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Investigating shared agency in student Knowledge Building discourse using epistemic network analysis

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Abstract

In computer-supported collaborative learning, students engage in both synchronous online and face-to-face discussions to enhance engagement and learning from peers. Recent research highlights the potential of quantitative modelling techniques, such as those used in Epistemic Network Analysis, to deepen our understanding of student collaboration through discourse, including the concept of shared epistemic agency in Knowledge Building. However, these efforts are still in the early stages. This study aims to advance this research by analysing student contributions in synchronous discussions (online and verbal) within a Knowledge Building framework. Data was collected from a Grade 5 class during a 2.5-hour Social Studies lesson designed to foster real-world problem-solving and collaborative discussions. Students participated in discussions on Knowledge Forum (online) and in face-to-face small groups. Transcripts of group discussions and Knowledge Forum notes were coded for semantic types and analysed for weighted connections between coded contributions using Epistemic Network Analysis. The analysis of overall student contributions revealed distinct patterns of weighted connections between codes and varying degrees of idea development in online versus oral discussions. Additionally, the study identified different engagement patterns within groups based on their epistemic networks. The findings offer insights into student engagement during collaborative talk and have implications for future research and practice.

Keywords: Shared epistemic agency, Knowledge Building, Epistemic network analysis, Discourse analysis, Computer-supported collaborative learning

Introduction

In the field of computer-supported collaborative learning, there is widespread attention on understanding and developing shared epistemic agency among learners. Epistemic agency refers to learners "being positioned with, perceiving, and acting on, opportunities to shape

the knowledge building work in their classroom community" (Miller et al., 2018, p. 6). In collaborative processes, as Damşa et al. (2010) explained, learners take on epistemic agency towards creating shared knowledge objects, Thus, individuals contribute their own expertise to build on each other's work with a common goal of advancing community knowledge, which embodies the notion of "shared" epistemic agency. In classroom discourse, when students become epistemic agents, they assume an active role in questioning and producing new knowledge and engage in more meaningful learning (Miller et al., 2018). However, for students to work as epistemic agents, it is important to provide dynamic classroom configurations that support student-driven inquiry and creative imagination (Tao & Zhang, 2021). Knowledge Building (Scardamalia & Bereiter, 2006) is an established learning sciences theory that seeks to promote innovative ideas and collective idea improvement among students via student-driven discourse. Knowledge Building (KB) discourse emphasises student ownership and student-driven inquiry to advance collective understanding of real-world problems, and there is keen research interest to explore how KB discourse can enhance learners' shared epistemic agency.

Extensive analytical frameworks can be found in the literature to understand shared epistemic agency in KB discourse. Some prominent frameworks include theory building moves (Chuy et al., 2010), epistemic complexity (Zhang et al., 2007, 2009, 2022) and threads analysis (Lin & Chan, 2018). These analytical frameworks inform shared epistemic agency based on students' agentic moves such as how they contribute to improving ideas or expand inquiry. However, as Tan and colleagues (2022) point out, it is still not clear from existing literature how shared epistemic agency develops over time through student discourse. Specifically, existing analytical frameworks are qualitative in nature and do not provide an understanding of the connections between actions and events (Tan et al., 2022). Furthermore, studies on shared epistemic agency have been largely focused on student discussions on the Knowledge Forum (an online platform) with relatively little understanding of synchronous discussion settings that may involve oral discussions as well. More recently, researchers are exploring quantitative modelling techniques such as Epistemic Network Analysis (ENA) to examine shared epistemic agency through connections of actions such as student talk moves (e.g., Ma et al., 2019; Tan et al., 2022).

Such modelling analyses potentially introduce new understandings in relation to characterisation and development of shared epistemic agency in KB discourse (Tan et al., 2022). Building on this promising line of inquiry, this paper attempts to explore shared epistemic agency in synchronous KB discourse (both online and face-to-face) by characterising the patterns of students' discourse moves using ENA. We will use epistemic networks to answer the following research questions: (i) How do elementary students participate in synchronous verbal and online discussions supported by KB? (ii) How does idea building vary between groups? The aim is to leverage ENA to provide insights into

how KB discourse might develop students' epistemic agency as they collaborate and build on collective inquiry through opportunities for both online and face-to-face interactions.

Review of the literature

Knowledge Building discourse for epistemic agency

Knowledge Building discourse is marked by the generation of novel and challenging student ideas, questions, and perspectives aimed at improving the collective understanding of the problem at hand. KB discourse emphasises the generative and creative nature of classroom discussions, moving away from traditional methods that focus on getting a single correct answer (Ong et al., 2021; Teo, 2023). The goal of Knowledge Building classrooms extends beyond information sharing or divide-and-conquer to collaboratively assemble a product together (Scardamalia & Bereiter, 2006, 2021). In KB discourse, students are encouraged to continuously question and refine their ideas collectively, connect with the larger problem, and help each other progress in the inquiry and advance community knowledge. KB discourse is typically supported by the Knowledge Forum, an online platform that facilitates students in posting and building on ideas (Scardamalia & Bereiter, 2006). Figure 1 shows a view of the Knowledge Forum where students interact and contribute to the discussion together. Each node (square box) represents a note containing ideas from a student, and the arrows show the progression from one node to another. In typical classrooms, it is also common for students to work in small groups and discuss verbally. Figure 1 also illustrates how students may use computer devices in a small group setting to engage in both online and oral discussions.

Research on KB has primarily focused on enhancing shared epistemic agency through collaborative discourse, where shared epistemic agency involves learners taking responsibility for contributing to and building on collective ideas to create shared knowledge artefacts (Hong et al., 2016; Scardamalia & Bereiter, 2006). Unlike simple

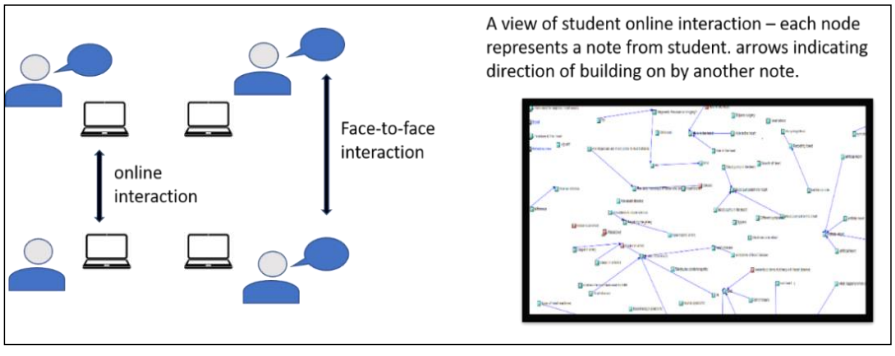


Fig. 1 Illustration of Knowledge Forum discussion and small group talk for Knowledge Building

participation in a collaborative discussion, shared epistemic agency is not merely about sharing and exchanging information. It entails students approaching collective inquiry with sophisticated thinking, improving their ideas, and offering diverse viewpoints, evidence-based claims, counterarguments, or probing questions to deepen the discussion with the goal of constructing knowledge and sustaining inquiry (Lin & Chan, 2018; Stroupe, 2014). Thus, shared epistemic agency can be seen as every student actively and continually questioning knowledge gaps, seeking evidence, and contributing new information to improve collective ideas.

Through engagement in KB discourse, shared epistemic agency can be developed among learners as young as Grade 4 and 5 (Hong & Lin, 2019; Sun et al., 2010; Tao & Zhang, 2018, 2021; Tong & Chan, 2023; Zhang et al., 2022). For instance, Zhang et al. (2022) demonstrated that KB supported Grade 5 students in co-constructing inquiry to develop shared epistemic agency. Their study involved 22 Grade 5 students in flexible group structures guiding their inquiry about human body systems over 7 months with a collaborative online environment. The study revealed that students contributed to theory building moves, which shaped the class's investigative focus. The flexible groups addressed student interests and facilitated various inquiries, leading to deepening investigation and extensive idea exchanges. However, understanding remains limited as studies also consider other factors influencing epistemic agency, such as student profiles, competencies and emotional behaviours (So et al., 2010; Yang, 2019; Yang et al., 2024; Zhu & Lin, 2023). For example, Yang (2019) examined low-achieving students' engagement in online KB discourse. The qualitative analysis revealed that shared epistemic agency is linked to academic performance, with low-achieving students often showing limited collaboration and inquiry capabilities, resulting in lower epistemic agency. Yang (2019) also advocated for scaffolding and suggested that reflecting on their inquiry and ideas and addressing knowledge gaps are ways to support low-achieving students in developing high-level shared epistemic agency.

Hence, while more studies are needed to enhance this understanding, the measurement of shared epistemic agency in KB discourse is also in question. A key focus is the characterisation of students' ideas or discourse moves (e.g., Chuy et al., 2010; Zhang et al., 2007, 2022). Chuy et al. (2010) proposed theory-building moves to code student discourse, developing an empirically grounded list of six major ways to contribute to productive KB discourse: asking thought-provoking questions, theorising, experimenting, working with evidence, creating syntheses and analogies, and supporting discussion. In a different study, Zhang et al. (2007) examined Grade 4 students' contributions based on the quality of their ideas. They developed the epistemic complexity scheme to categorise students' ideas into explanation-seeking versus fact-seeking questions and single-area versus cross-area questions. According to Zhang et al. (2007), students' explanations can also be assessed by

levels of epistemic complexity: unelaborated facts, elaborated facts, unelaborated explanations, and elaborated explanations. In our study, we adapted this epistemic complexity framework to study student ideas, as we believe this coding scheme is more generalisable to non-science subjects such as Social Studies.

A key limitation in understanding shared epistemic agency using these earlier frameworks, as Tan et al. (2022) point out, is their qualitative focus on outcomes. Often, shared epistemic agency is viewed as the presence of high-level agentic moves, such as counter-arguing or applying new knowledge, which are emphasised over lower-level moves like seeking facts and making claims (Tan et al., 2022, p. 1656). Some studies have extended the analysis of student discourse to map how students build on each other's ideas to progress knowledge (e.g., Lin & Chan, 2018; Ong et al., 2021). For instance, Lin and Chan introduced thread analysis to code the quality of student online discourse, identifying four epistemic levels of collective knowledge advancement. The basic level, Fragmented Discussion, showed weak or no connections between ideas, contributing minimally to knowledge advancement. The next level, Knowledge Sharing, involved connecting ideas mainly to exchange information, which might not solve the problem. Knowledge Construction represented a higher level with building connections to generate questions and explanations, while Knowledge Building was the highest level, featuring coherent connections that lead to new understanding and the progressive development of theories. This work highlights the need for greater emphasis on connections—such as between student ideas or actions and events—to better inform shared epistemic agency in KB discourse. This aligns with recent arguments for quantitative modelling techniques like epistemic network analysis to enhance this understanding (e.g., Tan et al., 2022; Yang et al., 2022).

Epistemic Network Analysis

Epistemic Network Analysis (ENA) is a method introduced by Shaffer to assess learner performance in digital learning systems (Shaffer et al., 2009). ENA models the weighted structure of connections in discursive data (Shaffer & Ruis, 2017). It was designed to analyse connections between ideas and actions using network-based methods, including visualisations and statistical modelling. For instance, when a student group discusses a topic, they share elements like their interests, questions, and information. ENA models how they connect these elements during their discourse. It quantifies the co-occurrence of codes in discourse or elements of interaction, producing a weighted network visualisation that shows connections for each unit of analysis (e.g., individual speakers or sub-groups) (Shaffer & Ruis, 2017). This visualisation helps understand an individual's epistemic frame, such as the connections between knowledge types and moves during an activity. According to Shaffer et al. (2016), an ENA network models the structure of connections among codes.

In engineering practice, an ENA network may model a student's epistemic frame in terms of connections between various knowledge types, skills, and other aspects of practice. Darker, thicker lines indicate stronger connections between codes. ENA thus offers a sociocultural perspective, assuming that meaningful data features can be identified and structured based on their connections (Shaffer & Ruis, 2017). ENA can inform contribution patterns in conversations, such as group or community discourse.

Emerging understanding of shared epistemic agency in KB discourse through Epistemic Network Analysis

The potential of modelling techniques to understand connections between student discourse moves in Knowledge Building is increasingly gaining research interest (Ma et al., 2019; Tan et al., 2022; Yang et al., 2022). For instance, Ma et al. (2019) explored Epistemic Network Analysis (ENA) to assess Knowledge Building discourse, focusing on "ways of contributing," such as connections between questions and theories. Their study used ENA networks to examine differences in contributing moves between groups. They found that the strength of connections between codes (e.g., theorising and questioning, or theorising and obtaining evidence) varied across groups. ENA networks can provide insights into the similarities and differences in discourse patterns between groups. As Ma et al. suggested, these network models can further help understand complementary engagement in group discussions and indications of collaborative engagement in both online and verbal discourse.

The modelling of epistemic networks raises new questions about shared epistemic agency in KB discourse. For example, Yang et al. (2022) found that the development of shared epistemic agency depends heavily on students' level of meta-cognitive engagement. Using ENA, they examined connections between discourse moves in low-achieving tenth-graders over four months. Their study showed that students who engaged in more reflective KB discourse produced higher-level moves, such as generating explanatory questions and contributing advanced notes. These higher-level moves were closely linked to their meta-cognitive activities. Tong and Chan (2023) supported this, finding that students' content learning was associated with deep Knowledge Forum (KF) inquiry. Similarly, using ENA, they demonstrated that students deepened their content learning through productive KB discourse and reflection. Additionally, Tan et al. (2022) used ENA to explore interactions between components of shared epistemic agency, such as epistemic and managerial actions. Their study challenged the notion that students' development of epistemic agency is linear over time, presenting a new perspective on shared epistemic agency as not solely dependent on engagement.

Such emerging understandings motivate further investigation into the development trajectory of shared epistemic agency in KB discourse, particularly in synchronous

discussion settings with oral talk. Existing studies focus primarily on student participation in online discussions supported by the Knowledge Forum, with little attention given to the role of verbal discussions in supporting KB discourse, despite their common use in small group settings (Ong et al., 2021). Studies outside of KB contexts show that verbal discussions do not always complement online discourse. For example, Bagheri and Mohamadi Zenouzagh (2021) found that students engaged differently in face-to-face and online conversations. Their study of 30 students revealed differences in verbal, paralinguistic, and functional aspects between face-to-face and online interactions. Specifically, online discourse was more productive: students had greater control of the conversation, engaged in richer exchanges like argumentation, and were less likely to seek teacher assistance or display pauses and silences (Bagheri & Mohamadi Zenouzagh, 2021). Since student engagement in different discussion modes may affect the quality of their collective inquiry in KB, further research is needed. This study aims to build on this line of inquiry by characterising patterns of students' agentic moves in KB discourse in synchronous discussions using ENA.

Research design and analysis

Methods

To capture students' verbal interactions during face-to-face discourse, we used a 360-degree camera placed in the middle of the group to record the interaction, as shown in Figure 2. The 360-degree video was then flattened to visualise each participant's interaction. To ensure high-quality verbal data, individual audio recorders with lapel microphones were attached to each student to capture their utterances (Figure 2). Students

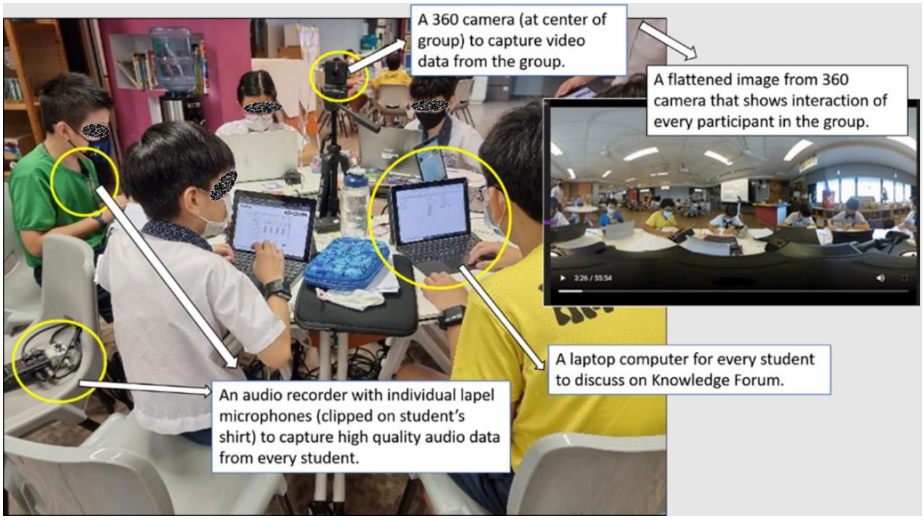


Fig. 2 Setup to capture students' face-to-face and online discussion in the classroom

were provided with computer devices to access and use the online platform (KF). This was part of a multimodal setup that also included students' self-reports on their emotions and physiological data from Empatica E4 wearables. We focused our analysis primarily on the video data and KF data for this paper.

Lesson design and implementation

In this case study, we collaborated with an experienced Knowledge Building teacher to implement the lesson. To promote Knowledge Building discourse, the lesson was designed around the KB principles of real ideas and authentic problems, providing students with real-world issues to enhance their understanding of social issues. Student discussions were guided by the KB principles of improvable ideas and idea diversity, allowing students to generate diverse perspectives and work with peers to continuously improve their ideas and solutions. Table 1 shows the KB-supported lesson design, which involved activities for idea generation and building on a real-world problem based on Social Studies. Students

Table 1 Activities from the teacher's lesson plan

Lesson phase	Teacher's instructions and class activities	Students' KF activities
Activating Activity	● Students played the roles of locals in three Southeast Asian areas (Sarawak Rainforest, Mekong River, and Anak Krakatoa). ● Students introduced to the KB task, which is a Town Hall discussion anchored on the question: "Should our community stay or relocate from our area?"	No KF activities recorded
Idea Generation	● Students discussed the anchor question in their respective groups. ● Students posted notes on KF stating their stand and with supporting reasons.	Discuss and post different perspective (stand) with reasons on KF
Idea Improvement – Build On	● Students discussed and built on their peers' ideas on the Knowledge Forum using build-on scaffolds. ● The teacher used learning analytics such as word clouds and an in-built Scaffold Tracker to conduct a meta-discussion and highlight value-adding contributions.	Read and build on groupmates' viewpoints, such as clarifying, inquiring, or proposing new elaborations
Idea Improvement – Rise Above	● Teacher introduced a Rise-Above scenario: Students took on newer roles as community representatives to potentially implement a solution to the respective area's issues.	Negotiate as a group, weighing pros and cons of different solutions to develop a solution
Idea Assessment	● Students consolidated their problems and solutions that were then shared with the class for comments and suggestions.	Post synthesis of group ideas and peer feedback for improvement
Reflection	● Students responded to three reflection questions on KF.	Post reflection on KF

were assigned roles representing three Southeast Asian regions (Sarawak Rainforest, Mekong River, and Anak Krakatoa) and discussed the pros and cons of relocation, ultimately deciding their group's stance with justifications. Each group addressed issues such as habitat loss, active volcanoes, and deforestation affecting the respective regions. Table 1 outlines the planned activities that facilitated both online and face-to-face discussions. A total of 17 Primary 5 (Grade 5) students participated in this 2.5-hour lesson.

Participants and analysis

In this study, we used the ENA Web Tool (Shaffer et al., 2009, 2016) to analyse both Knowledge Forum and verbal discussion data. ENA models the weighted structure of connections in discursive data (Shaffer & Ruis, 2017). This method visualises and statistically models connections between ideas and actions. For example, during a discussion, students share elements such as their interests, questions, and information. ENA quantifies the co-occurrence of discourse codes or interaction elements and produces a weighted network visualisation showing connections for each unit of analysis (e.g., individual speakers or sub-groups) (Shaffer & Ruis, 2017). Table 2 presents the profile of the student groups and the analysed data. This paper reports a case study involving one class of Primary 5 (Grade 5) students, aged 11, enrolled in a gifted education program designed to meet the needs of intellectually gifted students identified through a nationwide assessment. These students were considered high-achieving compared to those in the mainstream curriculum.

The class was divided into three groups (five to six students each). However, one group did not consent to further analysis, limiting the study to the remaining two groups, which were mixed-gender. Both groups comprised 6 students (Group 1 included S1 to S6; Group 2 included S7 to S12). During the 2-hour lesson, Group 1 and Group 2 generated 42 and 34 notes on Knowledge Forum (KF), respectively. Their verbal discussions were also recorded. Group 1 and Group 2 produced 2,416 and 807 utterances, respectively. We coded both KF notes and student utterances for contribution quality based on five semantic patterns as shown in Table 3 (adapted from Zhang et al., 2007, 2022). These patterns included CasualTalk, SimpleQuestion, ElaboratedQuestion, SimpleExplanation, and ElaboratedExplanation. CasualTalk referred to casual interactions or incomplete utterances

Table 2 Group profile and data analysed

Group (members)	Topic	Number of KF notes (Total codes generated)	Transcript Length	Number of Student utterance (Total codes generated)
1 (5 boys; 1 girl)	Anak Krakatoa	42 (51)	1hr 50min	2416 (2548)
2 (4 boys; 2 girls)	Mekong River	34 (35)	1hr 50min	807 (807)

Table 3 Description and examples of semantic levels of student ideas

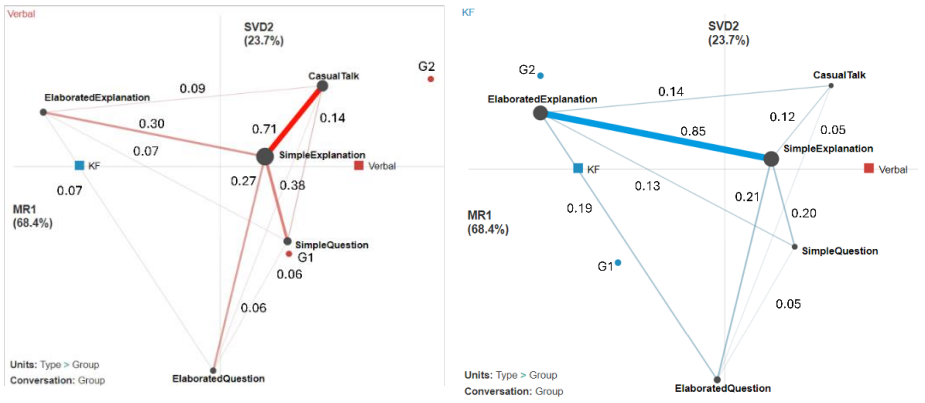
Semantic pattern	Description/Examples
CasualTalk	General information or inputs mostly irrelevant to the collective inquiry, e.g., "Wiggle wiggle wiggle", "Can I type now?"
SimpleQuestion (SQ)	Questions that elicit factual information, using when, where, or who, e.g., "Where do you want to go?"
ElaboratedQuestion	Questions which inquire into relations between facts and elicit elaborations, such as why, how, and what, e.g., "Why should we be affected by other people living in the modern world?"
SimpleExplanation	Simple statement without elaboration, e.g., "You are contradicting yourself. These are the exact reasons why we should move."
ElaboratedExplanation	Statement with elaborations to provide reasons, relationships, or synthesis of ideas, e.g., "We don't really have a government. Without a government, there is no law, no order. And with a government, we suffer under a dictatorship. People who are weaker will abuse power."

generally irrelevant to the inquiry. SimpleQuestion indicated straightforward factual queries, while ElaboratedQuestion sought explanations. SimpleExplanation involved basic statements without elaboration, and ElaboratedExplanation included detailed statements with reasons or relationships. Each student idea was analysed, typically in the form of a question or statement. For KF data, each note with a question and explanation was coded accordingly. For verbal data, each utterance was similarly coded. Inter-rater reliability was checked on 30% of the verbal and KF data by two team members, achieving an 86.48% agreement. Total codes were 51 and 35 for KF data in Group 1 and Group 2, respectively, and 2,548 and 807 for verbal data (as some utterances/KF notes included more than one idea).

We applied ENA to identify and quantify connections between these codes for each group. We constructed epistemic networks using discourse types (KF and verbal) as units for ENA. The two networks were aggregated using binary summation to reflect the co-occurrence of each pair of codes within a 4-line stanza window. This window represents the segment of conversations ENA uses to model connections between concepts, based on student utterances or KF notes. We modelled the patterns of association between concepts (codes), applying all five semantic levels of student contributions.

Findings

To answer the first research question, "How do elementary students participate in synchronous (verbal and online) discussions supported by KB?", we present the epistemic networks of student contributions in both verbal and online discussions throughout the lesson (Figure 3). Generally, the epistemic network for oral discussions showed frequent occurrences of SimpleExplanation (largest node) and a strong connection (strength of 0.71) between this code and CasualTalk, compared to other semantic codes. This suggests that



(a) Verbal discussion (b) Online discussion

Note: dots in red and blue represent students.

Fig. 3 Epistemic networks showing connections between student contributions in synchronous KB discourse (G1 - Group 1; G2 - Group 2)

while students engaged more in verbal talk, they often built on the topic inquiry with simple ideas and casual conversations, leading to basic factual points. In contrast, although students interacted less on KF, they used it differently to support idea building. The epistemic network for online discussions revealed more occurrences of SimpleExplanation and ElaboratedExplanation (larger node), with a very strong connection (strength of 0.85) between these two codes. The code connection (bi-directional) revealed that students responded with elaborations to build on simple ideas but also, at times, added simple suggestions following a deeper explanation. Nevertheless, the result indicated that codes of higher semantic levels (ElaboratedExplanation) were more connected in their online discussions, likely leading to extended topic understanding. To illustrate this shift in engagement patterns, we provide snippets of student interactions from both verbal and online discourse.

Table 4 presents an illustration to show connections between students' contributions in oral discussions. This episode occurred during the idea improvement phase (mid-lesson), where the teacher instructed students to consider each other's reasoning. The segment shows how the group built on student S1's idea of a future with wealth and family versus staying in the rainforest. Students S3 and S5 asked simple questions and offered simple explanations to challenge S1's assumptions. For example, S3 questioned the meaning of "good money" and the feasibility of earning money with limited survival skills in the rainforest. In response to S1's suggestion about fishing as a livelihood, S3 and S5 continued with simple responses to questioning the practicality of fishing. Towards the end, the discussion shifted to casual talk as S5 and S6 diverted from idea-building and moved away

Table 4 Illustration of idea building and codes connection in student verbal talk

Turn	Student	Text	Semantic Level of Idea
861	S1	It's not total crap. I'll live long until 80, and live a good life with good money and I'll find- I'll find a wife. I'll make a family, while you guys stay in the rainforest and die.	ElaboratedExplanation
862	S3	What do you mean good money? You, you.	SimpleQuestion
863	S2	Stop being the leader.	SimpleExplanation
864	S5	Nobody is going to accept you.	SimpleExplanation
865	S3	S1, S1, you can't get money using surviving in the rainforest skills.	SimpleExplanation
866	S1	Ya, I can just fish. Hey, have you heard of fisher-fishmongers?	SimpleExplanation SimpleQuestion
867	S5	No, I haven't heard of fishers that make good money.	SimpleExplanation
868	S1	I said fishmongers. At least it's a basic income.	SimpleExplanation
869	S3	I haven't heard, I haven't heard of a millionaire fisher before.	SimpleExplanation
870	S6	Fishmonger?	SimpleQuestion
871	S5	Can you just clip the thing, just?	CasualTalk
872	S6	I can't.	CasualTalk

from the main topic. Overall, the conversation reflected students' attempts to build ideas around livelihood and fishing but lacked depth, as they often shared short, incomplete factual statements or simple opinions and frequently shifted to casual conversation. This pattern of alternating between simple ideas and casual talk was prevalent throughout the oral discussion. However, casual talk was not necessarily detrimental to the topic learning; it also included activities like searching KF posts, conducting physical voting ("scissors, paper, stone"), and giving instructions, which supported group organisation and management.

Table 5 illustrates the interaction during the students' online discussions (mid-lesson, idea improvement phase). This series of notes focused on a group discussion about whether to stay in or relocate from the Sarawak forest, specifically addressing deforestation and its impact on rainforest communities. Student S4 began with a detailed explanation and a question about the destructive effects of deforestation, proposing an underground solution to preserve their homes. This note set the stage for other members to reconsider their positions. Student S3 contributed a factual update on deforestation rates with a simple explanation, adding context to the discussion. Supporting S4, S5 argued for preserving cultural heritage (with emotional ties to the rainforest) and raised related questions about relocation challenges. S1 asked a simple question about future visions but also offered an

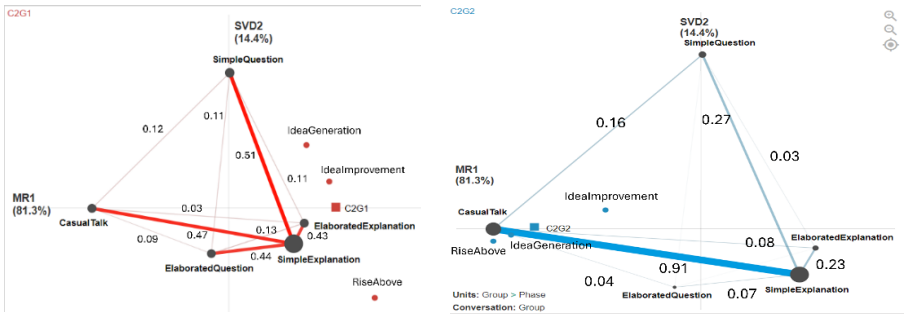
Table 5 Illustration of idea building and codes connection in student online talk

Turn	Student	Text	Semantic Level of Idea
6	S4	[- I heard there was a special place... where men could go and emancipate... Our homes are disappearing, but that's what they are. Homes. Our people have lived there for long periods of time. But our rainforests, our homes, are being deforested for paper and land. This is tyrannical of the government to destroy the homes of an innocent group of people for just some dumb old roads where four-wheeled stuff just move along. However, we cannot stand against a group of greedy men with guns and bombs. We would be incinerated or something. But, if we give in, would we live under tyranny and brutality of a government that we know took away our homes? I propose we head underground - literally. We head underground our rainforest homes and make a home out of them.-]	ElaboratedExplanation SimpleQuestion
7	S3	[-news.mongabay.com. 80% of rainforests in Malaysian Borneo logged-]	SimpleExplanation
8	S5	[- that we can adapt. We do not have to be scared. We have lived for so long and should preserve our culture. How can we relocate?? We were born in the rainforest and grew up there, don't you feel any loyalty to it? Where do you want to go? Who will accept you in the real world?-]	ElaboratedExplanation ElaboratedQuestion
9	S1	[- that I should always MOVE. Why would I need to stay in this relic of the basic? I will get a citzenship in Malaysia and start an occupation and fish for a living wth my skills in the Rainforest. I might even start a business selling all sorts of other rare and exotic fish. I would live abetter life here than in the forest.-]	ElaboratedExplanation SimpleQuestion
10	S5	[- what you said. Well, it looks like since there are more push than pull factors, we shoulld go. But that is not the case!-]	SimpleExplanation

elaborated plan to move to mainland Malaysia and earn a living. S5 attempted to summarise the debate by weighing push and pull factors but did so with limited clarity, which seemed to hinder idea development. Overall, this episode demonstrated how students interacted to provide detailed perspectives, reflecting stronger connections between elaborated and simple explanations in their epistemic network.

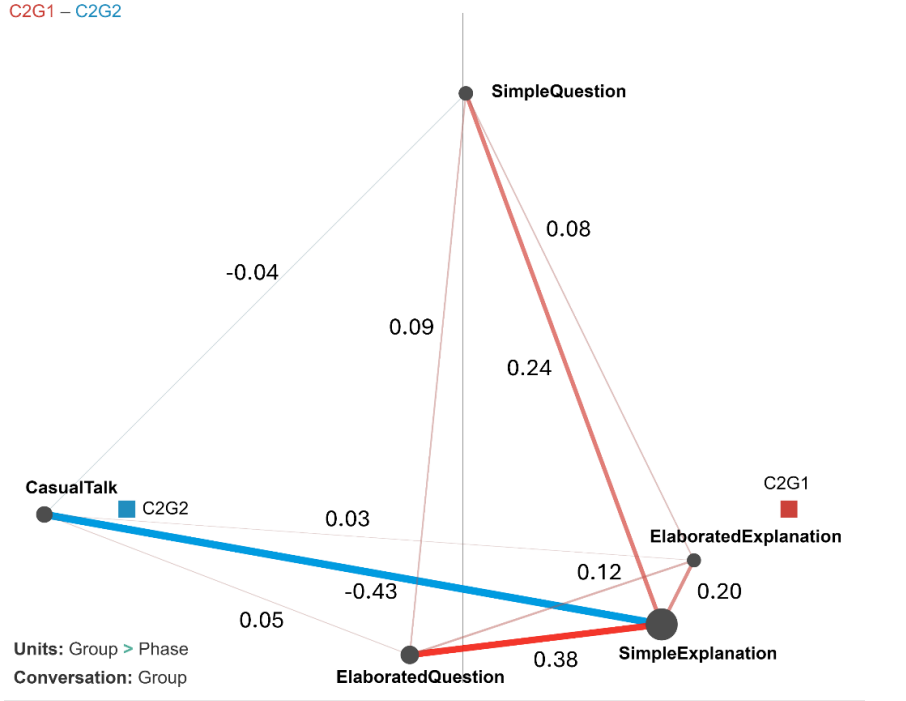
While the epistemic networks revealed dominant interaction patterns from the overall student discussions, there were considerable differences between the groups' talk connections as indicated by the positions of the group's mean (red and blue dots). This understanding is explored further in our second research question, "How does idea building vary between groups?". In comparing the epistemic networks of the two student groups

throughout the lesson, Figure 4 displays the epistemic networks for both groups, with Figure 4c showing the differences in connection strength between the groups (Group 1 minus Group 2). Clear differences in group engagement patterns emerged. The comparison network showed higher strength values for Group 1 (as compared to Group 2) in connections like SimpleExplanation-ElaboratedQuestion (0.38), SimpleExplanation-SimpleQuestion (0.27), and SimpleExplanation-ElaboratedExplanation (0.20). Conversely, Group 1 also had a high negative strength value in CasualTalk-SimpleExplanation (-0.43) compared to Group 2. This result indicates that Group 1 members likely engaged in more focused discussions and invested greater effort in deepening their understanding of the topic. We reviewed the transcript content to confirm this observation.



(a) Epistemic network of Group 1

(b) Epistemic network of Group 2



(c) Comparison network showing differences between weighted connections (G1 subtracted by G2)

Fig. 4 Epistemic networks showing student contributions and its connections between groups

Table 6 illustrates a segment of Group 1's talk interactions during the idea improvement phase (mid-lesson). The students were discussing whether to stay or relocate from the Sarawak forest and built on a suggestion from a member to construct trains in the rainforest. Student S5 suggested learning how to build a train, offering a simple explanation about technological learning. S2 challenged this idea by questioning the feasibility of suddenly learning to build a train after years of walking, providing a simple explanation of practical issues. S1 extended this by asking deeper questions about the local people's engineering knowledge. While S4 and S3 pointed out that transportation would be by boat, S3 noted that current explanations were unsatisfactory. Both S1 and S2 then posed detailed questions about the challenges of constructing a railway. S3 proposed a pragmatic solution for deforestation but lacked detail. S1 and S2 continued to question the practicality of this solution, with S2 offering detailed ideas on logistics and costs. S4 contributed a simple

Table 6 Illustration of idea building in Group 1's discussion

Turn	Speaker	Utterance	Semantic level of idea
1146	S5	Then they can learn how to make a train.	SimpleExplanation
1147	S2	If you've been walking for the past 50 years, you won't know how to make a train.	SimpleExplanation
1148	S1	It's a train. It's like, aerodynamics or something. I don't know. It's engineering. How can you just learn engineering all of a sudden? What, you just got a boat?	ElaboratedQuestion
1149	S4	This is a boat.	SimpleExplanation
1150	S3	Exactly. This is not, guys, guys, this is not a good explanation for the argument.	SimpleExplanation
1151	S5	Ya, it's like, it's like ya, S1.	CasualTalk
1152	S1	It is way more, it is way more logical to get- to-to find a job than make a train. By like what? Wood? That's not gonna make sense.	ElaboratedQuestion
1153	S2	It is not- honestly, how do you find a person to go to Penan rainforest to build a railway?	ElaboratedQuestion
1154	S3	Cut a deal with the people. They have already deforested enough.	SimpleExplanation
1155	S2	No, no, no, S3. Listen to me.	SimpleExplanation
1156	S3	So, wait. So are you relocating?	SimpleQuestion
1157	S2	How? 500 kilometres.	SimpleQuestion
1158	S1	This train doesn't make sense.	SimpleExplanation
1159	S2	No, I'm not relocating, but I don't agree with the shuttle. 500 people, no, 500 kilometres of track between-between the Sarawak rainforest and the nearest city. Through the jungle. How do you construct it? The cost will be more than we think.	ElaboratedExplanation ElaboratedQuestion
1160	S4	There is no law, no order.	SimpleExplanation

explanation about law and order, which somewhat deviated from the main infrastructure discussion. Overall, the conversation showed close connections between simple explanations, more detailed questions and elaborations, reflecting the group's progression of idea development on the feasibility of the train solution.

Table 7 illustrates a segment of Group 2's interactions as the members attempted to improve on their ideas (mid-lesson, idea improvement phase). The group discussed whether to stay or relocate from a volcano, with conversations shifting between idea building and casual talk. Student S7 initially suggested using fire on the volcano, but this idea was not developed further. S8 proposed hiring experts or obtaining equipment, offering an elaborated explanation of resource management. S7 dismissed this idea and suggested using fighter jets for defence, which was unrealistic. S12 and S8 then engaged

Table 7 Illustration of idea building in Group 2's discussion

Turn	Speaker	Utterance	Semantic level of idea
384	S7	Hey ASEAN, can you give us fire (extinguisher)? So we can spray on the volcano and kill it	SimpleQuestion
385	S8	OK. You pick, you pick this. They will monitor the volcano. (With more) money from the proposal, you can buy a lot of stuff. To get Wi-Fi and to hire full time volcanologist. Or they can invite volcanologist to do (research). That's free labour. Full-time volcanologist.	CasualTalk ElaboratedExplanation
386	S7	I mean this is not supposed. Give us fighter jets.	SimpleQuestion
387	S8	Give us fighter jets?	SimpleQuestion
388	S7	That sounds reasonable.	SimpleExplanation
389	S8	Oh yeah, it sounds very reasonable	SimpleExplanation
390	S12	Do you water on the book? You probably talk.	CasualTalk
391	S10	What is this?	CasualTalk
392	S8	Who is compiling the whole thing?	CasualTalk
393	S12	It is give us like the jet, this new information be (good). Come, coming down.	SimpleExplanation
394	S7	Guys next, what?	CasualTalk
395	S8	(Use) their own money. Because it's a good for ASEAN to raise people and (use them). So they (can help). You can't kill the volcano.	ElaboratedExplanation
396	S7	It when you put when you put water in the.	SimpleExplanation
397	S8	But it depends on how much water you put	SimpleExplanation
398	S7	Wait wait wait.	CasualTalk
399	S8	It's a super book.	CasualTalk
400	S7	The camera literally. One potato equal to 1 fighter jet. Come over here, get over here. This is a logical thing. May 1 potato for 1 fighter jet. You can trade crops for resources.	CasualTalk ElaboratedExplanation

in casual talk about fighter jets, deviating from the main discussion. S8 attempted to refocus the discussion by proposing to request funds and experts from ASEAN. However, S7 countered with another impractical idea of trading crops for fighter jets. Overall, while there were moments of constructive discussion about the volcanic crisis, the quality of the conversation was undermined by frequent shifts to irrelevant casual remarks and off-topic comments. The group focused on generating unrealistic solutions but with minimal effort to challenge or refine their ideas.

In addition, Figures 4a and 4b illustrate the means of code connections across phases in the epistemic networks, providing insight into how the groups' idea development evolved over time. In Figure 4a, the red dots represent Group 1's means across the various phases, while the blue dots in Figure 4c represent Group 2's means accordingly. Group 2's means tended to cluster around CasualTalk across phases, while Group 1's means were more distributed around the codes SimpleExplanation, ElaboratedExplanation, and SimpleQuestion. However, the results did not reveal clear distinctions across the phases, indicating that idea development occurred throughout all phases rather than building cumulatively from the initial phase of idea generation to the final phase of rise above. We conducted a qualitative analysis of the discussion content across various phases to verify this claim.

Table 8 summarises the key ideas discussed. Throughout, Group 1 focused on diverse perspectives about staying or relocating. In the idea generation phase, students debated their positions: those for staying highlighted preserving cultural identity and resisting deforestation, while those for relocating cited the risk of tribal extinction. As the discussion progressed, the pro-staying side proposed combining traditional values with modern advancements, such as building infrastructure like a train system and a "Minecraft City" to merge modern living with environmental protection. The pro-relocating side questioned the feasibility of these solutions and suggested migration benefits, such as improved living conditions. The group also discussed adaptation issues, like employment. In the closing phase, they proposed seeking ASEAN support for government measures and suggested constructing a defence wall and monorail for safety and connectivity. Despite these discussions, the group did not reach a consensus and ended with mixed solutions.

Group 2 discussed staying in or relocating from Anak Krakatoa. Initially, they debated volcanic risks and the benefits of fertile soil. The conversation included new information on soil content, agriculture, and volcanic threats. They considered using high-melting-point materials like tungsten for barriers and sought ASEAN support for a dam and expert monitoring. In closing, they proposed building a tungsten dam to continue living in Anak Krakatoa. Both groups demonstrated a good understanding of their environments and developed their topics from different angles. Common aspects included survival strategies, economic considerations, and engineering solutions. However, the deeper engagement in

Table 8 Key ideas discussed in the group conversations

	Reasons for staying/relocating discussed in Group 1 (Sarawak rainforest)	Reasons for staying/relocating discussed in Group 2 (Anak Krakatoa)
Idea generation	• Preserve culture (Identity) • Resist deforestation • Face tribe extinction	• Danger of volcanic eruption • Fertile soil
Idea improvement	• Resist by fighting/war (Sentinel people) • Adapt to modern world (no survival skills) • Build infrastructure in rainforest (train, minecraft city) • Uncertainty in government measures • Benefits of migration to modern world	• Generate income from fertile soil (nitrogen rich soil) • Danger of volcanoes (numbers of volcanoes, composition of volcanic ash) • Use a material to stop lava (Melting point/Cost of tungsten) • Trading crops e.g. potato
Rise above	• Seek protection and resources from ASEAN (materials for infrastructure) • Multiple solutions - defence wall; a monorail	• Seek resources from ASEAN (money, hire a volcanologist) • Build a dam with tungsen

questioning each other's ideas and considering mixed views in Group 1 likely contributed to more robust idea development. For example, Group 1 members integrated questions and explanations on diverse perspectives including cultural, environmental, and governmental factors, while Group 2 members focused on generating factual information about geological risks and economic benefits.

Discussion

Our findings from the students' epistemic networks align with and expand upon emerging understandings of shared epistemic agency reported in previous studies (Ma et al., 2019; Tan et al., 2022). The weighted connections between codes in epistemic networks facilitated a useful comparison for identifying contribution patterns and understanding shared epistemic agency among small groups' Knowledge Building (KB) discourse. We observed significant differences in students' contributions between online and verbal discussions within a synchronous setting. The epistemic network from Knowledge Forum (KF) discussions displayed stronger connections with higher-level semantic codes, such as elaborated questions and explanations. In contrast, the epistemic network from verbal discussions showed a greater emphasis on lower-level codes, including irrelevant talk, simple ideas, and brief factual questions and explanations. This variation in idea quality between student contributions via different discourse types aligns with findings from other comparative studies (e.g., Bagheri & Mohamadi Zenouzagh, 2021).

This finding raises questions about the impact of different discourse mediums on shared epistemic agency. We believed that several factors may have shaped this result. The observed patterns may be influenced by the inherent structure of the Knowledge Forum platform and its design. This platform supported students to use or reference KB scaffolds (sentence starters) to build ideas with different moves as well as to re-read and reflect on their ideas, which might encourage more complex interactions and deeper inquiry, thus affecting the patterns of epistemic agency. Thus, the observed growth in epistemic agency might therefore reflect the platform's affordances rather than solely students' intrinsic engagement. However, the observed patterns may also reflect differences in students' comfort with or preferences for different modes of communication. In this case, the majority of the students appeared to be comfortable posting ideas in online environments and formulating more refined contributions. Whereas, in oral discussions, the immediate real-time nature of interactions and the need to adhere to turn taking might limit the depth of individual contributions. In this case, although students talked actively in person, they tended to provide quick and concise responses rather than engaging in more elaborate explanations, affecting the overall discourse quality. More efforts are therefore needed to delve into the understanding of such impact of different discourse mediums in collaborative discussions.

From the ENA analysis, we observed detailed differences in the patterns of code connections and the depth of idea development among the groups. For instance, the results revealed notable differences in how the groups developed their ideas and used probing questions and detailed information to deepen their understanding. In Group 1, students frequently debated and critically challenged each other's positions on whether to stay or relocate, leading to stronger connections with elaborated questions and explanations. In contrast, Group 2 was less critical of their stances and focused more on generating factual information related to surviving volcanic eruptions. This observation raises questions about how inherent group dynamics influence students' shared epistemic agency. The levels of cooperation or collaboration within student groups may have shaped their contributions and affected the depth of idea development. However, examining these connections requires considering individual-level factors and other contextual elements, which are beyond the scope of the current analysis and may be explored in future research. Nevertheless, epistemic networks have the potential to further illuminate differences in student engagement within group settings, enhancing our understanding of how students interact and approach discussions with various group members. This insight could be deepened by examining additional codes, such as talk content and discourse moves within each student's epistemic networks, to better understand shared epistemic agency in small group discussions.

The ENA analysis revealed no notable differences in group contributions across the phases of Knowledge Building discourse. Patterns of students' contributions were generally consistent from the initial phase of idea generation through to idea improvement and the final phase of rise above, although slight variations in code connections were observed between groups as evidenced from the group means in the networks. This finding supports Tan et al.'s (2022) argument that idea development does not necessarily progress linearly; instead, students may engage in rich discussions throughout all phases of Knowledge Building. It also suggests that understanding shared epistemic agency in KB discourse must consider the activities and dynamics within each phase. However, it is possible that the observed consistency reflects a uniform approach to idea development among students, regardless of phase-specific activities. Future research should investigate the depth and progression of idea development in greater detail across different phases of KB discourse.

Implications and limitations

The findings from our study offer valuable insights for Knowledge Building (KB) discourse practices. Firstly, there was a noticeable difference in student engagement between verbal and KF discussions. Despite being high achievers, students' idea development in verbal discussions was significantly less effective compared to their online discussions. This suggests that students' preferences for different mediums and their contributions may vary. It also underscores the need for targeted engagement strategies to enhance verbal discourse. For example, introducing intermediate support strategies to encourage deeper thinking and more meaningful contributions could improve the quality of verbal discussions. Additionally, incorporating Knowledge Forum (KF) into lesson design is a key recommendation, as it can significantly enhance students' opportunities for engaging in collective inquiry. As demonstrated in this study, integrating KF into physical small group discussions facilitated deeper development of collective ideas.

However, simply incorporating KF as a communication tool is not sufficient. For KF to effectively support Knowledge Building, it must be embedded in lesson plans that actively promote KB processes. The lesson design in this study suggests that KB principles can significantly enhance collective inquiry. By starting with idea generation on a real-world social issue and progressing through idea refinement and group solution synthesis, the lesson provided a structured approach to fostering collective idea development. Allocating ample time (1.5 hours in this case) for group discussions and inquiry charting allowed students to engage deeply with their ideas and collaborate meaningfully. Nonetheless, these recommendations for improving practice require further examination. The effectiveness of KF integration may vary depending on its alignment with specific lesson objectives and student needs. Additionally, the study does not address potential challenges or limitations

in implementing KF, such as technical issues or varying levels of student familiarity with the platform (though students were familiar with the tool). Future research should investigate these factors to offer a more comprehensive understanding of how KF can be optimised alongside oral discussions in KB practices.

A key limitation of this study was the lack of examination of the teacher's role and facilitation in the process. For instance, the teacher's use of learning analytics—such as a word cloud and feedback on students' use of scaffolds in their online notes (via a scaffold tracker)—may have influenced the development of students' ideas. After an initial discussion where students generated ideas, the teacher conducted a brief (~10-minute) class session presenting a word cloud that highlighted frequently occurring terms from their online discussions. The teacher then encouraged students to formulate questions about these prominent terms. Although the primary focus of this study was not on the impact of learning analytics, this facilitation from the teacher might have shaped students' perspectives on their ideas, resulting in varying patterns of idea development. Previous studies in KB practice have shown that analytics feedback afforded students the ability to interpret and analyse knowledge gaps in their collective inquiry (Chen & Zhang, 2016; Yang et al., 2020; Zhang et al., 2022). For instance, Yang and colleagues (2020) found that integrating analytics feedback as a form of regular reflection led to higher levels of shared epistemic agency among students, facilitating idea negotiation, synthesis, and advanced thinking. In this case, the teacher's use of word clouds may have provided new perspectives for the students to expand upon in their talk.

However, LA intervention comes with challenges and risks to student learning as well. In this study, students might have struggled to interpret the word cloud and connect the terms to their discussions, potentially leading to confusion. The visual prominence of certain terms could have led students to focus on the most noticeable words, possibly neglecting less prominent yet important concepts that could have enriched their questions. Additionally, the whole-class discussion format might have resulted in questions that were not relevant to all groups, and insufficient instructional support on interpreting the word cloud could have diminished students' motivation to use the feedback effectively. Further research is needed to assess these risks and evaluate the actual impact of learning analytics on students' collective inquiry. Additionally, it is important to explore how learning analytics can be more effectively integrated into lesson planning.

Moreover, we observed varying contribution patterns in individual students' epistemic networks, which could provide insights into individual idea development. González-Howard and McNeill (2020) emphasise that shared epistemic agency is negotiated within a community, highlighting the need for targeted interventions. However, this aspect was not fully explored in this study, as some students contributed very few KF notes, limiting ENA analysis. Future research could delve into this area to offer insights for targeted

teacher interventions and facilitation in Knowledge Building (KB) discourse. For example, analysing individual epistemic networks could reveal whether students are actively engaging in idea development or struggling to negotiate meaning with peers. Students with patterns showing limited weighted connections (or lower-level semantic codes) may be contributing less effectively. Teachers can use these insights to offer targeted support and enhance student engagement. Finally, while epistemic network analysis offers a structured view of interactions, it may not fully capture discourse quality, individual contributions, or contextual influences. Alternative methods, such as qualitative discourse analysis or mixed-method approaches, might provide additional insights.

Conclusion

In this study, we explored the development of shared epistemic agency among students and how modelling techniques like Epistemic Network Analysis (ENA) can deepen our understanding of student engagement in Knowledge Building (KB) discourse. Our literature review highlighted the need for further research into how shared epistemic agency evolves in different discourse modes such as synchronous discussions typical of classroom settings. Our findings demonstrated how epistemic networks can characterise shared epistemic agency in both online and face-to-face discussions. However, we noted the disparity in idea quantity, with students generating more ideas in person compared to online. Despite this key limitation, we created network graphs from a small number of Knowledge Forum (KF) posts (30 to 40 notes), which revealed that more connections between sophisticated contributions from students were evident in online discussions. This suggests that students' preferences for different discourse mediums and their comfort levels influence their idea development. For example, students tended to use verbal discussions to quickly generate ideas but relied on online platforms to refine and elaborate on them. As a result, shared epistemic agency may vary by discourse mode, underscoring the need for additional support during verbal discussions to enhance collective inquiry. Moreover, the study revealed variations in idea-building across groups and indicated that not all students were equally motivated or contributed effectively to deepening collective knowledge, especially in oral discussions. Real-time feedback on students' epistemic networks may be developed to afford teachers the opportunity to enhance group discussions and support more productive engagement. Overall, these findings highlight ENA's value in assessing KB discourse in both online and verbal modes, offering insights into student engagement in synchronous discourse. Future research may explore cross-group interactions using ENA while also considering contextual factors that influence engagement.

Abbreviations

KB: Knowledge Building; ENA: Epistemic Network Analysis; KF: Knowledge Forum.

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Authors' contributions
The individual contributions of the authors to the manuscript are specified in this section. The first author contributed to the conceptualisation of the research design, implementation, data collection, data analysis, and manuscript preparation. The second author contributed to the conceptualisation of the research design, implementation, data collection, data analysis, and manuscript preparation. The third author contributed to the implementation and data collection, data analysis, and manuscript preparation. The last author contributed to the preparation of the manuscript.

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Availability of data and materials
Data is not available for public dissemination or storage due to university's privacy and data protection regulations and the need to protect identities of minors involved in the project.

Declarations

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The authors declare that they have no competing interests and that this manuscript and its content is not submitted nor reproduced in other journal publication.

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