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Using learning analytics to explore peer learning patterns in asynchronous gamified environments

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Abstract

This study explored the dynamics of students' knowledge co-construction in an asynchronous gamified environment in higher education, focusing on peer discussions in college business courses. Utilizing epistemic network analysis, sequence pattern mining, and automated coding, we analyzed the interactions of 1,319 business students. Our findings revealed that externalization and epistemic activity were prevalent, demonstrating a strong link between problem-solving and conceptual understanding. Three primary discussion types were observed: argumentative, epistemic, and social, each with unique patterns of engagement and idea integration. Effective knowledge co-construction patterns included open-ended questions with an epistemic focus, debates serving as intense knowledge co-construction arenas, and social interactions fostering a supportive and collaborative learning environment. The introduction of gamification elements led to increased student engagement and participation. Our findings emphasize the significance of structured analysis, collaboration, and argumentation in promoting effective knowledge co-construction in peer learning settings. This study offers insights into the temporal interplay of discourse dimensions and their potential for collaborative learning, enhancing our understanding of how learning analytics can be employed to discover ways in which students co-construct knowledge in asynchronous gamified environments.

Keywords: Asynchronous gamified environments, Business education, Epistemic network analysis, Knowledge co-construction, Learning analytics, Peer learning

Introduction

In the field of higher education, asynchronous gamified environments have revolutionized pedagogical approaches, profoundly shifting how knowledge is constructed, delivered, and elaborated through learner interactions (Ding, 2019; Ding et al., 2020). These environments enable students to build their knowledge while enhancing group engagement with peers and learning material (Areed et al., 2021; Featherstone & Habgood, 2019). This dynamic is particularly salient in business education, where students engage deeply with complex challenges, develop critical thinking skills, collaborate on ideas, and apply theory to practice (Monat et al., 2020). The diverse professional backgrounds of business students enrich the discourses, adding depth to peer interactions (Benjamin & O'Reilly, 2011; Cheng, 2000).

Integrating peer learning into asynchronous gamified environments creates a synergistic opportunity to enrich the learning experiences of business students. It enables them to exchange diverse perspectives on complex problems and decision-making in business contexts, aligning well with the collaborative nature of the business sector (Johnson et al., 2007; Stahl et al., 2006). With this consideration, it becomes evident that integrating asynchronous gamified environments in conjunction with a peer learning and interaction approach is a key factor in fostering effective business education. This strategy also closely aligns with the collaborative nature of the business world, where professionals must interact and co-construct knowledge (Dancer et al., 2015; Glen et al., 2015; Guldberg, 2008; Phusavat et al., 2019).

Peer learning in synchronous learning environments has been widely explored (Altınay, 2017; Cheng et al., 2022; Dillenbourg, 1999; Kapur et al., 2008). Despite the extensive exploration of peer learning within asynchronous gamified environments, its specific focus on college business students remains underexplored (Antonaci et al., 2015). In addition, learning analytics, though valuable for studying peer learning in digital settings like gamified environments, has not been widely used in college business courses (Banihashem et al., 2023a, 2023b; Huang et al., 2019). This study accordingly aims to bridge the gap by leveraging learning analytics techniques—epistemic network analysis and sequence pattern mining—to explore interaction dynamics among college business students in asynchronous gamified environments. By identifying interaction patterns, the study seeks to enhance understanding of how learners engage in knowledge co-construction in this context.

Literature review

Asynchronous gamified environments

Asynchronous learning enables learners to engage with course material and discussions without real-time interactions. This can pose challenges for both instructors and learners due to the absence of real-time interaction and limited social presence (Martin et al., 2022; Kehrwald, 2008; Woo & Reeves, 2008). Simultaneously, asynchronous learning offers benefits such as scheduling flexibility and increased time for reflection (Gacs et al., 2020). The demand for asynchronous learning surged significantly during the COVID-19 pandemic (Magda et al., 2020), causing a shift toward online education and the exploration of blended synchronous/asynchronous models (Banihashem et al., 2023a, 2023b; Watts, 2022).

The literature suggests that incorporating gamification elements like—points, badges, leaderboards, and quests—in asynchronous learning environments, termed "asynchronous gamified environments," can enhance student engagement and motivation (Subhash & Cudney, 2018). However, while these gamified environments show the potential to increase motivation and connection with the learning material, theimpact on learning outcomes is mixed (Subhash & Cudney, 2018). Critics argue that asynchronous gamified environments may oversimplify learning and risk extrinsic motivators overshadowing intrinsic interest (Dichev & Dicheva, 2017).

Recent years have witnessed a surge in incorporating asynchronous gamified environments into higher education, particularly in business education (Craven, 2015; Durrani et al., 2022; Skritsovali, 2023), aiming to balance flexibility for working professionals with engagement (Kurucay & Inan, 2017). However, effective implementation of these techniques requires accommodating diverse student backgrounds and complex, often collaborative course objectives (Bellotti et al., 2013).

Knowledge co-construction in asynchronous gamified environments

Effective instructional design in asynchronous gamified environments often relies on discussion scaffolds, which are structured prompts or frameworks that guide learners' interactions and foster meaningful discussions, deeper understanding, critical thinking, and knowledge co-construction (Cho & Jonassen, 2002; Gao et al., 2013; Zhu & Simon, 1987; Xun & Land, 2004). Several types of discussion scaffolds, such as question prompts (Davis et al., 1995), sentence starters (Nussbaum et al., 2002), and collaboration scripts (Kollar et al., 2006), can enhance interaction quality, promote higher-order thinking, and facilitate knowledge co-construction (Latifi et al., 2023). However, the effectiveness of discussion scaffolds may depend on factors such as their design, learners' prior knowledge, and task nature (Demetriadis et al., 2008; Xun & Land, 2004). In business education, discussion scaffolds are crucial for promoting collaborative decision-making skills (Öztok, 2016; Woo & Reeves, 2008). These skills are vital for future business leaders, as they enable them to effectively analyze complex problems, consider diverse perspectives, and approach well-informed decisions. By providing a structured discussion framework, scaffolds help students develop the critical thinking and communication abilities necessary to succeed in today's fast-paced, global business environment.

Knowledge co-construction involves learners collaboratively building understanding, sharing insights, and creating knowledge through social interactions (Scardamalia & Bereiter, 2014; Hull, & Saxon, 2009). In online settings, digital scaffolds like shared workspaces facilitate this process (Lei et al., 2022). Successful knowledge co-construction requires support from educators and technological approaches, such as learning analytics (e.g., Gunawardena et al., 2016). For example, Liang et al. (2022) used learning analytics to structure peer learning groups algorithmically and deliver data-driven support for knowledge co-construction. Structured prompts and discussion scaffolds area also essential for effective knowledge co-construction in asynchronous online environments (Bayat et al., 2022; Cho & Schunn, 2007; Gao et al., 2023; Noroozi et al., 2013), fostering continuous discourse.

Insights from computer-supported collaborative learning (CSCL) can offer valuable assistance (Cress & Kimmerle, 2023; Calonge et al., 2019). Noroozi et al. (2012) and Weinberger and Fischer (2006) proposed frameworks for effective collaborative knowledge co-construction (Noroozi et al., 2012; 2018). Additional research suggests combining multiple modalities can enrich asynchronous exchanges (Gacs et al., 2020).

Effective knowledge co-construction, especially in business education, requires the thoughtful use of peer learning, collaborative strategies, and the integration of advanced technologies such as learning analytics. These tools enable deeper insights into students' knowledge co-construction (Banihashem et al., 2022; Gunawardena et al., 2016; Schneider & Pea, 2017; Schneider et al., 2018; Tong et al., 2023).

Peer learning and temporal dynamics of student discourse: the potential of learning analytics

In business education, peer learning, where students actively engage in collaborative learning processes, enhances learning outcomes by fostering critical thinking, teamwork, and problem-solving skills (Boud et al., 1999; Nelson & Schunn, 2009; Noroozi et al., 2023; Topping, 1998) This approach aligns with key goals in business education, including the development of critical thinking ability, teamwork skill, and solving complex problems (Dancer et al., 2015). Peer learning approaches can be implemented synchronously and asynchronously (Kerman et al., 2024; Valero Haro et al., 2023). Asynchronous peer learning involves learners' co-constructing knowledge without real-time discussion (Ding et al., 2018; Kerman et al., 2022), providing space for reflection and participation (Watts, 2016). For working professionals, peer exchanges enable the sharing of diverse perspectives on business problems (DeRue & Wellman, 2009).

While peer learning holds promise in business education, its effective implementation in asynchronous online settings poses challenges. In such settings, students may not be concurrently present during discussions or collaborative activities, hindering dynamic team interactions. This absence of simultaneous engagement can diminish the spontaneity and fluidity of communication compared to synchronous learning (Kurucay & Inan, 2017; Latifi et al., 2021; Valero Haro et al., 2023). Additional concerns for asynchronous peer learning in business education include accommodating diverse backgrounds, ensuring depth in online exchanges, and maintaining student accountability (Bellotti et al., 2013).

This drawback underscores the potential of learning analytics to support peer learning in business education. As peer learning can create rich peer discussions, exploring the temporal aspects of these discourses sheds light on how learners collectively advance through phases of knowledge co-construction over time in asynchronous online settings (Wise & Chiu, 2011). Leveraging earning analytics techniques, such as temporal analysis, epistemic network analysis, and social network analysis can reveal patterns in online exchanges, like increased integration of perspectives later in a discussion (Chen et al., 2018; Hou & Wu, 2011). Visualizing sequential relationships within peer dialogues also aids in understanding group cognition processes (Medina & Suthers, 2009).

Learning analytics techniques for exploring temporal dynamics in asynchronous discussions include threading discourse graphs to model reply relationships, utilizing learning analytics dashboards to assess real-time idea development, and employing epistemic network analysis to track connections between concepts (Misiejuk et al., 2021; Shaffer, 2017). Such tools move beyond static discourse analysis to uncover evolving patterns. A The use of learning analytics in business education help decipher how students co-construct knowledge with peers.

Framework and research questions

The present study applied Weinberger and Fischer's framework (2006) to examine the sequential interactions of knowledge co-construction dimensions over time. While historically used in computer-supported collaborative learning (CSCL) environments, we tailored this framework to capture the dynamic learning process in a business education context by analyzing asynchronous discussion data. This adaptation allowed us to observe how learners collaboratively construct knowledge in an asynchronous gamified environment. The framework examines four dimensions of collaborative discourse important in knowledge co-construction: externalization, epistemic activity, argumentation, and social interaction modes.

First, *externalization (EX)* typically refers to the process where individuals articulate or express their internal thoughts, knowledge, or cognitive processes into a form that is communicable and understandable to others, referring to ideations. For example, a student might share their personal experience or perspective on a business case study, externalizing their thoughts for others to engage with. Second, *social interactions (SOC)* dimension categorizes how learners build on each other's contributions, from externalization to integration and conflict-oriented consensus building. This shows the extent of transactive knowledge co-construction. An instance of social interaction could be students engaging in a debate, challenging each other's ideas, and working towards a shared understanding. Third, *Argumentation (ARG)* dimension examines how learners construct individual arguments and sequences of arguments. This reveals how they build lines of reasoning. A student presenting a claim supported by evidence from course materials would be an example of argumentation. Fourth, *epistemic activity (EP*) dimension analyzes if learners are on task, what epistemic activities they use to construct knowledge, and whether they apply concepts correctly. For instance, students might engage in epistemic activity by connecting course concepts to real-world business scenarios.

The Weinberger and Fischer (2006) framework uses hierarchical segmentation of the discourse into micro and macro levels, which enables the analysis of multiple dimensions of discourse by breaking it down into appropriate size segments Using this framework as a guideline, we crafted the following research questions:

(1) What sequential patterns emerge during peer discussions in asynchronous gamified environments?
(2) How are the sequential interaction patterns of peer discussions related to knowledge co-construction in asynchronous gamified environments?
(3) What patterns of peer discussions are most effective for knowledge co-construction in asynchronous gamified environments?

Methods

Study context and participants

This study took place at a university in the southeastern United States, involving 1,319 students enrolled in both undergraduate and graduate business courses. The students were enrolled in two courses, "Essentials of Financial Literacy" and "Accounting and Finance for Managers," each offered at multiple grade levels and twelve sections combined. These courses aimed to develop students' financial decision-making skills and managerial problem-solving abilities by teaching fundamental financial principles

(Gitman, 2018; Hillman, 2014). The specific content included financial literacy, accounting principles, managerial finance, and decision-making skills. The learning objectives were focused on developing students' ability to understand and apply fundamental financial concepts, analyze financial statements, make informed financial decisions, and solve complex business problems collaboratively. Business education often involves case studies, real-world examples, and practical applications, which may prompt students to draw upon their own experiences and knowledge when participating in discussions (Bridgman et al., 2019; Culpin & Scott, 2012). The relevance and familiarity of the content may make it easier for students to externalize their thoughts and contribute to discussions, as they relate to the course material on a personal level or through real-world examples (Harrington & Griffin, 1990).

Furthermore, the specific competencies and skills targeted in these courses, such as financial decision-making and managerial problem-solving, require active engagement with course content, application of concepts to real-world scenarios, and collaboration with peers (Biggs & Tang, 2011). The gamified learning environment in this study aims to support the development of these competencies by providing opportunities for students to engage with course material, share their perspectives, and learn from one another (Plass et al., 2015; Sheldon & Biddle, 1998). The study was conducted during the fall semester of 2022, after the peak of the COVID-19 pandemic. The courses were delivered in a fully online format. Students had access to additional communication channels, such as video conferencing tools (e.g., Zoom) and a learning management system (e.g., Canvas), which facilitated interactions beyond the asynchronous gamified environment. Despite additional channels that may influence the study outcomes, they are limited to influencing our findings for several reasons. First, the gamified discussion platform was the primary focus of this study, and students were encouraged to use it as the main channel for course-related communication and collaboration. Second, the learning management system served primarily as a repository for course materials and assignments, rather than a platform for student interaction. Video conferencing tools were used sparingly, for occasional synchronous sessions or office hours, and were not the primary means of communication for most students.

Incorporating gamification elements

We enhanced the learning experience by incorporating *ClassCred* into *Microsoft Teams*, thus developing communication tools that fostered an interactive and engaging learning environment. Gamification elements were integrated into the courses at the beginning of the Fall 2022 semester. The specific gamification features used included points, badges, leaderboards, and quests. Points were awarded for participation in discussions, completion of assignments, and performance on quizzes. Badges were given for achieving specific milestones, such as posting a certain number of comments or receiving a high rating from peers. *ClassCred* introduces gamification elements—rewards, polls, debates, announcements, and a peer reward system—into the educational process. Students could earn points and badges, redeem points in a class store, and participate in competitions. They were encouraged to take part in weekly online discussions on course-related topics, including homework. This setup facilitated valuable peer feedback and instruction (Banihashem et al., 2024). Moreover, the platform supported tracking

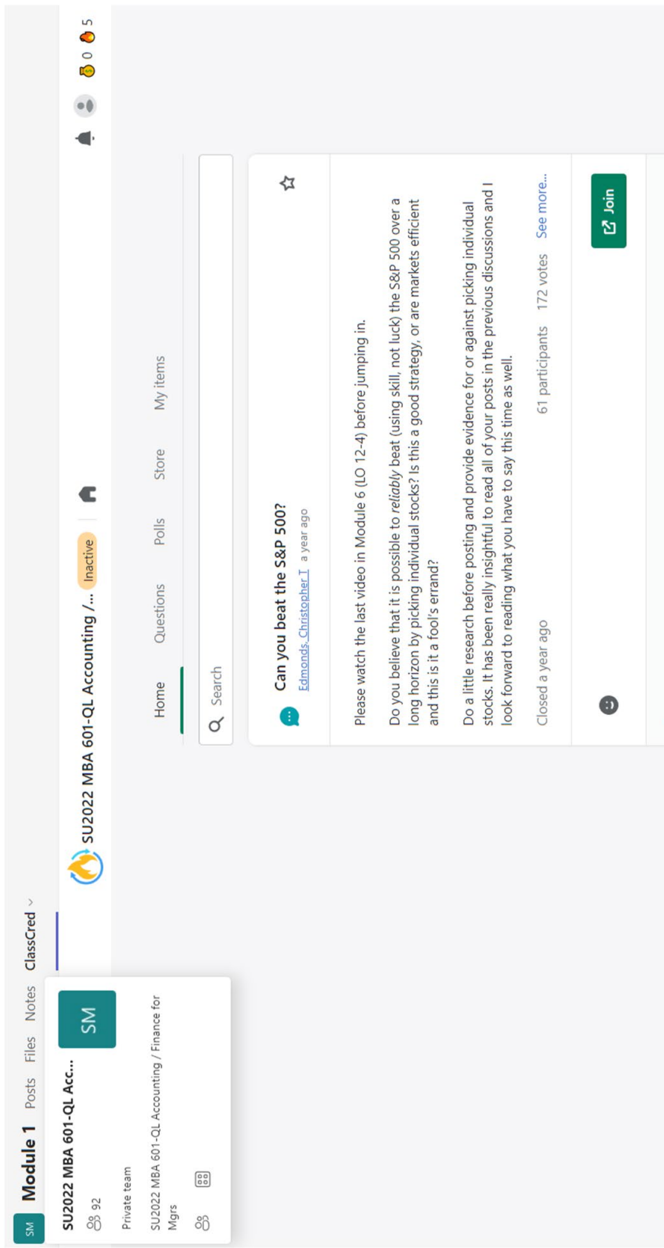

Fig. 1 Microsoft teams ClassCred interface

course questions and provided analytics for instructors, aimed at increasing student engagement, and optimizing workflows. The collected data included transcripts of asynchronous discussions, organized by timeframe-related information Fig. 1.

Research design

Our research adopted an explanatory mixed-method approach, as delineated by Guetterman & Fetters (2018), which merges qualitative and quantitative analyses to comprehensively investigate our research questions. Qualitative analysis involved coding discussion data using the designated framework, identifying patterns and themes related to knowledge co-construction. Quantitative analysis employed epistemic network analysis and sequence pattern mining to examine the structure and temporal dynamics of the discussion data. By combining both qualitative and quantitative approaches, we gained a holistic understanding of the complex interactions and processes in peer learning within the asynchronous gamified environment. This integrative methodology enabled a more nuanced comprehension of the data, harnessing the strengths of both analytical paradigms. We implemented three analytic approaches to answer the research questions: (a) epistemic network analysis, (b) sequence pattern mining with qualitative content analysis, and (c) automatic coding and reliability checking. Figure 2 shows the entire procedure of data analysis in this study.

Data and processing

The study collected raw group discussion data from students in an online forum, totaling 54,861 entries. Our analysis focused on 977 postings and 1,740 responses, which were selected based on the following criteria: (1) relevance to the course topics and learning objectives, (2) substantive content (i.e., excluding short or irrelevant posts), and (3) participation in meaningful interactions (i.e., part of a discussion thread with at least two participants). These criteria ensured that the data represented relevant discussion discourses aligned with course content and learning goals. Inclusion of these responses enabled examination of how students engaged with each other's ideas and collaboratively developed understanding of the course content. The average word count per post was approximately 36.66. We assessed relevance by determining the percentage of posts that remained on topic, utilizing keyword analysis for this purpose. We meticulously executed our data preprocessing and coding to ensure accuracy and ethical adherence. Our focus was on obtaining transcripts from learners' asynchronous discussions, resulting in a comprehensive dataset. During the preprocessing phase, we concentrated on enhancing quality and consistency. This involved converting text to lowercase, removing punctuation and numbers, tokenizing text, and applying stemming to distill words to their root forms. These steps were pivotal in normalizing the textual data for further analysis. The cornerstone of our analysis relied on classifying text data using a comprehensive coding scheme inspired by Weinberger and Fischer (2006). This scheme identifies discourses across four principal types: Participation, Epistemic Dimension, Argumentative Knowledge co-construction, and Social Mode, further subdivided into specific categories such as "Problem Space," "Argument," and "Elicitation."

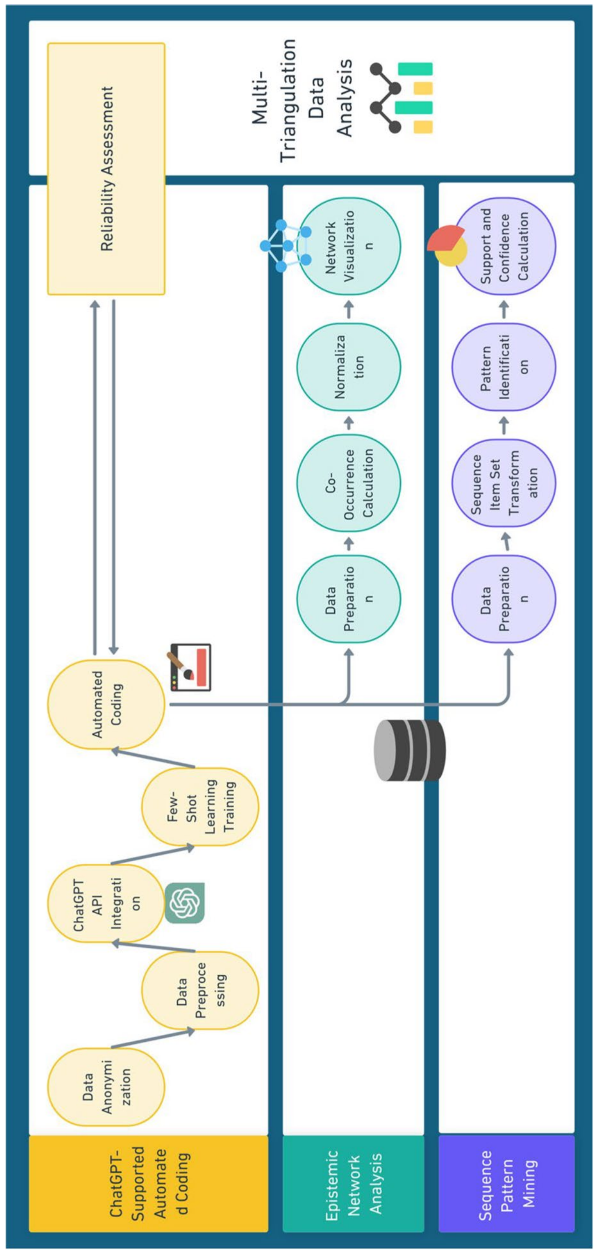

Fig. 2 Data analysis procedure

To classify the discourse, we utilized a blend of regular expressions and keyword matching techniques. Regular expressions helped identify patterns in the text corresponding to specific discourse categories. For example, the expression r'\b(I|we)\b.*\b(think|believe|consider)\b' captured instances of externalization, such as "I think" or "we believe." Keyword matching detected specific words or phrases indicative of discourse categories. For example, "problem," "issue," and "challenge" signaled discussions on problem space, while "concept," "theory," and "model" indicated conceptual space construction. Regular expressions and keywords for each discourse category were crafted based on the Weinberger and Fischer (2006) coding scheme definitions and examples. Manual validation involved reviewing a subset of 100 posts, comparing manual classifications with the automated results. Discrepancies were resolved through consensus, refining regular expressions and keyword iteratively.

Data processing utilized Python and libraries like NumPy, Pandas for data manipulation and visualization and preprocessing steps, including text cleaning, tokenization, and stemming. Regular expression-based classification and keyword matching were performed using Python. These tools and libraries were selected based on their efficiency and suitability for handling large text datasets and analyses.

Data analysis

Epistemic network analysis

We applied epistemic network analysis to dissect knowledge networks, emphasizing the interconnectivity of key concepts and individuals' or groups' knowledge acquisition processes (Shaffer et al., 2016). Utilizing the ENA (Epistemic Network Analysis) Web Tool, our analysis involved several steps. Initially, coded data was transformed into a matrix format, with rows representing discourse units (e.g., discussion posts) and columns representing codes or concepts. Binary values (1 or 0) indicated the presence or absence of each code in each discourse unit. Subsequently, co-occurrence of codes within a specified window size (e.g., within a moving window of 5 discourse units) was calculated to identify codes appearing together within the defined context. The resulting co-occurrence matrix was then normalized to adjust for differences in code frequencies. Finally, the normalized co-occurrence matrix was visualized as a network graph, with nodes representing codes and edges denoting the strength of co-occurrence between codes, determined by normalized values. Leveraging the coded data, we utilized concept mapping techniques to craft a visual depiction of the knowledge structure. In these maps, nodes represent concepts, while edges indicate the relationships between these concepts. We assessed the network's structure and dynamics, identifying central concepts, the tightness of the knowledge integration, and the presence of subgroups within the network.

Aligned with RQ2, we aimed to explore how and what knowledge co-construction emerged and evolved. Epistemic network analysis results illustrated the co-occurrence and connectivity of discourse elements related to knowledge co-construction, such as epistemic activities (e.g., problem space construction, conceptual space construction) and social interactions (e.g., consensus-building, argumentation). The presence of strong connections between these elements in the epistemic network indicate that the identified sequential patterns contribute to collaborative knowledge co-construction.

Sequence pattern mining

We utilized sequence pattern mining to uncover recurring patterns in student communication (Okolica et al., 2018), utilizing the Sequential Pattern Mining Framework (SPMF) software. This approach aimed to decode sequences of actions, revealing learners' experiences during cyclic collaborative interactions. Unlike Markov chain analysis, which primarily focuses on transitions between states, sequence pattern mining identifies common subsequences within the larger interaction sequence, spotlighting those that recur most frequently (Moon & Liu, 2019).

The analytical process involves transforming coded data into a sequence database, where each sequence represents a student's series of actions or discourse moves over time. Each action or move is represented by a unique identifier, such as a code or a combination of codes. Next, the algorithm is applied to the sequence database to identify frequent subsequences. It starts by finding frequent individual items (i.e., actions or moves), meeting the minimum support threshold and iteratively generates candidate sequences by joining frequent subsequences, pruning those not meeting the minimum support threshold. Support, calculated as the percentage of sequences containing the subsequence, guides the algorithm until no more frequent subsequences can be found. The resulting set of frequent subsequences represents the significant interaction patterns in the data.

For our analysis, we chose the Apriori algorithm, renowned for its efficacy in identifying frequent item sets consistently appearing together across transitions. Setting a support threshold at 0.10 ensured only sequences appearing at least 10% of the dataset were considered, which a minimum confidence level at 0.90 to include only transitions with a high likelihood of meaningful correlation. Through these stringent criteria, we aimed to isolate significant patterns providing deep insights into learning dynamics within collaborative environments. This analysis pinpointed specific sequences indicative of how students cyclically engage with each other and content.

Aligned with RQ3, our aim was to identify patterns of peer discussions most effective for knowledge co-construction in asynchronous gamified environments. To define success, we assessed the effectiveness of knowledge co-construction using the following criteria: (a) Depth of discussions (involve elaborate explanations, detailed reasoning, and critical analysis of ideas), (b) Relevance (e.g., number of replies, length of threads) and thematic consistency (i.e., staying on topic), and (c) Idea integration (synthesizing and extending the contributions of others, leading to the co-construction of new knowledge).

Automatic coding and reliability checking

We enhanced the methodological rigor with a tailored LLM tool, precisely aligned with the coding scheme for accurate categorization of textual data into predefined categories. Adhering to stringent guidelines for privacy and confidentiality, we initially anonymized student data by removing any identifying identifiers. Subsequently, we analyzed this data using a customized local application incorporating the ChatGPT API. To integrate the ChatGPT API into our application, we utilized the OpenAI API library in Python, providing a simple interface that sends requests to the ChatGPT model and receiving responses. We developed a custom Python script iterating through preprocessed student data, sending each piece of text to the ChatGPT API along with the relevant coding prompt. The API then returned the classified text, parsed in a structured format for further analysis.

After preprocessing the anonymized student data, we meticulously crafted a series of ChatGPT prompts comprising the coding scheme definitions and examples, providing clear instructions for the model to classify the text data into the appropriate categories. These prompts were strategically designed to facilitate the model's comprehension of the coding scheme, ensuring precise categorization. Leveraging a few-shot learning approach aligned with the current study's coding scheme, the model was trained to recognize patterns and classify text data with minimal supervision, thereby enhancing its accuracy and efficiency in handling diverse discourses.

To maintain the reliability of our automated coding process, we continuously monitored the program performance and fine-tuned the coding prompts as necessary, ensuring a consistently high level of accuracy throughout our analysis. We cross-checked and evaluated the data thoroughly. Through rigorous reliability assessments aligned with the coding framework, the researchers of the study aimed to reach 100% consensus.

To promote transparency and accountability, we retained a decision log that documented every step and adjustment, ensuring adherence to predetermined accuracy and reliability standards. Our approach capitalized on advanced natural language processing techniques, including few-shot learning, to facilitate a thorough and nuanced analysis of the textual data. We ensured operational independence and data security throughout the configuration of our program, aligning with ethical standards for data handling. This integration facilitated the seamless combination of a real-time, scalable application for qualitative data coding in academic research with ethical data practices. Finally, our research team internally validated the coding scheme and identified conversation patterns. The researchers independently and collaboratively examined portions of the coded data and identified patterns to reach consensus on thematic findings.

Results

Descriptive statistics

Descriptive statistics of the discourse dynamics in the asynchronous gamified environment provided essential context for our analysis and findings. We examined the frequency and nature of various social, argumentative, and exploratory constructs within this setting. Figure 3 reveals a distinct pattern across multiple discourse types, categorized into Epistemic (EP), Argumentative (ARG), and Social (SOC) dimensions. The x-axis represents the specific discourse types, while the y-axis indicates their frequency count. Each stacked bar visually breaks down the sub-categories within each dimension, such as 'Construction of Problem Space,' 'Construction of Conceptual Space,' and 'Construction of Adequate Relations' within the EP dimension. The percentage values on each sub-category illustrate their relative proportion within their respective dimensions, providing a clear view of the distribution and prominence of each discourse type. Table 1 shows the frequency and percentage of discourse dynamics observed in the asynchronous gamified environment.

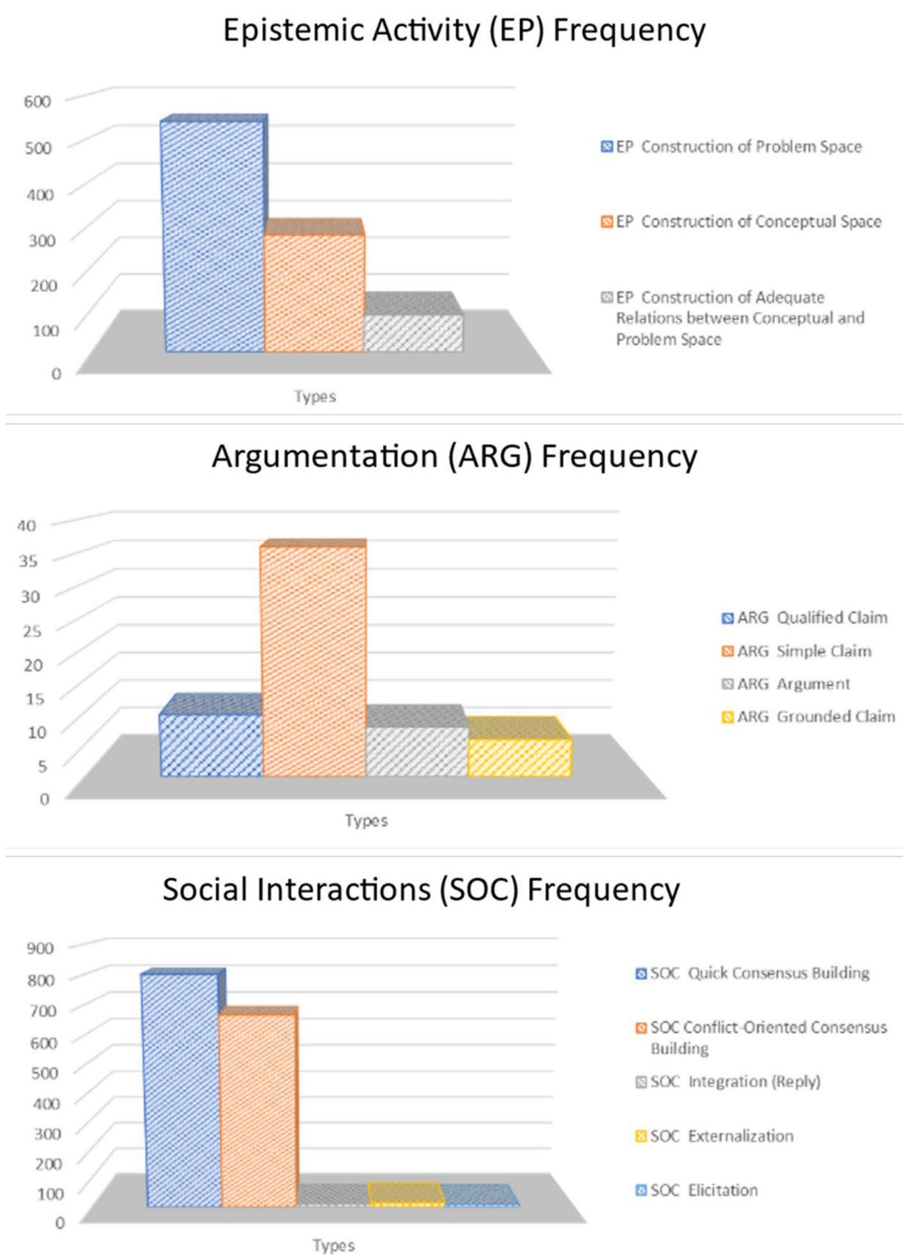

Fig. 3 Frequency distribution of students' discourse types across epistemic, argumentative, and social dimensions

Epistemic constructs

The epistemic dimension (EP) demonstrated a distinct pattern, with the Construction of Problem Space predominating at 542 occurrences (59.43%). This was followed by the Construction of Conceptual Space with 280 occurrences (30.70%), and the Construction of Adequate Relations between Conceptual and Problem Space noted 90 times (9.87%). This distribution suggests a discourse that prioritizes the definition and structuring of problems, at the expense of a more nuanced exploration of the relationships between problems and conceptual understanding. In sum, this detailed examination of discourse

Table 1 Frequency and percentage of different discourse types (e.g., epistemic, argumentative, and social)

Discourse Type	Sub-Category	Frequency	Percentage
Epistemic	Construction of Problem Space	542	59.43
	Construction of Conceptual Space	280	30.70
	Construction of Adequate Relations	90	9.87
Argumentative	Simple Claims	36	47.37
	Qualified Claims	10	13.16
	Arguments	8	10.53
	Grounded Claims	6	7.89
	Counter Arguments	4	5.26
	Other	12	15.79
Social	Quick Consensus Building	802	53.47
	Conflict-Oriented Consensus Building	666	44.40
	Integration (Reply)	10	0.67
	Externalization	14	0.93
	Elicitation	8	0.53

constructs provides valuable insights into the nature and dynamics of social, argumentative, and epistemic dimensions in a gamified online course.

Argumentation constructs

The analysis of Argumentation dimension (ARG) revealed a predilection for Simple Claims, which were noted 36 times (47.37%) of a total ARG-related instance. While Qualified Claims and Arguments were also present, with 10 (13.16%) and 8 (10.53%) occurrences respectively, they were less prevalent. This distribution suggests a discourse characterized by foundational argumentative structures rather than advanced or complex forms of argumentation. Grounded Claims and Counter Arguments, with six (7.89%) and four (5.26%) occurrences respectively, were infrequent, further supporting the notion of a discourse centered on basic levels of argumentative engagement.

Social constructs

Within the domain of SOC, activities centered on Quick Consensus Building, which manifested in 802 instances (53.47%), and Conflict-Oriented Consensus Building with 666 occurrences (44.4%), were predominant. This pattern underscores a pronounced emphasis on collaborative and integrative processes within the discourse, indicative of a learning environment where communal understanding and agreement are paramount. In contrast, other SOC constructs such as Integration (Reply), Externalization, and Elicitation were markedly less frequent, presenting only 10 (0.67%), 14 (0.93%), and eight (0.53%) occurrences, respectively. This suggests a more selective engagement with these aspects of discourse, indicative of specific contexts or stages within the broader educational dialogue.

Gamification support

The introduction of gamification elements like points, badges, and leaderboards in the college business courses led to a 15.09% increase in the number of posts and a 25.88%

increase in the average length of threads. However, it is important to note that due to the study design, these changes cannot be definitively attributed to gamification alone, as other factors such as course content, instructor guidance, and student dynamics may have also influenced participation levels. Specifically, threads featuring badge incentives saw a 22% increase in replies, suggesting a significant boost in engagement. Point-based leaderboards, particularly when enhanced with specific emojis, caused a 17% rise in daily active users, indicating the effectiveness of these strategies in tapping into intrinsic motivations for recognition and competition.

The strategic use of gamification, particularly points (mentioned 134 times), played a notable role in enhancing engagement and participation. While the direct impact on replies and idea integration was not quantifiable from the data, the frequent mention of points suggests they were a motivating factor for many participants. With a mixed qualitative lens, the data suggests that the gamified interactions in this business course fostered a vibrant social learning environment where students quickly build consensus and engage in problem construction. The use of emojis and affirmative language points towards a positive and engaging atmosphere, enhanced by game-like elements.

A gamified course environment can support learning by making the experience more enjoyable, motivating students to participate actively, and facilitating deeper cognitive processes through social and problem-based engagements. Specifically, we inferred patterns based on the usage of emojis and the context provided by the message text and codes as seen in Table 2

Table 2 Gamified emojis and their patterns

Emojis and Pattern	Descriptions
🔥 Enthusiasm and Agreement	The fire emoji (🔥) appears frequently in the messages, often associated with agreement or endorsement of a point made by another student. This could be part of a gamification strategy to encourage active participation and positive reinforcement. It suggests a lively, engaging discussion environment, where students feel motivated to contribute and support their peers' ideas.
👍✅ Quick Consensus Building	While not explicitly shown in the sample, emojis like thumbs up (👍) and check mark (✅) might be used to quickly show agreement or confirm understanding without elaborate text.
💬👏 Recognition and Encouragement	Emojis such as speech balloons (💬) or clapping hands (👏) could be used to acknowledge a student's contribution or applaud a particularly insightful comment. This type of recognition can boost confidence and encourage continued participation. In a gamified environment, it might be part of a system where students earn points or badges for quality contributions, fostering a sense of accomplishment and competition.
❓💡 Problem-Solving and Inquiry	The use of question mark (❓) or light bulb (💡) emojis can indicate moments of inquiry or ideation, reflecting deeper cognitive engagement or the start of a problem-solving discussion. These emojis signaled a shift from general discussion to more focused, analytical thinking. In a gamified setting, they might be encouraged or rewarded, promoting critical thinking and problem-solving skills.

Table 3 Sequence pattern mining results

Sequence ID	Top Sequence Patterns	Support Value
1	(EX) → (EX) → (EX)	0.85
2	(EP_Const_PS) → (EP_Const_CS) → (EP_Const_AR)	0.72
3	(EP_Const_PS) → (EP_Const_CS) → (SOC)	0.71
4	(SOC) → (EP_Const_CS) → (EP_Const_PS)	0.71
5	(EP_Const_PS) → (EP_Const_CS) → (EP_Const_AR) → (SOC)	0.71

RQ1: What sequential patterns emerge during peer discussions in asynchronous gamified environments?

Sequential Pattern Mining aims to yield the recurrent sequences that represent the participants' interactions, providing insights into the predominant modes of communication and thought processes within these gamified settings. The results, presented in Table 3, highlight the most prevalent and significant sequences, each with a distinct support value indicating its frequency and, by extension, its importance in the discourse patterns observed.

- (EX) → (EX) → (EX): This sequence represents a continuous stream of Externalization (EX), where participants are actively and consecutively expressing their ideas, thoughts, or knowledge. Such a pattern suggests a strong emphasis on the sharing and externalization of personal understanding or insights.
- (EP_Const_PS) → (EP_Const_CS) → (EP_Const_AR): This pattern indicates a comprehensive analytical process where participants initially identify and define the problem (PS), then develop relevant concepts or frameworks (CS), and establish connections or relationships between these concepts and the problem (ARG).
- (EP_Const_PS) → (EP_Const_CS) → (SOC): This suggests a workflow where after defining the problem and conceptualizing potential solutions, the group engages in social processes like consensus-building, discussion, or collaborative refinement of ideas.
- (SOC) → (EP_Const_CS) → (EP_Const_PS): This sequence begins with Social Mode (SOC), indicating an initial focus on group dynamics and consensus-building. It then moves into the Construction of Conceptual Space (EP_Const_CS) and finally to the Construction of Problem Space (EP_Const_PS).
- (EP_Const_PS) → (EP_Const_CS) → (EP_Const_AR) → (SOC): It begins with the Construction of Problem Space (EP_Const_PS), moves to the Construction of Conceptual Space (EP_Const_CS), then to the Construction of Adequate Relations (EP_Const_AR), and concludes with Social Mode (SOC).

Table 3 presents the Support Values for the identified sequence patterns. The Support Value is a metric that indicates the frequency or prevalence of a particular sequence pattern within the dataset. For example, a Support Value of 0.85 for the sequence pattern (EX) → (EX) → (EX) means that this pattern appeared in 85% of all the sequences analyzed. The Support Value was calculated as follows:

$$Support(X) = \frac{\text{Number of sequences containing pattern X}}{\text{Total number of sequences}}$$

The Support Value ranges from 0 to 1, with higher values indicating that the sequence pattern is more common in the dataset. Sequence patterns with high Support Values are considered to be more representative of the overall interaction dynamics within the analyzed discussions.

RQ2: How are the sequential interaction patterns of peer discussions related to knowledge co-construction in asynchronous gamified environments

In the exploration of asynchronous gamified learning environments, the Epistemic Network Analysis provided insightful visualization through a biplot, highlighting the intricate interplay of interaction patterns and cognitive processes among peers. The analysis was pivotal in understanding the dynamics involved in the sequential interaction patterns of peer discussions and their significant role in the process of collaborative knowledge co-construction.

Our epistemic network analysis findings revealed a complex network of cognitive and social constructs. The epistemic network analysis biplot specifically illustrates a strong connection between problem solving and conceptual understanding, which are fundamental to learning in these contexts. We observed that students frequently engage in argumentation, evident in the prevalent use of constructs like ’Simple Claim’ and

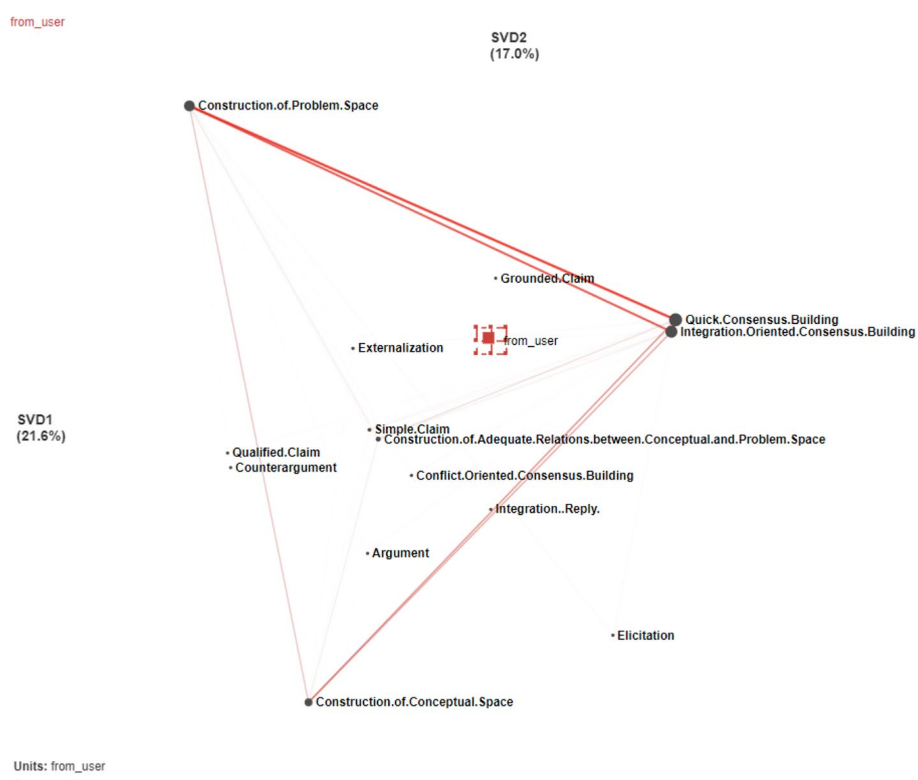

Fig. 4 Epistemic network of students' discussions

'Counter Argument.' This indicates that argumentation is a key component in the knowledge co-construction process.

Our data analysis results (Fig. 4) also demonstrated a robust connection between 'Quick Consensus Building' and 'Integration-Oriented Consensus Building.' This finding suggests collaborative understanding among the students. The clear association of these elements with both 'Construction of Problem Space' and 'Argumentation' underscores an educational ecosystem where students are not just arguing but are actively synthesizing information to rapidly achieve shared understanding. This pattern of interaction indicates that students are exchanging knowledge and cultivating critical thinking skills through acollaborative argument construction and resolution of conceptual challenges.

RQ3: what patterns of peer discussions are most effective for knowledge co-construction in asynchronous gamified environments?

Peer discussions pattern

In the online discourse, three primary types of discussions were observed: ARG, EP, and SOC, each demonstrating unique patterns of engagement and idea integration. ARG Discussions are highly interactive, with approximately 95.83% of ARG posts receiving replies. The high average of references per thread suggests that participants are not only engaging but are also building upon each other's arguments, indicative of a robust and dynamic exchange of ideas. EP Discussion threads are where participants delve deeply into topics, with around 93.12% of EP posts receiving replies. Like ARG discussions, EP threads commonly have multiple references per thread, showing a deep level of engagement where participants are not just responding but also integrating and expanding on existing knowledge. SOC discussions still maintain a high level of interaction with approximately 87.49% of posts receiving replies. The average references per thread are also significant, though potentially fewer than ARG and EP discussions. This indicates that while the nature of social interactions may be more varied, they still play a crucial role in maintaining the forum's energy and providing a foundation for more in-depth discussions.

Knowledge co-construction Indicators

To gauge the effectiveness of knowledge co-construction, we considered three main indicators: depth of discussion, relevance, and idea integration. Depth was measured by the average number of words per post and the linguistic complexity. Relevance was inferred from the level of engagement and the thematic consistency of the discussions. Idea integration was assessed by the frequency and nature of references to previous posts, indicating a buildup of collective knowledge.

Comparison of discussion types

Reflective discussions (typically epistemic) in nature, highlighted the deepest engagement levels, with participants sharing detailed individual experiences and theoretical insights in a rich, reflective dialogue that fostered profound personal growth and understanding. Though less frequent, debates (argumentative) served as instrumental platforms for critical thinking and analysis, pushing participants to engage critically with diverse perspectives, which enhanced the rigor and depth of discourse. Meanwhile, question-and-answer (social/epistemic) sessions, straddling social and epistemic lines, while not as deep, were pivotal for clarity and direct information exchange, creating a responsive environment marked by targeted knowledge sharing and active participation, as evidenced by an average of 2.78 posts per question.

Mechanism of knowledge co-construction

The online discussion forum was a vibrant hub for iterative inquiry, with 56% of threads demonstrating a dynamic cycle of questioning and answering. Reflective dialogues comprised 26% of all discussions, with posts averaging 36.6 words and 45% referencing previous comments, reflecting a high level of thought integration and collective understanding. Brainstorming sessions, accounting for 34% of total discussion comments, saw diverse contributions per thread, highlighting the synthesis of varied perspectives.

Effective patterns of knowledge co-construction

Our analysis identified several patterns that significantly contribute to effective knowledge co-construction within online discussions. These patterns vary across ARG, EP, and SOC discussions, each fostering a unique environment for collaborative learning and engagement. First, study participants demonstrated open-ended questions that showed epistemic focus, which was particularly effective, averaging 45.7 replies and 35 instances of idea integration. For example, a student posed the following question: "Follow up on the portion of bad debt expense. Why is the write-off being included with the bad debt expense? I was thinking the write-off would be a debit to Allowance for doubtful accounts and credit to AR? Thank you (perhaps because it is still just an estimate?)." This question prompted a series of responses that not only provided concrete examples but also led to a deeper exploration of the underlying principles and their practical implications. One student reflected on the discussion, stating, "The open-ended nature of the question allowed us to bring in our own perspectives and experiences, which made the discussion more engaging and meaningful. It helped me see the concept from different angles and understand its relevance in the real world." These discussions often branched into related sub-topics in 23% of cases, fostering rich, multi-dimensional conversations. This pattern was especially pronounced in EP discussions, where the average number of replies was approximately 1.54 per thread, indicating an environment ripe for deep exploration and knowledge building.

Second, debates (Argumentative Engagement) occurred serving as intense knowledge co-construction arenas, with an average of 2.45 replies per thread. Debates, serving as intense knowledge co-construction arenas, were characterized by the presentation of opposing viewpoints, critical analysis, and the integration of evidence to support arguments. For instance, students engaged in a debate on the ethical implications of financial decision-making. A student argued, "While profitability is important, companies have a responsibility to consider the social and environmental impact of their financial decisions." Another student countered, "Companies' primary obligation is to maximize shareholder value. Ethical considerations should be secondary to financial performance." The debate encouraged students to critically examine their assumptions, consider multiple perspectives, and construct well-reasoned arguments. As one student noted, "The debate pushed me to think more deeply about my own beliefs and to find evidence to support my position. It also made me more open to considering alternative viewpoints and finding common ground." While ARG discussions represented a smaller portion of the overall conversation, they support deeper, critical engagement, with each thread fostering multiple references and instances of idea integration.

Lastly, social interactions (SOC) showed the highest average number of replies at approximately 2.75 per thread, indicating active participation. While the discussions may not always focus on academic content, they are crucial for building a sense of community and engagement, which, in turn, supports more in-depth discussions. Social interactions played a crucial role in fostering a supportive and collaborative learning environment. For instance, students often used emojis and informal language to express agreement, encouragement, and shared understanding. A student commented on a peer's post, "Great point! 👍 I hadn't considered that perspective before. Your explanation really helped clarify the concept for me." These social interactions created a sense of camaraderie and psychological safety, which encouraged students to take risks, share ideas, and engage more actively in discussions. As one student reflected, "The supportive atmosphere made me feel more comfortable expressing my thoughts and asking questions. It felt like we were all in it together, working towards a common goal of understanding the material."

In addition to these categories, distinguishable conversational patterns, contributed to effective knowledge co-construction as follows: (a) branching into subtopics, (b) summary posts and continued engagement, (3) gamification interactions with engagement and acknowledgment. Branching into subtopics varied across discussion types, with SOC discussions showing a 2.15% rate of diversification into different subcategories, indicating a wide range of conversational threads. ARG and EP discussions showed higher focus and depth, with 4.17% and 2.54% rates, respectively, indicating more concentrated discussions around specific topics. Summary Posts and Continued Engagement emerged as the prominent pattern in the data. Summary posts, which recap key points and open new questions, led to a 27% increase in continued posts and replies. This practice was particularly effective in maintaining the momentum of discussions and highlighting key insights in the discourse.

Discussion and conclusion

Our study aimed to investigate business education students' peer discussions in an asynchronous gamified environment to explore the students' learning dynamics and patterns. The research illuminated the intricate patterns of peer discussions and knowledge co-construction in asynchronous gamified learning environments. By dissecting the observed sequential patterns and interaction dynamics, we aimed to unravel how these patterns are associated with effective knowledge co-construction and peer learning, thereby advancing our understanding of the interplay between gamification, interactive discourse, and collaborative learning outcomes.

Discussion on the results of RQ1

In terms of RQ1, we explored the interplay and progression of students' discourse patterns identified in the online discussion as below:

Continuous externalization: (EX) → (EX) → (EX)

The recurring EX sequence is indicative of a collaborative environment that heavily emphasizes the sharing of individual knowledge and ideas. This continuous stream of idea expression could reflect a brainstorming phase, where the free flow of thoughts is encouraged. Weinberger and Fischer (2006) suggest that externalization is a crucial step in collaborative knowledge co-construction, as it allows learners to articulate their understanding and make their knowledge explicit and accessible to others.

The dominance of externalization in our findings aligns with the theoretical perspective of knowledge building, which emphasizes the importance of idea sharing in the initial stages of knowledge co-construction. This is often a positive aspect of creative collaboration, fostering innovation and tapping into the diverse perspectives of students in peer discussion activities (Chen et al., 2018). The observed dominance of externalization in the sequence patterns could be attributed to several factors. First, the nature of the discussion prompts used in the course may have encouraged students to share their firsthand experiences, opinions, and ideas related to the topic at hand. Open-ended questions that invite students to contribute their thoughts and perspectives can naturally lead to a higher frequency of externalization moves. Second, the course content itself may have played a role in the prevalence of externalization. Business education often involves case studies, real-world examples, and practical applications, which may prompt students to draw upon their own experiences and knowledge when participating in discussions. Third, the students' prior knowledge, experience, or background could have influenced the dominance of externalization, allowing them to feel more confident in sharing their ideas and perspectives. Additionally, if the gamified environment and discussion prompts successfully engaged students and creates a safe and supportive atmosphere, students may be more willing to externalize their thoughts and actively participate in the discussions. The strong presence of externalization (EX) in the sequential patterns aligns with Weinberger and Fischer's (2006) framework, which considers externalization a crucial step in collaborative knowledge co-construction. However, the scarcity of other epistemic activities like elicitation and integration suggests that there may be room for improvement in facilitating a more comprehensive collaborative learning process, reflecting a combination of externalization, elicitation, integration, and conflict resolution activities.

Progressive epistemic understanding: (EP_Const_PS) → (EP_Const_CS) → (EP_Const_AR)

This sequence, which appeared in 72% of the analyzed sequences (see Table 1), reveals a systematic approach to problem-solving, beginning with problem space construction, moving through conceptual space formation, and culminating in the establishment of relationships between these elements. This progression aligns with Weinberger and Fischer's (2006) framework, which posits that collaborative knowledge co-construction involves the interplay of four epistemic activities: construction of problem space, conceptual space, relationships between conceptual and problem space, and those between prior knowledge and new information. The sequence identified in our study reflects the first three epistemic activities, suggesting a structured and progressive approach to collaborative knowledge co-construction. The initiation of the sequence with the construction of the problem space implies a careful consideration of the issue at hand, involving the identification and definition of problems, setting the stage s for well-defined problem-solving. The transition to conceptual space formation suggests a creative phase wherein diverse ideas and potential solutions are generated. This phase is critical for innovation and ideation in the co-construct of knowledge (Hou & Wu, 2011; Weinberger & Fischer, 2006).

The culmination of the sequence with the establishment of relationships between the constructed problem space and the formed conceptual space underscores the importance of connecting theoretical ideas with the practical challenges identified. This implies that effective problem-solving is not about generating abstract concepts but rather systematically integrating these concepts into the context of the identified issues (Cress & Kimmerle, 2023; Chen et al., 2018).

This pattern emphasizes the necessity of a structured analytical approach, wherein the systematic progression from problem space to conceptual space and the subsequent establishment of meaningful relationships ensures a robust and well-integrated solution, laying the groundwork for effective collaboration and knowledge generation.

From analysis to social mode: (EP_Const_PS) → (EP_Const_CS) → (SOC)

The transition from Evidential Processing (EP) stages to SOC reflects a workflow where initial individual or small group analysis sets the stage for broader group engagement. This pattern aligns with the social modes of co-construction, which highlights the importance of transitioning from individual to collaborative knowledge building. The sequence suggests that students first engage in epistemic activities to establish a shared understanding of the problem space and conceptual space before moving to social modes of interaction, like consensus-building and conflict resolution (Hull & Saxon, 2009).

The initial EP stages involve individual or small-groups gathering and analyzing relevant information, establishing key insights, and formulating preliminary conclusions, allowing for the accumulation of diverse perspectives and data. The subsequent transition to SOC signifies the expansion of the analytical groundwork into a broader group context. This could involve sharing individual analyses, exchanging perspectives, and collectively synthesizing information to arrive at a consensus or make informed decisions (Weinberger & Fischer, 2006).

Social dynamics informing analysis: (SOC) → (EP_Const_CS) → (EP_Const_PS)

This sequence, beginning with social interactions and followed by analytical tasks, introduces an alternative approach to knowledge co-construction, in which initial group consensus or understanding guides subsequent analytical stages, like defining and refining problem-solving tasks. This pattern identifies the importance of social interaction and consensus-building in collaborative knowledge co-construction (Weinberger & Fischer, 2006; Tong et al., 2023). The sequence could serve as a foundation for subsequent epistemic activities, such as the construction of conceptual space and problem space. This approach supports a holistic and interconnected model of collaboration, where the social fabric of a group actively informs and influences the cognitive tasks undertaken in the pursuit of shared knowledge and problem-solving (Chen et al., 2018; Noroozi et al., 2013).

Comprehensive problem-solving cycle: (EP_Const_PS) → (EP_Const_CS) → (EP_Const_AR) → (SOC)

This holistic sequence illustrates a full cycle of problem-solving that incorporates both analytical and social elements. This sequence emphasizes the interplay of epistemic and social dimensions in collaborative knowledge co-construction. The sequence encompasses all four epistemic activities (construction of problem space, conceptual space, relations between conceptual and problem space, and relations between prior knowledge and new information) and culminates in social modes of co-construction, such as consensus-building and conflict resolution.

It implies that an effective approach to knowledge co-construction entails well-structured and sequential engagement with various stages, encompassing problem identification, conceptual development, relational establishment, and collaborative consensus (Weinberger & Fischer, 2006). This sequence represents an ideal workflow in complex problem-solving scenarios, balancing individual analytical processes with collective decision-making.

Discussion on the Results of RQ2

The epistemic network analysis for RQ2 provided insights into the nature of peer discussions in asynchronous gamified environments, reflecting and complementing the findings of RQ1. Specifically, the epistemic network analysis revealed the interplay among various discourse dimensions, emphasizing the role of social interaction SOC and ARG in the learning process.

Dominance of social interaction and argumentation

The epistemic network analysis findings revealed a substantial emphasis on social interaction (SOC) and argumentative (ARG) processes within peer discussions play a crucial role in facilitating collaborative knowledge co-construction. This aligns with patterns identified in RQ1, where a consistent trend of idea sharing (denoted as "EX") was prevalent. The analysis indicates that beyond sharing ideas, students engage in discussions rich with argumentation and social interactions. For example, students frequently presented claims, provided supporting evidence, and challenged each other's ideas (ARG), while also engaging in consensus-building and collaborative reasoning (SOC). This dynamic interplay of ARG and SOC enhances the depth and quality of the conversations and reflects a complex interplay of learning processes (Bayat et al., 2022; Noroozi et al., 2013; Weinberger & Fischer, 2006).

The dominance of SOC and ARG in the epistemic network suggests that social and argumentative processes play a crucial role in facilitating collaborative knowledge co-construction. By engaging in these processes, students actively negotiate meaning, challenge assumptions, and co-construct understanding. This finding aligns with sociocultural theories of learning that emphasize the importance of social interaction and dialogue in mediating cognitive development (Vygotsky, 1978).

Synergy between cognitive and social components

Our analysis also revealed a seamless exchange between knowledge-focused activities (EP) and social interactions (SOC) within the discussions, mirroring the sequences identified in RQ1. This result indicates that the dialogues extend beyond simple idea sharing to include a dynamic blend of knowledge dissemination and social engagement. For instance, students often moved from identifying problems (EP_Const_PS) and developing conceptual understanding (EP_Const_CS) to engaging in collaborative reasoning (SOC) and argumentation (ARG) to integrate and apply their knowledge.

This synergistic interplay between cognitive and social components fosters a more enriched and collaborative learning experience (Chen et al., 2018; Dillenbourg, 1999; Scardamalia & Bereiter, 2014). By engaging in both knowledge-building activities and social interactions, students can leverage the collective intelligence of the group to construct deeper and more coherent understanding.

The strong connections between EP, SOC, and ARG in the epistemic network, as revealed by the quantitative analysis, support the initial findings from RQ1 and align with Weinberger and Fischer's (2006) framework, which emphasizes the importance of epistemic activities and social modes of co-construction in collaborative knowledge co-construction. .These findings enhance understanding of the interplay between cognitive and social dynamics in a gamified online learning environment, highlighting the potential to support and enrich students' collaborative learning experiences by facilitating a balanced engagement in epistemic activities and social interactions.

The epistemic network analysis offered a comprehensive view of how social and argumentative elements interweave with and bolster the previously identified discourse patterns. The strong connections between EP, SOC, and ARG in the network suggest that these components work together synergistically to support collaborative knowledge co-construction. For example, engaging in argumentation (ARG) can help students clarify and refine their conceptual understanding (EP_Const_CS), while social interactions (SOC) can facilitate the integration and application of knowledge in authentic contexts. In general, this finding not only validates the initial findings from RQ1 but also enhances our understanding of the intricate interplay between cognitive and social dynamics in a gamified online learning environment. It reflects a commitment to comprehending the multifaceted nature of online interactions in a manner that is both academically rigorous and accessible, with a particular focus on how gamified systems can support and enrich students' collaborative learning experiences.

Discussion on the results of RQ3

In addressing RQ3, our analysis focused on identifying and understanding the patterns of peer discussions that significantly contribute to collaborative knowledge co-construction within asynchronous gamified environments. The identified patterns, highlighted by epistemic network analysis and sequence pattern mining results, reveal the intricate interplay between cognitive and social constructs, as well as the role of gamification in enhancing these discussions. The effectiveness of knowledge co-construction was assessed using metrics aligned with the success criteria defined in the Methods section. These metrics included the depth of discussions (measured by the average number of words per post and linguistic complexity), relevance (inferred from the level of engagement and thematic consistency), and idea integration (assessed by the frequency and nature of references to previous posts). Patterns of peer discussions that consistently demonstrated high levels of depth, relevance, and idea integration were considered the most effective for knowledge co-construction. In summary, our finding highlights the multifaceted nature of online discussions and their potent role in fostering a dynamic, collaborative, and deeply engaged learning environment. Through the interplay of ARG, EP, and SOC discussions, along with strategic gamification, our forum not only facilitated knowledge sharing but also significantly enhanced the quality and depth of intellectual engagement.

Integrated cognitive and social constructs

The epistemic network analysis results demonstrated a significant interconnectedness between cognitive and social constructs, with notable co-occurrences of problem-space and conceptual-space constructions alongside social interaction constructs. This suggests that in effective asynchronous gamified environments, discussions are not purely cognitive or social but are an integrated blend of both. Participants seem to navigate seamlessly between sharing knowledge, constructing understanding, and engaging socially, indicating an environment where learning is both a collaborative and communal activity (Schellens & Valcke, 2005).

Patterns of progression and engagement

The sequence pattern mining results further illuminate this by identifying specific sequences such as EX → ARG → EP and SOC → EX → EP, which reflect a progression from initial idea sharing to structured argumentation and deeper epistemic engagement. These patterns suggest that effective discussions often start with a broad sharing of ideas or social interactions, which then funnel into more focused and deep cognitive processing, which corroborated Kuhn et al.'s (2013) findings. Our qualitative observations endorsed that the presence of gamification elements served as catalysts or anchors for these transitions, providing motivation, structure, and recognition throughout the discussion process. The quantitative findings, which reveal a synergistic relationship between cognitive and social components, have important design suggestions. Specifically, the prevalence of sequences such as (EP_Const_PS) → (EP_Const_CS) → (SOC) and (EP_Const_PS) → (EP_Const_CS) → (ARG) suggests that incorporating game elements that promote a balanced progression of knowledge-building activities and social interactions can create more engaging and effective learning experiences. This aligns with Weinberger and Fischer's (2006) notion of transactivity, which highlights the importance of students building on each other's contributions and engaging in a collaborative discourse that leads to the integration of knowledge.

Depth, relevance, and integration as key indicators

Our analysis also emphasized the importance of depth, relevance, and idea integration in discussions. The depth was evident in the linguistic complexity and the average number of words per post, suggesting that participants are not just conversing but are explaining, describing, and elaborating on their ideas (Stokoe, 2000). Relevance, measured by the percentage of posts staying on topic, underscores the focused nature of discussions, while idea integration, seen in the frequency and nature of references to previous posts, indicates a buildup of collective knowledge and understanding.

Distinctive discussion types and their roles

The study delineated three primary types of discussions - ARG, EP, SOC - each demonstrating unique patterns of engagement and contributing differently to knowledge co-construction. ARG discussions, characterized by their interactive nature attracting students' attention, serve as a space for critical analysis and debate. EP discussions, with their deep dive into topics and high level of engagement, foster a thorough exploration and understanding of complex ideas. Lastly, SOC discussions, while less deep, are vital for maintaining the vibrancy and responsiveness of the forum, provide a foundation for a more comfortable space that delivers peers' emotional support through gamified interactions.

Gamification as a catalyst for engagement

Through our observations, delivering gamified elements into an online discussion might increase student participation and discussion length (Ding et al., 2018; Subhash & Cudney, 2018), indicating that such strategies effectively harness participants' intrinsic motivations and enhance engagement. We found that students in the module with gamified systems applied had more participation, evidenced by longer and more discussion posts. As evidenced by the descriptive statistics, the introduction of gamification elements like points, badges, and leaderboards coincided with a 15.09% increase in the number of posts and a 25.88% increase in the average length of threads. This finding suggests that gamification might contribute to more engaging student interactions.

These gamification elements enhance both intrinsic and extrinsic motivation among students. Points and badges act as immediate rewards that acknowledge and reinforce positive behaviors, such as contributing to discussions and providing thoughtful responses. Leaderboards introduce a competitive element that can further drive engagement by fostering a sense of achievement and recognition among peers. The increase in the number of posts suggests that students were more motivated to participate actively in discussions, likely due to the tangible rewards and social recognition provided by the gamified system.

Similarly, the increase in the average length of threads indicates that students are not only participating more frequently but also engaging in more in-depth and meaningful exchanges. Furthermore, the strategic use of game-like interactions contributes to a dynamic and enjoyable learning experience, encouraging ongoing and deeper involvement (Welbers et al., 2019), fostering continuous participation and deeper involvement. Emojis in particular are linked to increased motivation, affecting both the emotional and cognitive dimensions of student engagement (Chans & Portuguez Castro, 2021) and making the learning process more interactive and effective.

Multi-triangulation data analysis finding

Our study employed a multi-triangulation data collection and analysis approach, combining epistemic network analysis, sequence pattern mining, and automated coding, to provide robust evidence supporting our findings on the dynamics of knowledge co-construction in asynchronous gamified learning environments. The results from RQ1 revealed distinct sequential patterns in peer discussions, such as the progression from problem space construction (EP_Const_PS) to conceptual space construction

(EP_Const_CS) and the integration of social and epistemic dimensions. These patterns suggest that students actively engaged in collaborative problem-solving, conceptual understanding, and the integration of ideas, which are key components of knowledge co-construction. Furthermore, the epistemic network analysis conducted for RQ2 demonstrated the strong connections between EP (e.g., problem space construction, conceptual space construction) and SOC (e.g., consensus-building, argumentation). These connections indicate that students were not merely communicating or cooperating, but actively co-constructing knowledge through meaningful collaborative discourse. The findings from RQ3 highlighted specific patterns of peer discussions that were most effective for knowledge co-construction, such as open-ended questions with an epistemic focus, debates serving as intense knowledge co-construction arenas, and social interactions fostering a supportive and collaborative learning environment. These patterns were characterized by high levels of engagement, idea integration, and the application of course concepts, providing compelling evidence that the observed interactions indeed contributed to genuine co-constructive activities.

Given that we acknowledge that these quantitative measures alone do not necessarily imply an increase in co-constructive activities, our comprehensive qualitative analysis of the discussion content, as demonstrated by the findings from RQ1, RQ2, and RQ3, reveals specific patterns and discourse moves that are strongly associated with co-constructive activities. The combination of quantitative and qualitative analyses, as well as the transparent reporting of our methods and results, supports the validity and reliability of our findings, indicating that the observed patterns are indicative of co-constructive processes, rather than mere cooperation or communication. Our study contributes to understanding how learning analytics can be used to discover how students co-construct knowledge in asynchronous gamified environments.

Business education on learning processes and knowledge co-construction

The specific content and competencies targeted in the business education courses, such as financial literacy, accounting principles, managerial finance, and decision-making skills, likely influenced the learning process and the observed patterns of knowledge co-construction in several ways. First, the emphasis on financial literacy and accounting principles may have encouraged students to engage in more epistemic activities, such as defining problem spaces and constructing conceptual understanding. The need to grasp and apply these technical concepts could have driven students to focus on building a shared understanding of the problem at hand and the relevant conceptual knowledge. Second, the focus on managerial finance and decision-making skills may have fostered more argumentative and social interactions. As students worked on case studies and problem-solving tasks, they likely engaged in discussions where they presented claims, provided supporting evidence, and challenged each other's ideas. The collaborative nature of these activities could have encouraged students to build on each other's contributions, negotiate conflicts, and work towards consensus. Lastly, the business education context, with its emphasis on practical application and real-world relevance, may have influenced the way students approached the learning tasks. The authenticity of the problems and the need to develop viable solutions could have motivated students to engage in deeper exploration of the problem space, generate multiple perspectives, and iteratively refine their ideas through social interaction and feedback.

Theoretical contributions

This study makes several important theoretical contributions to the fields of CSCL and gamification. First, our findings bolster the understanding of peer learning dynamics and knowledge co-construction processes in asynchronous gamified environments. We provide empirical evidence for the complex interplay between cognitive, social, and argumentative dimensions of collaborative learning by identifying dominant discourse patterns and their subsequent relationships. These insights extend and refine existing theories, such as Weinberger and Fischer's framework (2006), by demonstrating how these dimensions manifest and interact in asynchronous gamified discussions.

Second, our study contributes to the growing literature on gamification's role in education. While previous research examined the gamification's impact on student engagement and motivation (e.g., Dichev & Dicheva, 2017; Subhash & Cudney, 2018), our findings offer a more nuanced understanding of how gamification elements influence the quality and depth of students' interactions and knowledge co-construction processes. We suggest valuable insights for designing and implementing gamified learning experiences by highlighting the discourse patterns that appear in gamified environments and their relationship to collaborative learning.

Third, this study attempted to close the gap between theoretical understanding and practical application by contextualizing the study in business education. We expand the domain-specific application of the frameworks by examining how the specific contents, competencies, and learning objectives of business the patterns of peer discussions and knowledge co-construction. Our findings can inform the design of effective instructional strategies and interventions that leverage the affordances of gamification and collaborative learning to support the unique needs and goals of business education.

In summary, this study advances our theoretical understanding of peer learning dynamics, knowledge co-construction, and the role of gamification in asynchronous online environments. By integrating insights from educational technology, collaborative learning, and gamification research, we contribute to the development of a more comprehensive and nuanced framework for understanding and supporting effective, engaging, and knowledge co-construction-facilitating learning environments.

Implications

The predominance of SOC, ARG, and EP discourses highlight the intrinsic value of social engagement in online learning communities. The findings suggest a need to explore how social dynamics influence cognitive and analytical processes in learning. The interconnectedness between cognitive and social constructs indicates that learning in these environments is inherently integrative, urging researchers to consider the holistic nature of learning interactions and how different dimensions of discourse contribute to knowledge co-construction.

The role of gamification in enhancing engagement and deepening discussions has implications for designing engaging and interactive online learning environments. The increased post quantity and length, along with the progression of discussions from idea sharing to analytical debates, demonstrate that gamified elements are effective in motivating students and fostering a more interactive and engaging learning experience. Exploring how different gamified elements trigger emotional responses will provide insights into designing emotionally engaging and effective learning environments.

Designing gamification with layered objectives that align with distinct levels of cognitive skills, from recall and understanding to analysis and creation will be considered for knowledge co-construction. For instance, a dynamic badge system could foster knowledge co-construction: ’Explorer’ badges for idea sharing, ’Analyst’ badges for problem analysis, and ’Innovator’ badges for synthesizing concepts. This tiered approach encourages natural progression through higher cognitive engagement levels. Implementing peer recognition systems where students are award points or badges for valuable contributions, fosters a community of practice, critical evaluation, and collaborative knowledge building.

The identified patterns of peer discussions in the current study offer valuable insights into how business students engage in collaborative learning and knowledge co-construction. Peer discussion patterns echo the importance of fostering a balance between individual idea generation, structured problem-solving, and social consensus-building in business education. By understanding and leveraging these patterns, educators can design more effective learning activities and interventions that cater to the specific needs and dynamics of business students. For example, incorporating gamification elements that encourage diverse perspectives, critical analysis, and collaborative decision-making can enhance the quality of peer learning experiences and prepare students for the challenges they may face in their future business careers.

Limitations and future research

The present study recognizes several limitations and suggests avenues for future research. First,

While the observed changes in student behavior, such as increased post quantity and thread length, suggest a potential positive influence of gamification on engagement, it is not possible to conclusively attribute these changes solely to the introduction of gamification elements. Future research should employ more rigorous experimental designs, such as randomized controlled trials or interrupted time series analysis.

Second, while self-reported data on student engagement and motivation could provide valuable insights, we relied on records from the gamified course, which may reflect active participation. Further studies are essential to seek alternative data sources, such as behavioral logs or learning analytics metrics, to capture students’ actual participation patterns and engagement levels.

Third, given the exploratory and descriptive nature of this study, it is important to acknowledge the limitations of attributing changes in student behavior solely to gamification. Future research could focus on the qualitative aspects of students’ interactions, examining the content and quality of contributions in relation to patterns of knowledge co-construction. . Future research should employ experimental designs that control for confounding variables to assess the specific impact of gamification more accurately on student behavior and learning outcomes in asynchronous online environments.

Fourth, it is important to note that while the dominance of externalization can be beneficial for idea generation and diverse perspective-sharing, it may not necessarily lead to deep knowledge co-construction on its own. Future research could investigate the factors that contribute to the dominance of externalization in more detail, such as examining the specific characteristics of the discussion prompts, analyzing the content of the externalization moves, and exploring the relationship between students' prior knowledge and their participation patterns. In addition, interventions or scaffolding strategies could be tested to encourage a balanced distribution of discourse moves and promote deeper cognitive engagement.

Fifth, while the identified increase in posts and thread lengths suggests elevated levels of engagement, we acknowledge that these quantitative measures alone do not necessarily imply an increase in co-constructive activities. Accordingly, the present study conducted a comprehensive qualitative analysis of the discussion content with multiple data triangulations to reveal specific patterns and discourse moves strongly associated with co-constructive activities. To establish a more definitive connection between the increase in posts and the effectiveness of knowledge co-construction, future replication studies should be considered, incorporating diverse association analyses to corroborate the findings of the current study.

Sixth, while the present study offers insights into the potential role of gamification in fostering engagement and learning, it is crucial to acknowledge the limitations of interpreting meaning from emojis. Emojis can have subjective and culturally dependent meanings, which may vary across individuals and contexts (Bai et al., 2019; Kaye et al., 2017). Therefore, while this study provides a valuable starting point for understanding the role of emojis in gamified learning environments, future research should consider the complexities of emoji interpretation and explore methods to mitigate potential ambiguities.

Lastly, while our study context is limited to specific courses and a particular cultural context, we argue that the findings could be extended to other learning settings in higher education where peer learning takes place. Caution is needed to avoid overgeneralizing the results. Replication studies across diverse business course contexts should examine the consistency and transferability of the identified patterns and relationships.

Conclusion

This study examined the dynamics and patterns of knowledge co-construction in online peer discussions within an asynchronous gamified environment in higher education. We aimed to determine how these discussions facilitate knowledge co-construction. Guided by three research questions, the study identified sequential discourse patterns emerging during peer discussions, understood their relation to collaborative knowledge co-construction, and corroborated the most effective patterns for this learning goal. The outcomes of this study enhance our understanding of the connections between gamification and interactive discourse in asynchronous gamified environments, contributing to the literature on the dynamics and patterns of collaborative learning in technology-enhanced environments. The findings highlight the importance of examining the interplay between cognitive, social, and argumentative dimensions of discourse in understanding students' knowledge co-construction, offering effective strategies to facilitate students' collaborative knowledge co-construction within online gamified environments.

Appendix

Coding scheme

Definitions

- ARG (Argumentation): Occurrences of learners constructing arguments or counter-arguments.
- EP (Epistemic Activity): Activities where learners engage directly with learning materials or tasks, showing understanding or application of concepts.
- SOC (Social Interaction): Elements of social interaction, such as consensus building, elicitation, or conflict-oriented discussion.

Examples

Dimension	Example Categories	Details
Epistemic	Construction of Problem Space	:fire: :fire: I really like question 1, I think that the motivation behind an entrepreneur being willing to take a business public instead of private is really an interesting case study! I would think it would take a lot of thought and sleepless nights to be willing to give up control of a business that you or your parents started as a single restaurant
	Construction of Conceptual Space	I've already taken Principles of Accounting and another tip I could offer is flash cards for the terminology. They work wonders!
	Construction of Adequate Relations between Conceptual and Problem Space	we need math to fix calculators and upgrade them by programming 😊 I solve for x, y, and z from the time I wake up until I try to shut my brain off at night. Whether we know we're using it or not… we use math."
Argumentative Knowledge co-construction	Simple Claim	Couldn't agree more with your point about... I agree with the cost of the solution...
	Qualified Claim	I agree that hate is a strong word, but in this context..." Good question! Your point about X might be valid, however..." I completely agree about Y, although we should consider..."
	Grounded Claim	Enjoyed reading your opinions. You have good voice backed by great evidence. I also was a bit uneducated in this but now, also intrigued. How do you think businesses will adapt to decentralized systems? My interest is in the safety of cryptocurrency with the rise in AI and technology, and how the government will aim to monitor these transactions."

Dimension	Example Categories	Details
	Argument	You will need to be sure to multiply $19.95x2 days for the car rental and then the gas used was 1/4 tank or 6 gals. x $1.19 and last they went 120 miles x $0.22/mile. All added =$73.44. The hotel cost is $79.95 x 2 people x 2 days equaling $319.80. Dinner is $182.12 - $50 discount=$132.12. Breakfast 1 is $24.17 - $7.98 ($3.99x2 people) equals $16.19. Breakfast 2 is $26.88-7.98 ($3.99x2 people) equals $18.90. The sum of all parts equals $560.45
	Counterargument	I wish I could make it but I will be at work! Will it be recorded by chance?
	Integration (Reply)	:fire: imagine balancing a career in medicine and doing more school, that's awesome
	Externalization	thanks for sharing Good question! Your understanding..."
	Elicitation	For clarification, is the Exams in the same format as the Timed quizzes? I just completed the time quiz for Module 2 but I was anticipating more of a multiple-choice format? Although I prepared for the timed-quizzed, it seemed to be very hard for me
Social	Quick Consensus Building	I really cannot argue/ debate with you your viewpoint. I find myself agreeing with you about lobbyists (large corporations) not caring about what the public wants.
	Conflict-Oriented Consensus Building	XX![💕] Congrats on all the major life events. I imagine it will be very challenging running your own business while also maintaining your school work.

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Authors' contributions
To ensure a transparent attribution of contributions, we detail each author's involvement in the study. [JM, CE, LM, ON, KB]: Conceptualization of the study, methodology development, data collection, data analysis, and drafting the manuscript. [JM, CE, LM]: Assisted in data analysis, contributed to the methodology section, and review and editing of the manuscript. [ON, CE, KB, LM]: Contributed to the literature review, interpretation of data, and critically revised the manuscript for important intellectual content. [JM, ON]: Specify other contributions such as providing technical support, assisting with the epistemic network analysis, or facilitating the sequence pattern mining.

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Availability of data and materials
The datasets analyzed during the current study are available only by reasonable request.

Declarations

Competing interests
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