scholars argue that instructor involvement may be perceived as authoritative and deter higher order thinking (Correia & Baran, 2010; Hew, 2015). In contrast, research has shown that when students assume the role of facilitators in peer learning processes in AODs, both engagement levels and discussion quality significantly improve (Chan et al., 2009; Veranika, 2017; Xie et al., 2017). Peer learning, as defined by Noroozi and Wever (2023), is a process in which peers gain knowledge and skills through mutual support and the exchange of ideas, involving activities such as written or oral interactions, peer assessment, collaboration and feedback among peers. While peer learning has demonstrated positive outcomes, it is not without its challenges. Common issues include unequal participation, lack of structure, difficulties in peer assessment and variations in the levels of peer competence (Hoo et al., 2021; Topping, 2005). Such challenges can impede the overall effectiveness of peer learning, as students may struggle to engage meaningfully or may lack confidence in their peers' ability to guide the learning process (Doyle, 2008). To address these challenges, the concept of peer facilitation has emerged as a valuable solution. Peer facilitation refers to a structured role where one or more students take on the responsibility of guiding and managing group discussions, ensuring that all participants engage in meaningful dialogue and supporting the development of critical thinking (Croft & Lozada, 2020). In this model, peer facilitators actively guide discussions, set the tone and encourage participation, providing a scaffolded environment that helps peers reflect and critique ideas in more depth (Hew, 2015; Lin et al., 2021). Assigning the peer facilitation role in learning groups in AODs helps to create a sense of ownership and responsibility among students, improving engagement and the overall quality of the discussion. Furthermore, the success of peer-facilitated AODs depends on the techniques used by peer facilitators, which attract active participation and encourage critical thinking (Hew, 2015; Hew & Cheung, 2008; Lin et al., 2021).

Recent studies have investigated the development of college students' critical thinking in AODs, highlighting that online interaction patterns significantly affect participation and discussion threads (Bai et al., 2022; Chen et al., 2024). These studies emphasize the impact of online interaction sequential patterns of participants on critical thinking, especially the sequential patterns of peer facilitation techniques. However, few have examined the associations between peer facilitation techniques and critical thinking in peer-facilitated AODs from learners' perspectives. This research aims to investigate college students' peer facilitation and critical thinking in AODs, focusing on the sequential patterns of peer facilitation

techniques and critical thinking development in peer-facilitated AODs. This study contributes by (1) examining the associations between peer facilitation techniques and critical thinking, filling a research gap, and (2) revealing the impact mechanisms through which peer facilitation promotes critical thinking, offering practical guidance for higher education.

LITERATURE REVIEW

Critical thinking

Definition of critical thinking

Critical thinking is widely recognized as a crucial educational objective in higher education. However, its definition remains ambiguous due to its complexity and dynamic nature (Liu & Pásztor, 2022). Levy (2009) defined critical thinking in psychology as an active, systematic strategy for examining, evaluating and understanding events, solving problems and making decisions based on sound reasoning and evidence. Educators view it as a problem-solving skill aiding learners in analysing information and making objective judgements without pre-prepared procedures (Mafarja & Zulnaidi, 2022). In philosophy, Dewey (1933) described 'reflective thinking' as active, persistent and careful consideration of beliefs based on supporting grounds and their conclusions. This concept is widely regarded as a cornerstone of critical thinking (Farahian et al., 2021; Orakçı, 2021). Despite showing differences across various fields, all definitions of critical thinking emphasize the importance of cognitive skills and strategies for informed decision-making, problem-solving and analytical thinking (Cruz et al., 2021; Shaw et al., 2020). In the current study, critical thinking is defined as an ability to reason logically, question assumptions, evaluate evidence and engage in reflective analysis to make informed judgements and decisions.

Due to the variations in the definitions of critical thinking across fields, the components of critical thinking skills have also been described from diverse perspectives (Liu & Pásztor, 2022). Watson (1980) proposed five indicators, namely, *reasoning*, *identification*, *deduction*, *explanation* and *argument*, that represent critical thinking skills based on the argument that critical thinking comprises attitude, knowledge and skills. According to Facione (1990), the American Philosophical Association reported six components of critical thinking skills, namely, *interpretation*, *analysis*, *evaluation*, *inference*, *explanation* and *self-regulation*. These components have become crucial in the development of instruments for measuring critical thinking in psychology, such as the California Critical Thinking Skills Test. Additionally, the cognitive presence in the Community of Inquiry model summarized four consecutive components, namely, *triggering event*, *exploration*, *integration* and *resolution*, to represent the critical thinking skills of learners, that is, their ability to construct and confirm meaning (Garrison et al., 2001).

Critical thinking in AODs

AODs have gained increasing popularity in higher education as a means of promoting active learning and student engagement, which can lead to critical thinking (Galikyan & Admiraal, 2019; Heilporn et al., 2021). The existing literature has produced ample evidence showing that instructional support from instructors played a crucial role in promoting students' critical thinking in AODs. The following points have been identified from the literature: (1) The design of online discussion tasks, such as discussion topics (Wang & Woo, 2010), discussion strategies (Zhang et al., 2024), group size and role assignment (Luo et al., 2023;

Zhang et al., 2023) and discussion duration (Hew & Cheung, 2011); (2) the scaffolding provided by instructors, such as relevant information and prompts for discussion (Klisc et al., 2012) and questioning to facilitate the discussion (Yang et al., 2013); and (3) the direct support provided by instructors, such as instant evaluation and feedback on the online discussion (Karaoglan Yilmaz & Yilmaz, 2019). Related studies suggest that AODs are learner-centred learning activities, where students' engagement and discussion threads can significantly influence their critical thinking (Bai et al., 2022; Dascalu et al., 2021). Foo and Quek (2019) summarized the following focal points from the literature that may impact the development of learners' critical thinking in AODs: (1) peer interaction styles (Jeong, 2003); (2) peer feedback and comments (Szabo & Schwartz, 2011); and (3) peer facilitation techniques (Lim et al., 2011) and the number of peer facilitators (Thormann et al., 2013).

The identification and measurement of critical thinking in AODs are primarily achieved through a content analysis of discussion posts. The critical thinking analysis models used for content analysis are developed based on the characteristics of online learning environments and the participants' behavioural performance. For instance, Henri (1992) proposed a cognitive-based critical thinking analysis model for identifying and measuring learners' critical thinking in online collaborative learning environments. This model, which includes *participative*, *social*, *interactive*, *cognitive* and *metacognitive* elements, has been widely used in previous research as a critical thinking encoding scheme for online learning content analysis (Garrison & Arbaugh, 2007). Inspired by previous research, Murphy (2004) developed a five-process coding scheme that encompasses *recognize*, *understand*, *analyse*, *evaluate* and *create* and explains the phase of learners' critical thinking development in AODs.

Peer facilitation

Peer facilitation in AODs

Peer facilitation, also known as peer learning (Ashwin, 2003) or peer tutoring (Goodlad & Hirst, 1989), is a process in which students support and guide one another through collaborative activities (Chen et al., 2019). During this process, students take on the role of peer facilitators, who assist the peer participants in acquiring knowledge, solving problems and developing critical thinking skills (Croft & Lozada, 2020). In this study, peer facilitation involves assigning one or more students the structured role of guiding and managing group discussions. Previous studies have reported the positive effects of using peer facilitation in teaching and learning. For example, in a 6-week speech course study, the experimental group using peer tutoring (30 participants) showed significant improvements in success, speech self-efficacy and speaking skills compared to the control group with teacher-centred instruction (27 participants) (Uzuner Yurt & Aktaş, 2016). When learners act as peer facilitators, they not only assist their peers but also reinforce their understanding of the subject matter by explaining concepts (Tanga & Luggya, 2022). These approaches offer opportunities for learners to actively engage with the subject matter, exchange ideas, negotiate meaning and solve problems together (Gedamu & Shewangezaw, 2022).

Recent studies have shown that AODs present an opportunity to enhance learners' construction knowledge levels and foster deeper collaborative learning (Koszalka et al., 2021; Ye & Pennisi, 2022). Therefore, investigating the effects of peer facilitation on students' thinking and learning is necessary. Literature reveals the impact of peer facilitation in AODs on learners' learning behaviours and metacognition. For example, Baran and Correia (2009) pointed out that peer facilitation can promote meaningful dialogues to encourage a high level of participation in AODs. Xie et al. (2014) claimed that students demonstrated significant improvements in their participation level when they were assigned as peer facilitators. In addition, studies

have supported the positive correlations between peer facilitation and higher order cognitive and thinking processes. Ghadirian et al. (2018) investigated the distribution and patterns of discussion behaviours among 84 undergraduate students engaged in a peer-facilitated AOD by conducting a quantitative content analysis and a lag sequential analysis revealing the underlying connection between peer facilitation and higher order cognitive processes among college students. Oh et al. (2018) analysed online discussions using the cognitive presence framework and social network analysis, revealing that peer facilitation significantly enhances learners' critical thinking and collaborative discourse in open-ended tasks.

Peer facilitation techniques

Peer facilitation techniques play crucial roles in promoting interaction and knowledge construction in AODs (Ng et al., 2012). Over the past few years, several studies have delved into the facilitation techniques employed by peer facilitators. Hew and Cheung (2008) summarized seven peer facilitation techniques, namely, *giving own opinions or experiences*, *questioning*, *showing appreciation*, *establishing ground rules*, *suggesting new direction*, *personally inviting people to contribute* and *summarizing*, that encourage learner participation in AODs. Ng et al. (2012) identified two effective peer facilitation techniques, namely, *showing appreciation* and *considering others' viewpoints*, that encouraged the most online interactions. Chen et al. (2019) proposed six peer facilitation techniques, namely, *questioning*, *making clarification*, *promoting connection*, *summarizing and revoicing*, *providing information* and *using positive social cues*, to analyse the facilitation behaviours in online discussions. However, scholars have produced differing views on how these techniques further encourage learners' higher order thinking and cognition in peer-facilitated AODs. For example, Lim et al. (2011) found that *showing appreciation*, *questioning*, *expressing agreements* and *providing opinions or explanations* were common peer facilitation techniques in the top 30% of forums, termed the in-depth critical thinking group. Chen et al. (2019) found that there was no significant correlation between learners' cognitive presence and peer facilitation techniques, despite evidence of their link to higher order thinking.

Research questions

The limited empirical studies on the relationship between peer facilitation and critical thinking in peer-facilitated AODs highlight the need to understand how peer facilitation techniques impact critical thinking. This study aims to examine this by addressing three research questions:

RQ1: How do peer facilitators use peer facilitation techniques in peer-facilitated AODs?
RQ2: What critical thinking development characteristics do peer participants demonstrate from the perspective of peer facilitation techniques?
RQ3: How do peer facilitation techniques encourage critical thinking among peer participants in peer-facilitated AODs?

METHODOLOGY

Participants and context

A total of 40 undergraduate students from a Chinese university majoring in Electronic Information Engineering and Technology participated in this study. The sample included

14 males and 26 females with an average age of 19.10 years ($SD = 0.59$, range: 18–20 years). All participants were enrolled in the fall semester of 2020 and participated in a blended teaching course entitled *Information Science and Technology with Society* during the spring semester of 2021. Additionally, although the participants had prior experience with online learning during school closures caused by the COVID-19 pandemic in the preceding year, the majority of their exposure was limited to synchronous online lectures with live chat features, rather than AODs. Before their involvement in the study, all participants were informed about the experimental procedures and materials, which were reviewed and approved by the IRB of the university where the authors were affiliated. Subsequently, participants signed a written informed consent. Participation was entirely voluntary; participants had the freedom to withdraw from the study at any point without consequence. Anonymity of personal data was assured, and the research adhered strictly to institutional and international ethical standards for studies involving human participants. Gender differences were not considered significant based on Artino and Jones' (2012) findings on peer interactions in online discussions. Therefore, the potential impacts of different genders were not considered in this study.

The *Information Science and Technology with Society* course was developed for undergraduate students majoring in Electronic Information Engineering and Technology, and its primary objectives were to acquaint students with the forefront of information science and technology and to foster their critical thinking by discussing the relationship between information technology and society. According to the university calendar and course schedule, this 32-hour course consisted of nine chapters and was intended to be completed over 16 teaching weeks from 2nd of March to 20th of June. To effectively cultivate critical thinking among the students, blended learning was implemented in this course. Specifically, the course was hosted on the university's learning management system, known as the StarC Cloud Classroom (http://spoc.ccnu.edu.cn). During face-to-face classroom lectures, the instructor primarily focused on delivering the course content. Meanwhile, online learning was specifically structured in the form of peer-facilitated asynchronous online discussions with the aim of encouraging students' critical thinking and deepening their comprehension of the course materials.

Research design and procedures

The research design and procedures are illustrated in Figure 1. During the first week of classes, all 40 enrolled undergraduate students were informed about the experiment and participated voluntarily. They were then randomly assigned to six groups, with four groups comprising seven students and two groups comprising six students each. The decision to form groups of six or seven students was based on two considerations. First, Luo et al. (2023) found that small groups (14 members or fewer) in AODs achieve higher task standards due to better coordination, despite similar participation levels compared to medium-sized groups (range from 15 to 34 members). Second, limiting group size ensured equitable rotation of the peer facilitation role across six discussion tasks, maintaining both fairness and discussion quality. These participants then attended training sessions to learn how to use peer facilitation techniques effectively in their online discussions as peer facilitators. During the second and third weeks, the course introduction and key concepts were delivered through face-to-face classroom lectures. No discussion tasks were assigned yet. From the 4th week until the 15th week, six discussion tasks related to the course were posted on the notice board of the StarC Cloud Classroom, with each discussion task having a 2-week duration. The 2-week duration for each discussion task was set to give students ample time for reflection, meaningful engagement and thoughtful responses (Foo & Quek, 2019), while also aligning efficiently with the semester schedule to ensure the completion of all six discussion tasks.

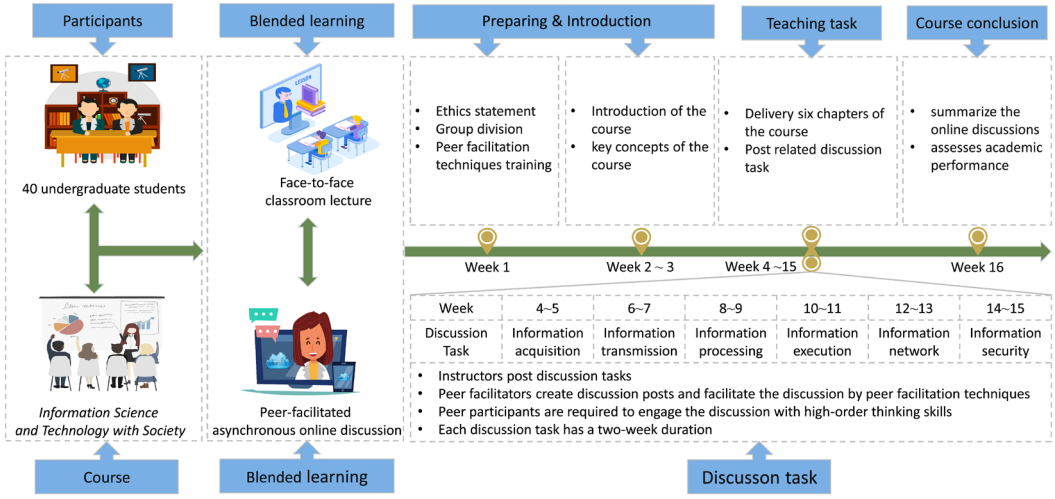

FIGURE 1 Research design and procedures.

For each discussion task, peer facilitators were randomly selected from each group, and those who had previously served as peer facilitators were excluded from this selection process to ensure that each group had a different facilitator for each task, thereby mitigating potential biases or confounding variables arising from individual differences in these facilitators' personal characteristics, styles or approaches. The designated peer facilitator for each group was required to post the discussion question for their respective group on the discussion board following the notification. These peer facilitators were also expected to employ the appropriate peer facilitation techniques to guide the entire discussion thread. All other group peer participants were encouraged to actively participate in the discussion by applying their higher order thinking skills. In the 16th week, the instructor summarised the online discussions and assessed the academic performance of the students.

During the asynchronous online discussions spanning from weeks 4 to 15, the role of the instructor was limited to posting discussion tasks, designating peer facilitators for each group and posting announcements on the notice board. The instructor did not interfere with any of the discussion threads. All discussion posts generated from the six discussion tasks were stored in the form of log files in the StarC Cloud Classroom database.

Data collection and coding scheme

Discussion posts from the six AOD tasks were collected for investigating peer facilitation techniques and critical thinking. Figure 2 illustrates the data collection process. First, log files were exported from the StarC Cloud Classroom's database, and then, discussion posts were extracted and organized into an Excel file by discussion thread sequence. Next, all discussion posts were segregated into two distinct datasets: posts authored by peer facilitators and posts authored by peer participants, to enable an individual content analysis for each dataset. Pandas and NumPy were used for data cleaning due to HTML tags and special symbols in the discussion posts. Processed data were categorized into peer-facilitated and critical thinking discussion posts, saved in Excel based on temporal order. A total of 1097 posts were collected, including 344 peer-facilitated discussion posts and 753 critical thinking discussion posts. Table 1 presents descriptive statistics of the number of discussion posts in six discussion tasks.

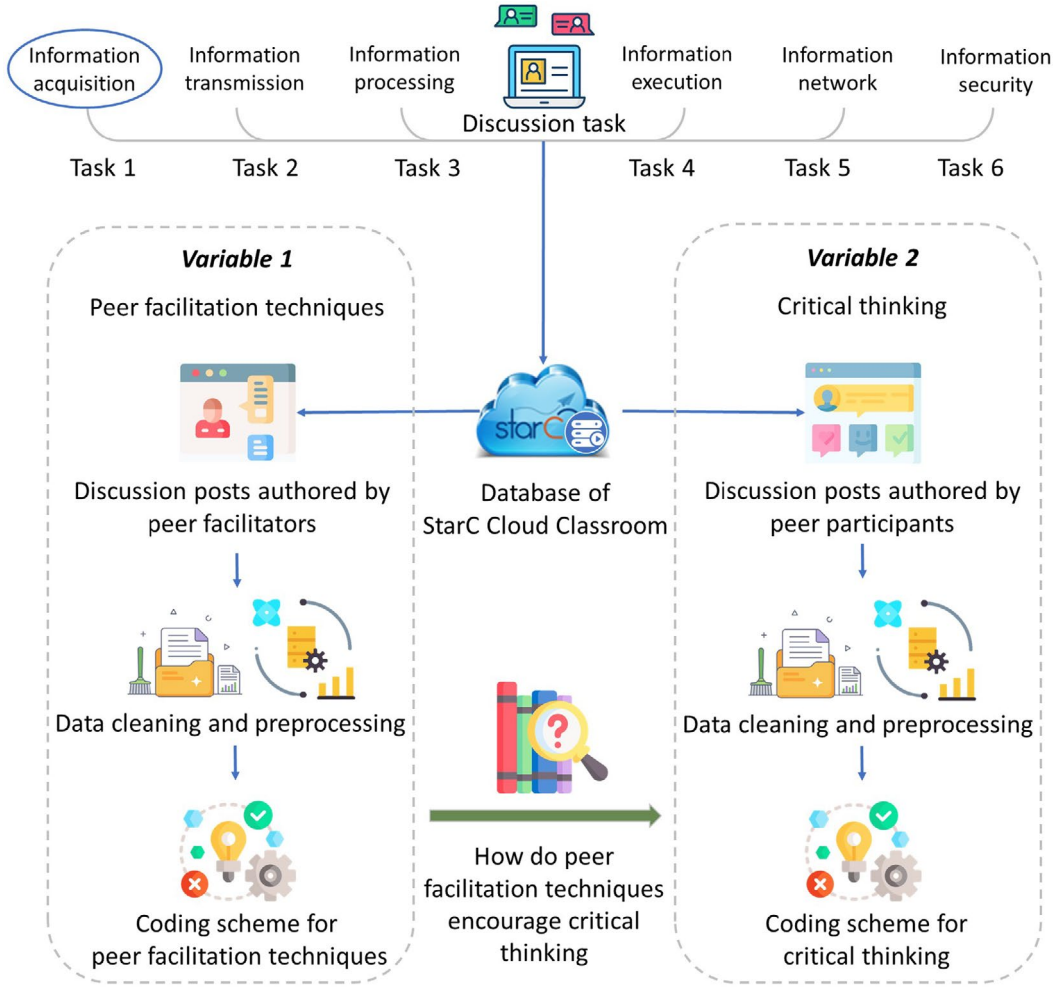

FIGURE 2 Data collection process.

To analyse peer facilitation techniques, the seven peer facilitation techniques proposed by Hew and Cheung (2008) were used as coding schemes for peer-facilitated discussion posts. However, these schemes did not cover all the techniques observed, so an additional coding indicator *other technique* was introduced. This indicator did not include irrelevant discussion posts that did not reflect any peer facilitation techniques because these irrelevant posts were already removed during the data preprocessing. The final coding scheme included eight indicators, as shown in Table 2. Peer participants' critical thinking was evident in their discussion posts, and Murphy's (2004) coding scheme for critical thinking, which includes five indicators, was used to examine these characteristics. Definitions are detailed in Table 3.

Data analysis

This study employed three main data analysis methods and procedures. First, content analysis was used to code peer-facilitated and critical thinking discussion posts using predefined coding schemes. Frequencies of peer facilitation techniques and critical thinking indicators

TABLE 1 Descriptive statistics of the number of discussion posts in six discussion tasks.

	Information acquisition		Information transmission		Information processing		Information execution		Information network		Information security		
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	Total
Group 1													
PF-P	14	7.8	8	4.5	8	4.6	12	6.5	6	3.2	11	5.7	185
CT-P	18	10.0	18	10.1	18	10.3	24	12.9	23	12.4	25	13.0	
Group 2													
PF-P	9	5.0	9	5.1	9	5.1	9	4.8	10	5.4	8	4.1	174
CT-P	17	9.4	23	12.9	15	8.6	21	11.3	23	12.4	21	10.9	
Group 3													
PF-P	9	5.0	10	5.6	10	5.7	9	4.8	9	4.9	7	3.6	185
CT-P	24	13.3	19	10.7	26	14.9	19	10.2	18	9.7	25	13.0	
Group 4													
PF-P	11	6.1	11	6.2	9	5.1	11	5.9	13	7.0	7	3.6	192
CT-P	22	12.2	19	10.7	24	13.7	18	9.7	16	8.6	31	16.1	
Group 5													
PF-P	10	5.6	9	5.1	11	6.3	11	5.9	9	4.9	11	5.7	182
CT-P	20	11.1	22	12.4	18	10.3	24	12.9	24	13.0	13	6.7	
Group 6													
PF-P	8	4.4	7	3.9	10	5.7	9	4.8	11	5.9	9	4.7	179
CT-P	18	10.0	23	12.9	17	9.7	19	10.2	23	12.4	25	13.0	
Total	180	100	178	100	175	100	186	100	185	100	193	100	1097

Abbreviations: CT-P, critical thinking discussion post; PF-P, peer-facilitated discussion post.

TABLE 2 Coding scheme for peer facilitation techniques.

Indicator	Coding	Description
Giving own opinions or experiences	T1	Personal opinions or experiences about an issue or topic
Questioning	T2	Asks for other students' opinions or experiences about an issue or topic and ask for clarification or elaboration about an idea or issue
Showing appreciation	T3	Offering thanks for some action, posting
Establishing ground rules	T4	Setting expectations of desired online behaviour
Suggesting new direction	T5	Proposing a different area for potential discussion
Inviting people to contribute	T6	Encouraging particular people to post
Summarizing	T7	Giving a short synopsis of what has been discussed so far
Other techniques	T8	Being not fully represented in the former seven techniques

TABLE 3 Critical thinking coding scheme (Murphy, 2004).

Indicator	Coding	Descriptor
Recognize	R	Recognizing or identifying an existent issue, dilemma, problem, etc.
Understand	U	Exploring related evidence, knowledge, research, information and perspectives
Analyse	A	Seeking in-depth clarification, organizing known information, identifying unknown information, and dissecting the issue, dilemma or problem into its fundamental components
Evaluate	E	Critiquing and judging information, knowledge or perspectives
Create	C	Producing new knowledge, perspectives or strategies, and implementing them or acting on them

across six discussion tasks were calculated based on these coding results. Second, lag sequential analysis, a method widely used to explore the temporal dynamics of behavioural interactions, was conducted to uncover sequential patterns between peer facilitation techniques and critical thinking. The lag sequential analysis method identifies statistically significant sequences by analysing the likelihood of one behaviour following another within a given time lag, providing insights into interactional patterns and their underlying structures (Bakeman & Gottman, 1997). GSEQ was used to compute *Z*-scores, highlighting the significant sequential relationships observed in AODs. Lastly, a chi-squared test was employed to examine associations between peer facilitation techniques and critical thinking, drawing conclusions from the results of lag sequential analysis.

RESULTS

Usage and sequential patterns of peer facilitation techniques

All 344 peer-facilitated discussion posts from six discussion tasks were thoroughly coded and analysed, as shown in Figure 3. The distribution of peer facilitation techniques across these tasks was consistent. *Questioning* (T2) was the most frequently used technique, with counts ranging from 12 to 22 posts per task. *Giving own opinions or experiences* (T1) followed with counts ranging from 8 to 10 posts per task. *Suggesting new direction* (T5) and *inviting people to contribute* (T6) were the least employed techniques, with counts ranging

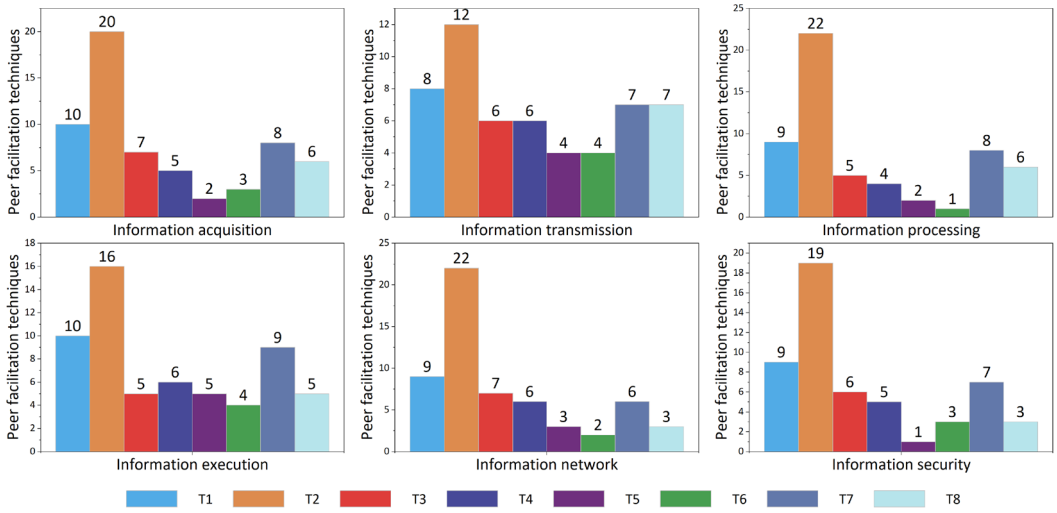

FIGURE 3 Numerical statistics of peer facilitation techniques used in six discussion tasks.

from 1 to 5 posts for *Suggesting new direction* (T5) and from 1 to 4 posts for *inviting people to contribute* (T6) across tasks.

Lag sequential analysis was conducted to further investigate the sequential patterns of peer facilitation techniques in peer-facilitated AODs, involving the calculation of transition frequencies and an adjusted residual table (Table 4). In this table, columns represent the initial application of peer facilitation techniques, while rows represent the subsequent applications. Sequences with a *Z*-score of the adjusted residual greater than 1.96 (*Z*-score >1.96) are statistically significant. Ten significant sequences were identified: *giving own opinions or experiences* (T1)→*questioning* (T2), *questioning* (T2)→*giving own opinions or experiences* (T1), *questioning* (T2)→*showing appreciation* (T3), *showing appreciation* (T3)→*questioning* (T2), *showing appreciation* (T3)→*inviting people to contribute* (T6), *showing appreciation* (T3)→*summarizing* (T7), *establishing ground rules* (T4)→*questioning* (T2), *suggesting new direction* (T5)→*summarizing* (T7), *summarizing* (T7)→*suggesting new direction* (T5) and *other techniques* (T8)→*other techniques* (T8). A sequence pattern diagram was created based on these sequences (Figure 4), with nodes representing peer facilitation techniques, connecting lines indicating significant transitions, arrows showing direction and line thickness representing *Z*-score magnitude.

Critical thinking in peer-facilitated AODs

All 753 critical thinking discussion posts were analysed using Murphy's (2004) coding scheme. Figure 5 provides a summary of the descriptive statistics for critical thinking coding across six discussion tasks. *Analyse* (A) consistently had the highest frequency across all tasks, with counts of 35, 45, 44, 45, 41 and 54. Following analyse (A), *evaluate* (E) had counts of 22, 33, 30, 36, 34 and 33. *Recognise* (R) posts were the least frequent, with counts of 11, 5, 11, 8, 10 and 6. Overall, the majority of critical thinking posts focused on *analyse* (A, 35.1%) and *evaluate* (E, 25.0%), with a noticeable increase in these levels throughout the discussion tasks. *Recognise* (R, 6.8%) posts were less frequent and decreased as the tasks progressed.

The five indicators of Murphy's (2004) coding scheme represent the progressive development of critical thinking. To examine the changes and sequential patterns of critical thinking

TABLE 4 Results of the sequential analysis of peer facilitation techniques (adjusted residuals table).

Z-score	T1	T2	T3	T4	T5	T6	T7	T8
T1	−1.62	**2.18***	0.45	0.5	−0.21	−0.48	−0.21	−1.39
T2	**2.88***	−0.20	**2.11***	−0.45	0.24	−2.12	−1.58	0.26
T3	0.04	**2.96***	−2.2	−0.67	−0.84	**4.39***	**3.83***	0.05
T4	0.74	**3.92***	−0.34	−0.65	−0.76	−0.51	−1.86	0.18
T5	−0.21	−1.93	0.28	−0.54	−0.39	−1.15	**2.39***	1.57
T6	0.20	−1.95	0.68	−1.98	−0.16	−1.03	−0.41	−2.05
T7	−1.51	0.77	0.19	−0.56	**3.07***	−0.21	−0.84	−0.81
T8	−0.86	1.37	−0.34	−0.65	−0.76	−1.16	−0.23	**2.05***

*$p < 0.05$; Bold values, significant adjusted residuals.

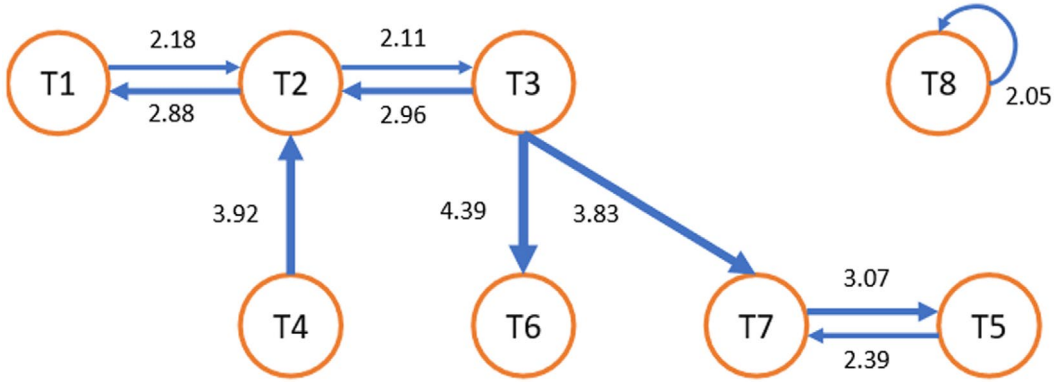

FIGURE 4 Sequential patterns of peer facilitation techniques.

in peer-facilitated AODs, a lag sequential analysis was performed on the coded results of 753 critical thinking discussion posts across six discussion tasks. Table 5 presents the adjusted residual table of critical thinking sequential analysis generated based on the coding transition frequencies. Seven significant sequences with adjusted *Z*-scores greater than 1.96 were reported, namely, *recognize* (R)→*recognize* (R), *recognize* (R)→*understand* (U), *understand* (U)→*recognize* (R), *understand* (U)→*understand* (U), *analyse* (A)→*evaluate* (E), *evaluate* (E)→*create* (C), *create* (C)→*create* (C). Figure 6 presents the sequence pattern diagram of critical thinking in all discussion tasks and reveals the characteristics of critical thinking development in peer-facilitated AODs.

Associations between peer facilitation techniques and critical thinking

In this study, discussion posts were analysed in temporal order to collect critical thinking encodings for each peer participant. Figure 7 shows the frequencies and distribution of critical thinking within the context of peer facilitation techniques. *Questioning* (T2) encouraged more diverse and frequent critical thinking, while *establishing ground rules* (T4) did not. Furthermore, *analyse* (A) appeared frequently in *giving own opinions or experiences* (T1) and *questioning* (T2), and *evaluate* (E) showed similar results. *Analyse* (A), which represents the lowest level of critical thinking, showed minimal distribution across all peer facilitation

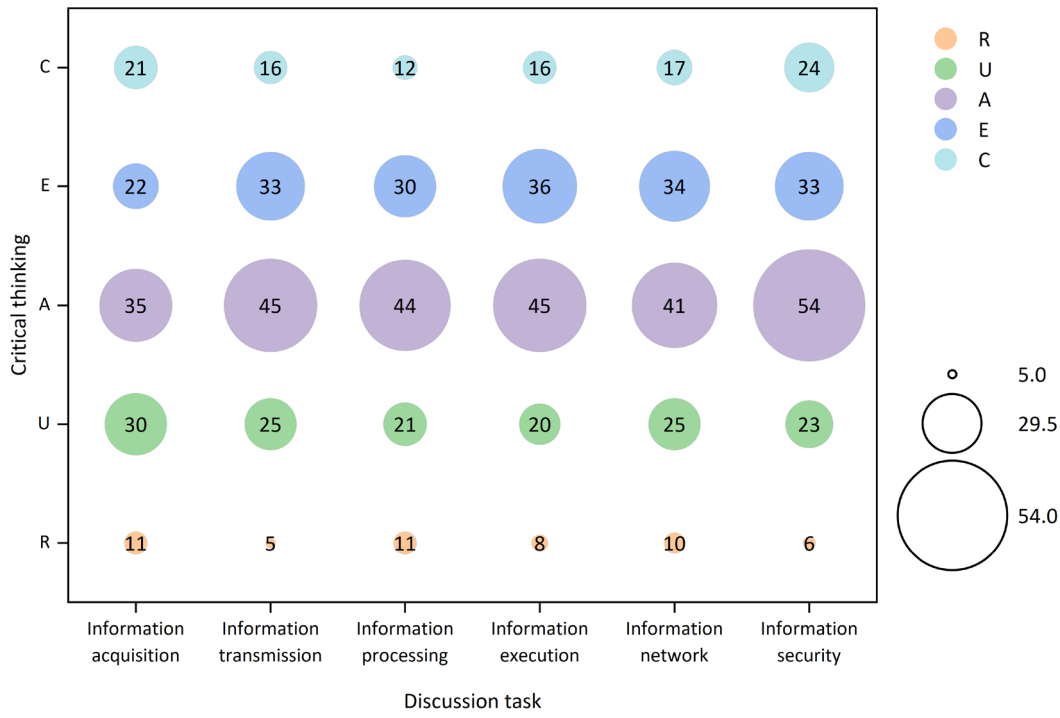

FIGURE 5 Numerical statistics of critical thinking in six discussion tasks.

TABLE 5 Results of the sequential analysis of critical thinking (adjusted residuals table).

Z-score	*R*	U	A	E	C
R	**4.75***	**3.02***	−0.73	−3.02	−1.81
U	**1.97***	**8.09***	−0.06	−5.13	−3.69
A	−0.68	−4.16	1.59	**6.01***	−5.05
E	−2.98	−2.9	−2.56	−0.46	**7.34***
C	−1.14	−2.27	−4.8	−3.52	**14.02***

*$p < 0.05$; Bold values, significant adjusted residuals.

techniques, except for *summarising* (T7). Conversely, *create* (C), which represents the highest level of critical thinking, was most frequently observed in *questioning* (T2), followed by *giving own opinions or experiences* (T1). Interestingly, higher levels of *create* (C) were observed in the limited statistical quantities of *suggesting new direction* (T5) and *inviting people to contribute* (T6).

A chi-squared test was conducted to investigate the associations between peer facilitation techniques and critical thinking. Table 6 shows the standardized residuals and correlations of different categories within peer facilitation techniques and critical thinking. *Giving own opinions or experiences* (T1) and *suggesting new direction* (T5) were strongly linked with *evaluate* (E); *questioning* (T2) was significantly correlated with *create* (C); *showing appreciation* (T3) and *other techniques* (T8) were closely related to *analyse* (A); *establishing ground rules* (T4) was directly associated with *recognize* (R); *inviting people to contribute* (T6) was significantly connected to *understand* (U); and *summarizing* (T7) showed a high level of significance with *recognize* (R) and *understand* (U). All of these associations are presented in Figure 8.

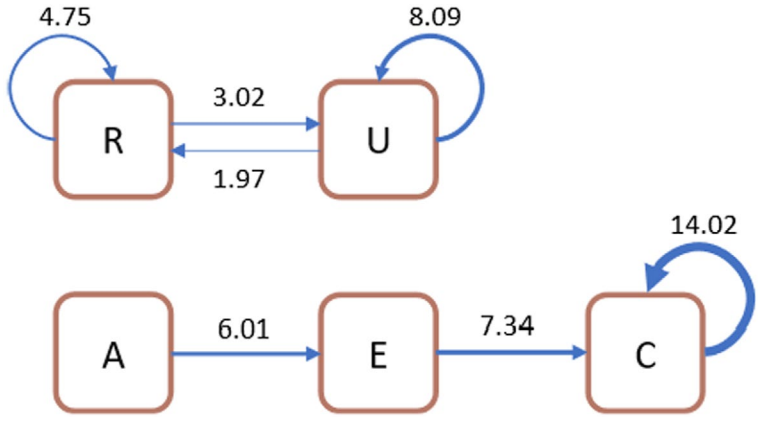

FIGURE 6 Sequential patterns of critical thinking.

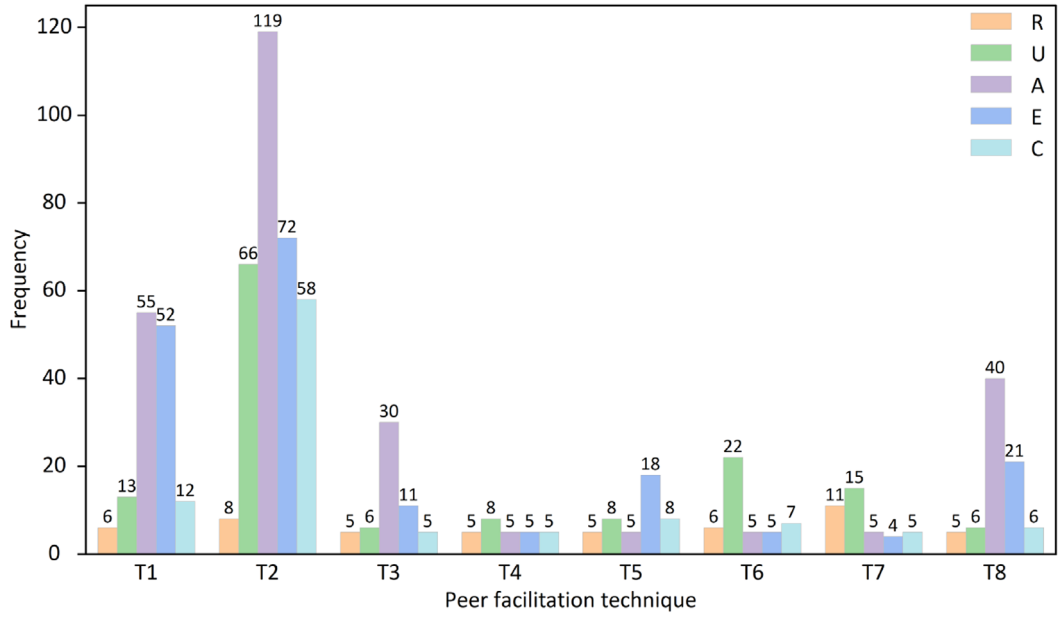

FIGURE 7 Frequency statistics of critical thinking in peer facilitation techniques.

DISCUSSION

Patterns of dynamic peer facilitation techniques

This study initially examined the overall situation and sequential patterns of peer facilitation techniques in peer-facilitated AODs. *Giving own opinions or experiences* (T1) and *questioning* (T2) were the most frequently employed peer facilitation techniques. This finding aligns with previous research (Hew & Cheung, 2008; Lim et al., 2011), which emphasizes the significance of questioning and personal engagement in facilitating meaningful AODs. Peer facilitators sustain AODs by effectively using *giving own opinions or experiences* (T1) to share prior knowledge or personal experiences, acting as scaffolds for participants (Chen et al., 2019). *Questioning* (T2) encourages active participation, stimulates critical

TABLE 6 Chi-squared analysis results of the peer facilitation techniques with critical thinking (standardized residuals table).

Critical thinking						
		R	U	A	E	C
Peer facilitation techniques	T1	−1.10	−2.60	1.00	**3.00***	−1.70
	T2	−3.00	0.50	0.50	−1.00	**1.90***
	T3	0.60	−1.50	**2.20***	−0.90	−1.10
	T4	**2.30***	1.10	−1.50	−0.80	0.50
	T5	1.20	−0.10	−2.70	**2.10***	0.70
	T6	1.70	**4.60***	−2.70	−1.90	0.30
	T7	**5.00***	**2.70***	−2.40	−1.90	−0.30
	T8	−0.10	−2.30	**2.40***	0.30	−1.50

*$p < 0.05$; Bold values, significant standardized residuals.

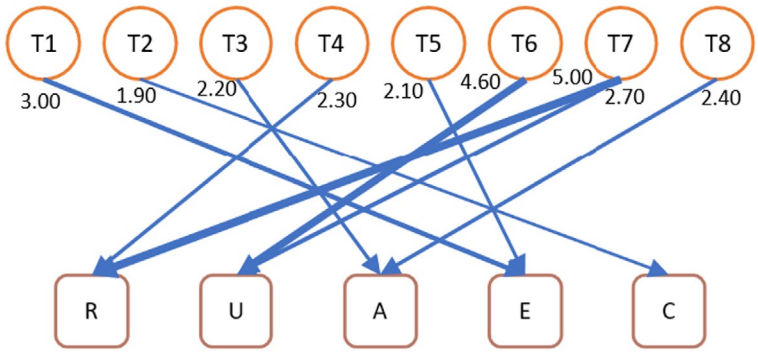

FIGURE 8 Transition diagram of critical thinking with peer facilitation techniques.

thinking and promotes deeper reflections among participants (Elder & Paul, 1998). In addition, Hew and Cheung (2008) reported that *establishing ground rules* (T4) and *summarizing* (T7) were identified as the least frequently used peer facilitation techniques in graduate student online discussions. Contrary to their findings, this study suggested that peer facilitators rarely employed *suggesting new direction* (T5) and *inviting people to contribute* (T6) to lead discussion threads. Moon, McNeill, et al.'s (2024) use of sequence mining techniques provides a valuable lens for understanding why certain techniques may emerge less frequently. According to their findings, participants' sequential patterns often reflect their immediate cognitive focus or task familiarity. In this study, undergraduate students may lack the confidence or experience needed to effectively implement advanced techniques like *suggesting new direction* (T5) or *inviting people to contribute* (T6). These patterns highlight the importance of targeted training to build proficiency in underutilized facilitation techniques.

Moon, Yeo, et al. (2024) highlighted the significance of epistemic framing in collaborative peer learning environments, noting that structured contributions like *questioning* (T2) help guide discussions and connect participants' inputs to broader learning objectives. In analysing the sequential patterns of peer facilitation techniques in this study, 10 significant sequential patterns were identified, with *questioning* (T2) appearing in five of these, underscoring its critical role in peer-facilitated AODs. First,

establishing ground rules (T4) → *questioning* (T2) highlights *questioning* (T2) as pivotal in guiding participants' contribution of postings. The primary objective of *establishing ground rules* (T4) is to foster a mutually respectful online discussion environment and prevent procrastination (Hew et al., 2010). Research indicated a mutually respectful online discussion environment can encourage participants to contribute more knowledge, ideas and opinions (McLure et al., 2000). Peer facilitators use *questioning* (T2) to guide peer participants in asking questions or sharing their viewpoints freely on specific issues without concerns of derogatory or disrespectful language. Second, *giving own opinions or experiences* (T1) → *questioning* (T2), *showing appreciation* (T3) → *questioning* (T2), *questioning* (T2) → *giving own opinions or experiences* (T1) and *questioning* (T2) → *showing appreciation* (T3) emphasize the essential role of *questioning* (T2) in leading the depth of discussion threads. *Giving own opinions or experiences* (T1) and *showing appreciation* (T3) keep the discussion going and make the peer participants feel at ease during the discussions (Hew & Cheung, 2008). When peer facilitators further organize the discussions, they tend to use *questioning* (T2) as their core technique to encourage the peer participants to express or clarify their opinions and use *giving own opinions or experiences* (T1) and *showing appreciation* (T3) to enhance the depth of discussion threads. Additionally, *showing appreciation* (T3) → *inviting people to contribute* (T6) and *showing appreciation* (T3) → *summarizing* (T7) illustrate the essential role of *showing appreciation* (T3) in creating positive social cues. These cues are established when peer facilitators adopt *showing appreciation* (T3) to express their gratitude or praise and to encourage silent peer participants to contribute more posts. Several studies suggest that positive social cues benefit online environments (Chen et al., 2012; Chen & Chiu, 2008; Cho & Kwon, 2015). However, expressing gratitude and compliments as social cues becomes ineffective when peer facilitators use *showing appreciation* (T3) without highlighting the contributions of the peer participants' discussion posts (Hew & Cheung, 2011). Further research is needed to understand the role of showing appreciation (T3) in facilitating positive peer interactions in AODs. *Other techniques* (T8) → *other techniques* (T8) suggests that peer facilitators face difficulties in returning to the existing techniques when using *other techniques* (T8). Such difficulties highlight the challenges that peer facilitators may encounter when selecting the most suitable technique for specific contexts and underscore their need for additional practical experience to enhance their proficiency in using these techniques. In conclusion, Moon, McNeill, et al. (2024) demonstrated that structured interaction sequences, particularly those involving argumentation and justification, play a pivotal role in co-constructing knowledge during peer learning. Our findings align with this observation, as peer facilitation techniques often prompted sequences that encouraged reflective and critical dialogue. By examining these recurring patterns, our study reinforces the value of structured guidance in shaping productive learning environments.

Development of critical thinking in peer-facilitated AODs

Peer participants' critical thinking in peer-facilitated AODs primarily fell in *analyse* (A) and *evaluate* (E). This finding contrasts the conclusions of Zhang et al. (2023), who found that participants' critical thinking in online discussions mainly stayed at *understand* (U). This disparity reflects the significant advantage of peer-facilitated AODs in promoting learners' critical thinking. Moreover, as the discussion tasks progressed, an upward trend in *analyse* (A) and *evaluate* (E) became evident, while a corresponding decline in *recognize* (R) was reported. One possible explanation for this trend is the gradual accumulation of course-related knowledge by peer participants. As they engage more deeply with the course and

discussion topics, they become more adept and well-versed, enabling them to use higher order critical thinking skills in discussions.

The study revealed two key findings regarding the sequential patterns of critical thinking indicators. First, *recognize* (R) and *understand* (U) serve as foundational stages for higher order critical thinking skills. This result ties well with Murphy (2004). The four significant sequential patterns like *recognize* (R)→*understand* (U), *understand* (U)→*recognize* (R), *recognize* (R)→*recognize* (R) and *understand* (U)→*understand* (U) indicate active participation by peer participants in discussions to comprehensively grasp ongoing tasks, laying the groundwork for deeper exploration and development of higher order critical thinking skills. Second, sequential patterns like *analyse* (A)→*evaluate* (E), *evaluate* (E)→*create* (C) and *create* (C)→*create* (C) suggest that as critical thinking progresses to the *analyse* (A) stage, higher order skills such as *evaluate* (E) and *create* (C) are increasingly fostered through deeper discussion threads. Participants engage in analysing and evaluating evidence, contributing to academic interaction and knowledge construction, thereby enhancing their critical thinking depth (McKenna et al., 2022). However, significant sequential patterns between *recognize* (R) or *understand* (U) and higher stages of critical thinking were not observed, highlighting the need for further investigation into methods that promote higher level critical thinking from initial stages.

Critical thinking with regard to dynamic peer facilitation techniques

Peer facilitation techniques significantly correlated with critical thinking development in peer-facilitated AODs. Specifically, the early stage of critical thinking, such as *recognize* (R) and *understand* (U), was notably influenced by positive social cues set by peer facilitators (eg, *establishing ground rules* (T4)→*recognize* (R), *summarizing* (T7)→*understand* (U)). Advanced stages of critical thinking, including *analyse* (A), *evaluate* (E) and *create* (C), were significantly correlated with deep discussion threads led by peer facilitators (eg, *showing appreciation* (T3)→*analyse* (A), *giving own opinions or experiences* (T1)→evaluate (E), *questioning* (T2)→*create* (C)). These findings hold practical implications for enhancing critical thinking through peer facilitation in AODs. For example, *establishing ground rules* (T4) can foster a positive discussion environment, encouraging participants to freely express their views and develop *recognize* (R) skills. Using *questioning* (T2) strategically prompts participants to think critically and develop *create* (C) skills. Notably, effective peer facilitation involves adapting techniques dynamically to support the diverse critical thinking abilities of participants.

In Hew and Cheung's (2008) study, all seven peer facilitation techniques were categorized into introduction, engagement and monitoring phases. However, they did not explore the specific connections among these phases. This study addressed this gap by linking the introduction and engagement phases through *establishing ground rules* (T4)→*questioning* (T2), and linking the engagement and monitoring phases through *showing appreciation* (T3)→*inviting people to contribute* (T6) and *showing appreciation* (T3)→*summarizing* (T7). A new three-phase model was developed to describe these connections and their impact on critical thinking in peer-facilitated AODs (see Figure 9). This model illustrates a cyclic pattern where critical thinking varies with changes in peer facilitation techniques across phases. Previous research indicated that learners' online discussion interactions exhibit a cyclic nature (Huang et al., 2022). In this study, similar critical thinking indicators were observed in the introduction and monitoring phases (*establishing ground rules* (T4)→*recognize* (R), *summarizing* (T7)→*recognize* (R)). However, significant sequential patterns of peer facilitation techniques between these phases were not found. Future research should explore these interphase connections further.

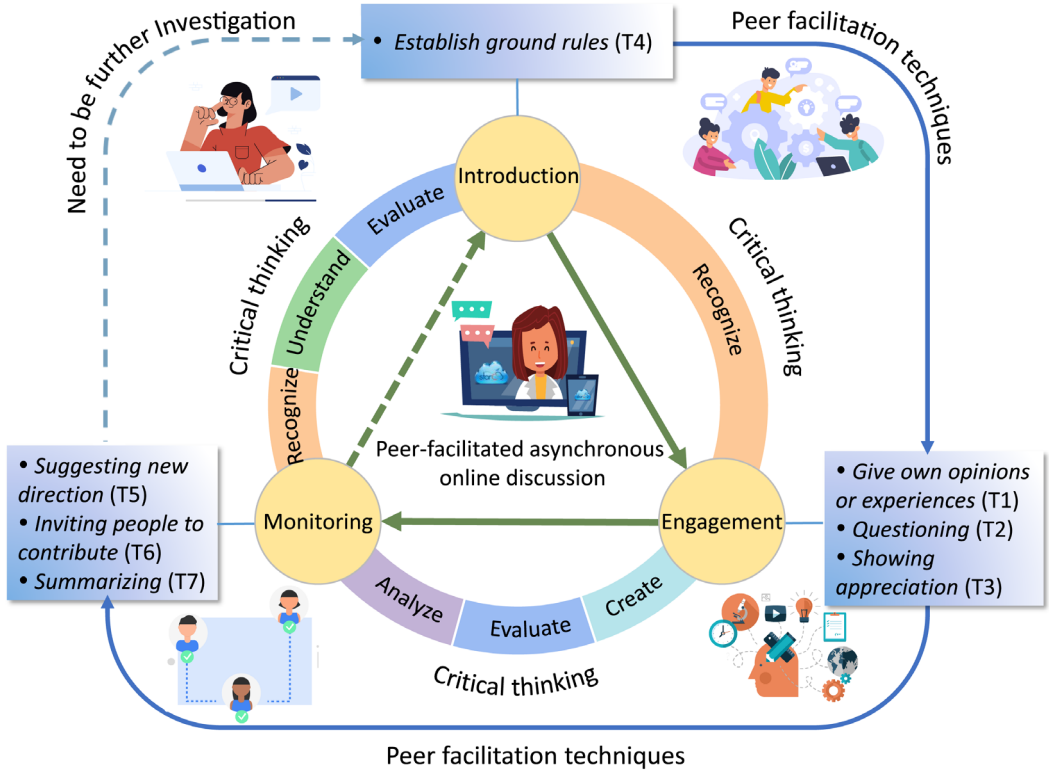

FIGURE 9 New three-phase model for describing the association between peer facilitation techniques and critical thinking in peer-facilitated AODs.

CONCLUSIONS, LIMITATIONS AND FUTURE WORK

This study investigated peer facilitation techniques and critical thinking in AODs. The main findings are as follows: (1) The most common peer facilitation techniques in AODs are *giving own opinions or experiences* (T1) and *questioning* (T2), with the least common being *suggesting new direction* (T5) and *inviting people to contribute* (T6). *Questioning* (T2) is particularly dynamic, appearing in 5 of the 10 significant sequence patterns; (2) critical thinking in peer-facilitated AODs is mainly distributed in *analyse* (A) and *evaluate* (E). Lower stages of critical thinking show growth in *recognize* (R) and *understand* (U), while higher stages progress from *analyse* (A) to *create* (C); (3) the findings of the chi-squared test suggest that peer facilitation techniques significantly influence critical thinking, and a new three-stage model is developed to explain their relationship. These findings indicate that dynamic peer facilitation techniques effectively promote critical thinking and reveal specific relationships between different phases of critical thinking and peer facilitation techniques. This study offers several theoretical and practical contributions. From a theoretical perspective, this study explored the sequential patterns of dynamic peer facilitation techniques in AODs and their impact on the development of critical thinking among peer learners, addressing a significant gap in peer learning research. Meanwhile, the study developed a new three-phase model to explain the relationship between peer facilitation techniques and critical thinking, extending the theoretical framework of prior research. From a practical perspective, the findings of this study highlighted the importance of strategies such as *questioning* (T2), *showing appreciation* (T3), and others in sustaining meaningful AODs, providing actionable insights for effectively guiding students in the use of facilitation techniques. Furthermore, the study offered recommendations for developing targeted

training programmes for peer facilitators, aimed at enhancing their skills in creating positive social cues and facilitating deeper, more meaningful discussions.

However, this study also has some limitations that need to be addressed in future work. First, all participants were undergraduate students with limited cognitive abilities, making it challenging for them to create positive social cues and deep discussions as peer facilitators. Second, time constraints prevented participants from fully understanding peer facilitation techniques despite pre-training. Third, the contextual and course-specific nature of the study limits the generalisability of the findings, necessitating more comprehensive future studies. Additionally, this study did not consider potential gender-related differences in dynamic peer facilitation and critical thinking. Prior research suggests that males and females may process and provide feedback differently in peer learning settings, which could influence their effectiveness as facilitators (Banihashem et al., 2023; Latifi et al., 2020). Future studies could explore these gender-based variations to provide deeper insights into their impact on peer interactions and critical thinking development. Moreover, the absence of a control group without peer facilitators makes it difficult to isolate the specific effects of peer facilitation on critical thinking. Including such a control group in future research could provide a clearer understanding of the added value of peer facilitation compared to unguided peer learning environments. Finally, this study did not examine the differences in learning outcomes between students who served as peer facilitators and those who did not. Investigating these differences could help determine how taking on the facilitation role influences individual learning and development. Future research should explore whether and how the act of facilitating discussions enhances cognitive skills, engagement and overall learning compared to simply participating in discussions. Addressing these limitations in future studies would provide a more nuanced understanding of the mechanisms and impacts of peer facilitation in asynchronous online discussions.

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CONFLICT OF INTEREST STATEMENT

There is no potential conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

This study was conducted in accordance with the ethical standards of the Helsinki Declaration. Ethical approval for the study was granted by the Institutional Review Board (IRB) of the university where the researchers were affiliated.

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