Intern. J. Comput.-Support. Collab. Learn (2023) 18:353–391
https://doi.org/10.1007/s11412-023-09403-2

Promoting knowledge building through meta-discourse and epistemic discourse understanding

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Received: 7 August 2022 / Accepted: 14 June 2023 / Published online: 10 August 2023

Abstract
This study examined students' understanding of, and reflective inquiry into discourse, specifically their epistemic discourse understanding and meta-discourse, and investigated their roles and relationships in fostering productive inquiry in knowledge building. The participants comprised two classes of ninth grade visual arts students inquiring into art and design. The experimental class ($n=31$) engaged in knowledge building using Knowledge Forum® (KF) enriched by meta-discourse involving reflective inquiry and classroom discussion about their discourse. The comparison class ($n=32$) similarly worked on KF but using regular classroom discussion. Quantitative analysis indicated that the experimental group students, who engaged in meta-discourse, showed a deeper epistemic discourse understanding and domain knowledge than the comparison students, and that epistemic discourse understanding was associated with productive KF inquiry. Qualitative analysis of the classroom meta-discourse showed that metacognitive reflection, principle-based inquiry, and idea development (i.e., meta-epistemic reflection, meta-epistemic principles, and meta-epistemic theory) support epistemic understanding and productive inquiry. We also discuss the implications of using meta-discourse to enhance epistemic discourse understanding and productive inquiry for knowledge building and computer-supported collaborative learning.

Keywords Knowledge building · Collaborative inquiry · Discourse · Meta-knowledge · Knowledge Forum

Introduction

Discourse is central to learning, thinking, and understanding (Mercer & Littleton, 2007; Resnick et al., 2015), and is pivotal to the creation of new ideas and knowledge advances (Scardamalia & Bereiter, 2021). In today's knowledge era, students need to develop the capacity to inquire, innovate, and engage in creative knowledge work and progressive

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discourse (Chan & van Aalst, 2018; Scardamalia & Bereiter, 2014, 2021). Considerable progress has been made in designing computer-supported collaborative learning (CSCL) environments (Cress et al., 2021). However, the collaborative problem-solving inquiry remains difficult (Kuhn et al., 2020), and students often engage in information-sharing rather than knowledge-building discourse (van Aalst, 2009). Supporting students to engage in productive discourse for creative knowledge work is an important goal of CSCL but continues to be challenging (Zhang et al., 2020).

While most CSCL studies have investigated the collaborative process of the discourse itself, there is limited research on the meta-level understanding into the collaborative discourse. Meta-level understanding refers to students' understanding of the goals and strategies of collaboration (Kuhn et al., 2008) and includes students' reflections on and inquiry into their discourse, which is called meta-discourse (Bereiter & Scardamalia, 2016). Meta-discourse, a form of meta-level understanding, has been defined as the discourse about discourse, with students reflecting on their ongoing discourse, tracing highlights of the discussion and ongoing work (Bereiter & Scardamalia, 2016). Meta-level understanding, involving goals, strategies, and reflections on discourse, provides the foundation for collaboration (Kuhn et al., 2013) and supports students' epistemic agency and collective responsibility for knowledge advancement (Bereiter et al., 2019). Some recent studies have illustrated the importance of a meta-level understanding of discourse; for example, Kuhn et al. (2020) examined students talking about group processes as opposed to the content, and Yuan et al. (2022) investigated metacognitive conversations in the classroom, in which students discussed their ongoing discourse in knowledge building. While there has been some interest thus far, limited attention has been given to systematic designs and investigations into the dynamics and mechanisms for promoting students' meta-level understanding of discourse for productive inquiry in CSCL.

This study examined the meta-level understanding of discourse described above, situated in the context of knowledge building, supported by Knowledge Forum®. Knowledge building is a major CSCL model in which students engage in knowledge creation using progressive discourse involving ever deepening and continued inquiry to advance community knowledge (Scardamalia & Bereiter, 2014). The knowledge building/creation model is more than a pedagogical approach; it is also an epistemological model of how knowledge is advanced in the community (Chan & van Aalst, 2018), and an emergent CSCL approach using progressive discourse for sustained idea improvement. Bereiter et al., (2019) discussed the need to consider the meta-knowledge of knowledge building, similar to meta-level understanding, which involves a rise-above layer of epistemic and metacognitive processes in supporting students' creative and productive inquiry.

The present study examined two key ideas relevant to meta-level understanding (meta-knowledge) in promoting productive inquiry in knowledge building. The first is epistemic discourse understanding, which is grounded in meta-knowing knowledge (Kuhn et al., 2008) that involves knowledge about the goals, standards, and criteria of discourse. In this study, the idea of epistemic discourse understanding is drawn from three modes of discourse (van Aalst, 2009) and the epistemic cognition model of Aims, Ideals, and Reliable processes (AIR; Chinn & Rinehart, 2016; Chinn et al., 2014). In light of the substantial evidence in support of the role of students' epistemological understanding in learning, thinking, and understanding (Greene et al., 2016), this study examined the dialogic aspects of epistemic cognition embedded in social and discourse practices (Knight & Littleton, 2017; Sandoval, 2012).

The second is students' meta-discourse, which involves reflection on and inquiry into discourse and theories in action, grounded in meta-strategic knowledge (Kuhn et al., 2008).

In CSCL discourse, students' ideas are often scattered and fragmented (van Aalst, 2009), and they often find it difficult to see the conceptual landscape of their collective work for identifying knowledge advances (Zhang et al., 2012). Preliminary evidence from online and offline meta-discourses that involve writing online e-portfolios (Lei & Chan, 2018) and classroom metacognitive conversations (Yuan et al., 2022) indicates that students can connect disparate ideas and deepen their discourse for community knowledge advancement.

Various studies have provided preliminary support for meta-discourse processes, including students discussing their group activities (Kuhn et al., 2020), engaging in reflective activities and inquiring in argumentative discourse (e.g., Felton, 2004; Iordanou, 2022; Shi, 2019), and developing metacognitive conversations in knowledge building (Yuan et al., 2022). These studies have generally focused on reflection on group activities and discourse content but not the epistemic components of discourse. Specifically, the goals, values, and criteria that students consider to be important for productive discourse and the relationship between epistemic discourse understanding and meta-discourse have not been investigated. Primarily, the scope and nature of meta-discourse involving metacognitive, epistemic, and conceptual aspects and how they would influence students' productive inquiry and knowledge building need to be examined.

In summary, this study examined the nature, dynamics, and roles of epistemic discourse understanding and meta-discourse for promoting CSCL discourse in the context of productive knowledge-building inquiry. We designed a knowledge-building environment enriched with meta-discourse in which students reflected on and inquired into their discourse processes, enriching epistemic components and embedding idea development. We investigated whether and how this meta-discourse approach supported students' epistemic discourse understanding and productive knowledge-building inquiry with the goal of discovering theoretical and design implications.

Literature review

Knowledge building and productive inquiry

Knowledge building is a CSCL model that examines how knowledge is collectively created and improved. Participants in the knowledge-building community engage in collective inquiry that adds value to their community, akin to the value added by scientists and scholars to their communities (Scardamalia & Bereiter, 2014). Productive inquiry in knowledge building goes beyond sharing information, as it continuously advances existing community knowledge through the collective improvement of ideas. Discourse is critical to knowledge building, as improving discourse improves knowledge building (Bereiter & Scardamalia, 2016). In knowledge-building discourse, when different ideas are posed, questioned, and examined, new perspectives emerge—participants contribute and synthesize ideas, improve theories, and identify gaps to deepen the inquiry. Improving these discourse processes would help to advance individual and collective knowledge for community growth.

Knowledge Forum® (KF, Fig. 1) is central to knowledge building, a multimedia collaborative online platform (Scardamalia, 2004) equipped with a rich array of features that enable students to advance their collective knowledge through progressive discourse. Scardamalia (2002) proposed 12 principles (e.g., epistemic agency) that are the essential themes of knowledge building. In knowledge-building classrooms, students use online and offline discourse to advance their collective knowledge. Students

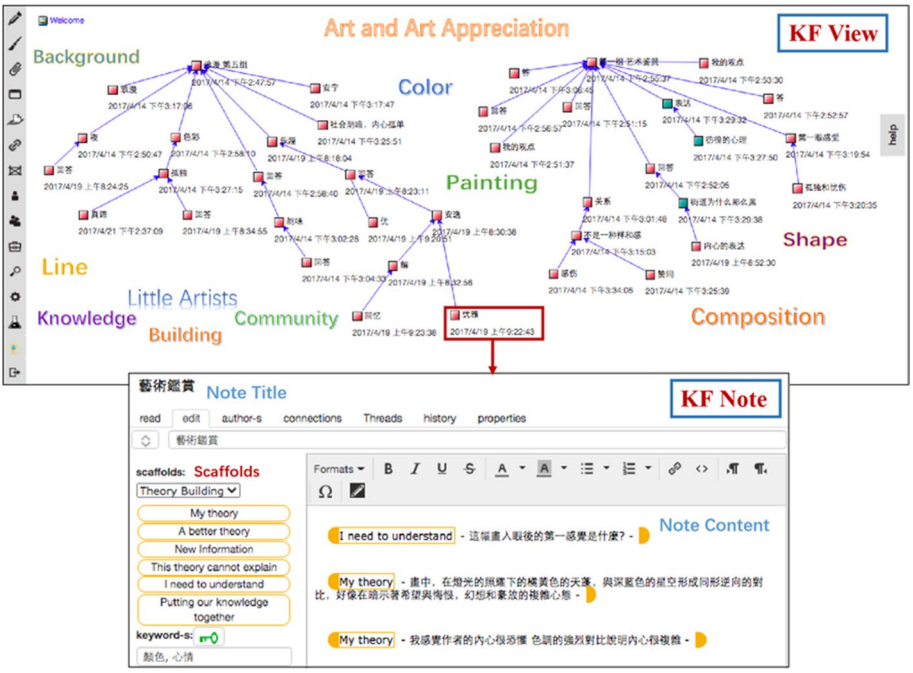


Fig. 1 Key Knowledge Forum features are displayed, including "View" as a collaborative workspace (top) and scaffolds (thinking prompts, e.g., "My theory," "I need to understand") for writing Knowledge Forum notes (bottom)

begin with classroom discourse and then continue their collective inquiry into authentic problems in KF. Teachers and students engage in classroom talks as they reflect on the progress of their online KF discussion, which helps them deepen their KF discussion for productive inquiry. The study specifically investigated the interface of KF and classroom discourse using meta-discourse that involves students reflecting and inquiring into KF discussion to promote advances.

In knowledge building, progressive discourse for continual idea improvement is pivotal (for a review, see Chen & Hong, 2016). Distinct from other discourse patterns, knowledge-building discourse is not primarily expository or argumentative; focus is given to progressive idea improvement (Scardamalia & Bereiter, 2021). Various analytic schemes (e.g., ways of contribution; Chuy et al., 2011) emphasize community processes to examine productive inquiry. Specifically, van Aalst (2009) discussed three discourse patterns to depict the shifts towards community-based knowledge building: (i) knowledge sharing (idea accumulation and sharing), (ii) knowledge construction (constructing understanding with explanations), and (iii) knowledge creation (progressive discourse with sustained idea improvement). To assess productive inquiry, KF writing can be examined using these three discourse patterns and explanatory discourse moves for collective idea improvement. Various knowledge-building studies also examined improvement in domain knowledge to illustrate that collective knowledge diffused to individuals (for a review, see Chen & Hong, 2016).

Epistemic discourse understanding and nature of discourse

In line with Kuhn's explanation of meta-level understanding about argumentation (2008), epistemic understanding involves meta-knowing knowledge about goals, standards, and strategies of discourse. We first highlight that discourse is epistemic in nature—historically, discourse is the basis of knowledge creation in all disciplines. Currently, new knowledge is created through progressive discourse in innovative organizations (Bereiter & Scardamalia, 2005; Chen & Hong, 2016). Many studies have shown how epistemic practice can be advanced through discourse (Greene et al., 2016) and discourse for socializing intelligence (Resnick et al., 2015). In terms of extending individual epistemic cognition, there is increased interest in socializing epistemic cognition. When engaging in knowledge, knowing, or understanding the world, people fundamentally engage in social practices of discourse; group processes and practices mediate epistemic cognition (Knight & Littleton, 2017). Sandoval (2012) also argued for a situated approach to epistemic cognition, alluding to the importance of examining the epistemic aspects of discourse.

Substantial theoretical and empirical literature has addressed how one's epistemological understanding of knowing and knowledge influences one's thinking, learning, and understanding (e.g., Greene et al., 2016). In science learning, students construct scientific understanding both by discussing the scientific content and by developing an epistemic understanding of the nature of science (e.g., the knowledge about how to do science; Sandoval, 2014). Despite the advances in research, relatively little is known about epistemic discourse understanding. As discussed above, epistemic understanding has been conceptualized as a fundamental meta-level foundation of argumentative reasoning (Kuhn et al., 2008). Specifically, students' meta-level understanding of the goals of argumentation is needed, which goes beyond performance in argumentation skills. Based on these studies, we propose that epistemic discourse understanding also influences students' knowledge-building discourse activity. For example, if students think the goal of discourse is information sharing, they will engage in sharing; if they think the goal is meaning making, they will work on co-constructing understanding. Only when they think of knowledge building as involving collective community advancement will they focus on rise-above and synthesis strategies.

Research in knowledge building has shown how knowledge-building discourse advances students' epistemic views (Chen, 2017; Hong et al., 2016) and students' views of knowledge-building discourse predict scientific understanding (Lin & Chan, 2018). Despite the pervasive role of discourse in knowledge building, limited research has been conducted examining students' epistemic discourse understanding; that is, how these epistemic views are manifested, how these views may contribute to productive online inquiry, and how individual and collective epistemic views can be fostered in knowledge building environments. The present study addresses current research gaps by examining how students' epistemic discourse understanding is manifested and how it influences productive KF inquiry.

This study draws from the AIR model to examine students' understanding of discourse pertaining to the three components of the AIR model. The first component refers to aims and value (learners' goals and the value they place on them), the second component is epistemic ideals (standards or criteria by which an individual assesses the achievement of epistemic ends), and the third component is the reliable processes for achieving epistemic ends (whether the processes/strategies are reliable for achieving

epistemic products) (Chinn & Rinehart, 2016; Chinn et al., 2014). We adapted these components to students' understanding of aims, criteria, and strategies for achieving knowledge-building discourse. Research has examined how students' evaluation of epistemic criteria supports the construction of scientific models and the evaluation of scientific visual representations (e.g., Barzilai & Eilam, 2018; Pluta et al., 2011; Ryu & Sandoval, 2012). Building on prior works, this study examined students' epistemic discourse understanding adapting from the AIR model (Chinn et al., 2014) and investigated its role in productive knowledge building.

Meta-discourse as reflection and inquiry into discourse

Meta-discourse refers to students' reflection, discussion, and inquiry into their discourse to reflect on what they have experienced and the identification of gaps for possible directions (Bereiter et al., 2019; Chan et al., 2019; Zhang et al., 2012). Meta-discourse is different from the linguistic term that involves markers and stances in discourse. Primarily, it is student discourse about their discourse as they reflect on and synthesize disparate and promising ideas to advance community knowledge (Zhang et al., 2012). The research on meta-discourse in knowledge building includes online and classroom discussions about discourse. Regarding online discussion, meta-discourse has been examined with students writing e-portfolio notes synthesizing collective knowledge guided by epistemic goals and principles (Lei & Chan, 2018; van Aalst & Chan, 2007). Regarding classroom discussion, meta-discourse involves metacognitive conversations (Yuan et al., 2022) and classroom talk (Resendes et al., 2015), with students discussing and reviewing their ongoing work on KF. Following prior research, this study uses the term meta-discourse to refer to classroom talk in knowledge building (see Resendes et al., 2015).

Although some studies have shown the importance of meta-discourse (Yuan et al., 2022; Zhang et al., 2012, 2020), the focus has been on conceptual advances; relatively less is known about epistemic dimensions of discourse. This study addresses current gaps to examine more systematically the nature, characterization, and mechanism of meta-discourse encompassing metacognitive, epistemic, and conceptual dimensions of discourse. Specifically, this study involved design of a computer-supported knowledge-building environment enriched with meta-discourse to promote productive inquiry. A key goal was to characterize meta-discourse. To that end, we draw from the literature to identify possible areas of reflection: (a) reflections on and metacognitive awareness about collaborative activities, (b) reflections on the goals/standards/strategies of discourse, and (c) reflections on the topic knowledge developed in the discourse.

First, it has been postulated that meta-discourse involves metacognitive reflection, which is considered important for productive collaborative inquiry in CSCL (Järvelä & Hadwin, 2013). Research on knowledge-building discussion has shown the role of social metacognition, in which students help their peers become more aware of their thinking by making their ideas public (Yang et al., 2020). The role of reflection combined with argumentation practice has been shown to have a greater influence on developing argument skills than practice alone (e.g., Felton, 2004; Iordanou, 2022; Shi, 2019). Shi (2019) found that an experimental class that engaged in evidence-based joint metacognitive reflection with argumentation practice outperformed the comparison class that engaged in argumentation practice only. Iordanou (2022) had experimental students use reflective activities when engaging in dialogic argumentation and found they developed greater argumentation skills than students who did not engage in reflective activities, suggesting that metacognitive reflection on inquiry is

required. Metacognition has been extensively studied in connection with regulation in CSCL, but the focus has been placed on specific activities. In our work, we examined metacognitive reflection at the discourse level to help students organize the flow of their discussion.

Second, meta-discourse includes epistemic elements, namely the goals, standards, and strategies for discourse that are linked to principle-based understanding in knowledge building. Research has suggested that inquiring into principles helps students understand the epistemic criteria of knowledge building and enhances productive inquiry. For example, van Aalst and Chan (2007) designed an e-portfolio approach guided by an adapted set of principles to help high-school students reflect on their peers' conceptual understanding when tracking the knowledge-building discussions, and Hong et al. (2015) explored principle-based assessment tools to help students engage in community knowledge advancement. The literature has shown that pedagogical design emphasizes principles; however, further investigation is needed to understand whether and how students explicitly inquiring into principles in meta-discourse helps them develop epistemic discourse understanding and productive inquiry.

Third, meta-discourse includes theory building in alignment with current research on meta-discourse (Resendes et al., 2015; Zhang et al., 2012). Meta-discourse emphasizes theory building by revising ideas, reflecting on the progress of knowledge-building efforts, and identifying problems that lead to further inquiry. Zhang et al. (2012) showed that fifth/sixth grade students could engage in meta-discourse by identifying good questions or co-monitoring key concepts for deeper inquiry. Yuan et al. (2022) examined metacognitive conversations to help students reflect on the discourse and connect different body system parts for idea improvement. The literature on meta-discourse in knowledge building has highlighted conceptual knowledge for improvable ideas and community knowledge (Scardamalia, 2002). Knowledge-building discourse involves horizontal and vertical dimensions that integrate multiple ideas and emphasize rise above and theory building (Wegerif, 2013; Zhang et al., 2020). However, how students work on meta-conceptual aspects in meta-discourse needs further examination.

Related to the above, we discuss the rationale for the design and argumentation in support of the importance of meta-discourse. First, meta-discourse supports a metacognitive understanding of the process of reflecting on and revising what the community has accomplished. When meta-discourse takes place in a collaborative knowledge-building context, it can foster student knoweledge contribution and extention. Second, meta-discourse involving epistemic elements can help students to focus on the goals, standards, and strategies of discourse. With such understanding, students can better engage in discourse using core knowledge-building principles and practices. Third, meta-discourse involves conceptual elements and student engagement in the authentic practice of knowledge building and idea development. Students should reflect on their discourse processes and epistemic elements as they engage in rich knowledge-building and theory-building processes. These experiences of theory building can provide the background for them to work like scientists and continue the sustained inquiry. Building on the above studies, this study examines how students engage in the meta-discourse processes involving metacognitive, epistemic, and conceptual reflections and investigates whether students who engage in meta-discourse processes achieve deeper epistemic discourse understanding and greater domain knowledge.

The present study

Developing productive collaborative inquiry and discourse is a major theme in CSCL (Cress et al., 2021) and knowledge building (Chen & Hong, 2016). However, few studies have examined meta-level understanding, which can provide a foundation for collaborative

inquiry (Kuhn et al., 2013). Specifically, few studies have investigated what students think about the epistemic aspects of discourse, including goals, criteria, and processes; how these understandings influence productive inquiry; and how they can be promoted in the knowledge building and CSCL contexts. There has been some recent interest in examining reflection on discourse, such as reflective activity in the context of argumentative discourse (Iordanou, 2022), meta-talk involving reflecting on group activity (Kuhn et al., 2020), and metacognitive conversations in knowledge building (Resendes et al., 2015; Yuan et al., 2022). Primarily, the focus has been placed on conceptual and metacognitive dimensions. In this study, we characterize classroom meta-discourse and examine further the metacognitive, epistemic, and conceptual elements of it and their roles in epistemic discourse understanding and productive inquiry.

This study postulates a framework (Fig. 2) for examining the conceptual relationships among meta-discourse, which includes (a) reflections on collaborative activities and processes, (b) reflections on principles, and (c) reflections on concepts; and epistemic discourse understanding, which includes the goals, standards, and reliable processes of discourse. We also investigated their roles in promoting productive inquiry, which includes collective idea improvement, knowledge-building discourse moves, and domain knowledge.

Previous research has shown how students' epistemic views of knowledge building (Lin & Chan, 2018) and meta-discourse influence knowledge advancement (Resendes et al., 2015; Zhang et al., 2012) and domain knowledge (Lin & Chan, 2018). This study further investigates the interrelationships among meta-discourse, epistemic discourse understanding, and productive inquiry. We designed an epistemically rich knowledge-building environment incorporating meta-discourse designs. Students explicitly reflected on and discussed their KF discourse in classroom talks relating to the metacognitive, epistemic, and conceptual elements. We conjecture that meta-discourse would help students think about the epistemic nature and role of discourse that influences their productive inquiry and knowledge advancement.

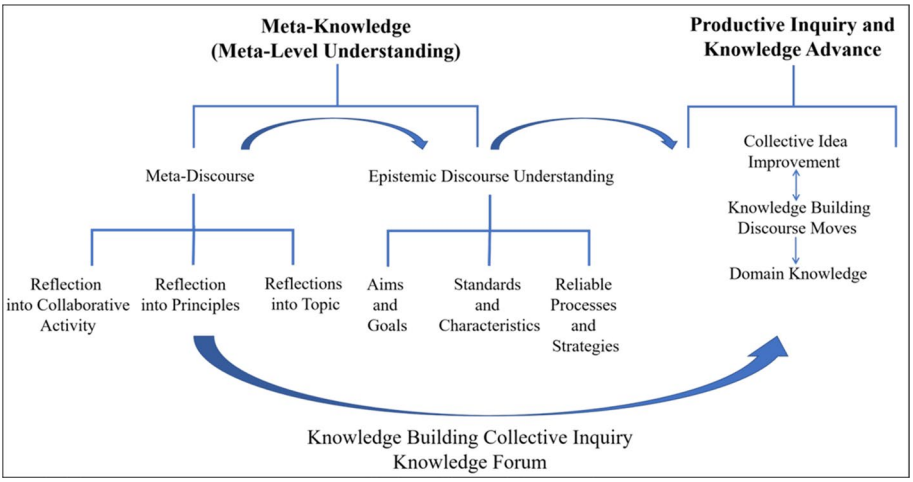


Fig. 2 Examining meta-discourse, epistemic discourse understanding, and productive inquiry in knowledge building

There are several possible explanations for why meta-discourse supports epistemic discourse understanding, productive inquiry, and, subsequently, the improvement of domain-specific knowledge. As discussed in the literature above, these reasons may be related to different dimensions and elements of meta-discourse. First, metacognition involving collective reflection supports students' meta-level awareness of the lack of knowledge about the nature of productive inquiry. Second, understanding of the goals, criteria, and standards of discourse helps students develop a culture and norms of knowledge building. Third, meta-discourse about topics and concepts supports advances in idea development and domain knowledge.

In summary, we investigated the design, roles, and processes of a computer-supported knowledge-building environment, which has been enriched by a meta-discourse design for examining and developing students' epistemic discourse understanding, productive online inquiry, and knowledge advancement. Two classes were included in the study: an experimental class, which engaged in meta-discourse processes, and a comparison class, which worked in a regular knowledge building environment. Three research questions were addressed:

1. How did the experimental and comparison students differ regarding their epistemic discourse understanding and domain knowledge with the meta-discourse intervention in the knowledge building environment?
2. How did the experimental and the comparison students engage in Knowledge Forum inquiry, and how were students' epistemic discourse understanding related to their knowledge building inquiry on Knowledge Forum?
3. How did the students engage in meta-discourse reflecting on and inquiring into their discourse for epistemic discourse understanding and knowledge building?

Methods

Participants and contexts

Students (aged 14–15 years) in two grade 9 visual arts classes at a Hong Kong secondary school and their teacher (with approximately 30 years of teaching experience) participated in the study. Thirty-one students (14 females, 17 males) engaged in a meta-discourse design enriched knowledge building class. A comparison class of 32 students (15 females, 17 males) engaged in regular knowledge building inquiry. A quasi-experimental design was employed, and the baseline data indicated no significant differences in prior domain knowledge ($F(1, 57) = 1.037$, $p = 0.313$) between the classes, suggesting the two classes were of similar backgrounds (see later sections on domain knowledge).

Designing the knowledge-building environment augmented by meta-discourse

The study lasted 4 months and included 15 weekly lessons. The experimental and comparison classes studied the same curriculum unit on art appreciation and used KF. The key intervention in the experimental class was the enriched knowledge building environment using meta-discourse to support students' development of discourse understanding for productive inquiry. While both classes experienced knowledge building using KF, specific designs were employed (Fig. 3) in the experimental class to support the meta-discourse processes. Specifically, the experimental students engaged in classroom

Four-component pedagogical design	Purpose	Designing the knowledge building environment augmented by meta-discourse	Experimental Class	Comparison Class
Component 1: Creating a collaborative knowledge building classroom culture for productive inquiry (Lessons 1 to 4)	Creating an inquiry culture and inviting students to generate initial ideas. Creating a collaborative and community culture and developing students' collaborative skills. Scaffolding students to engage in metacognitive reflection processes.	1. Students were involved in group inquiry work and created mind maps to illustrate their understanding of art. 2. Students participated in group discussions and activities and presented their group to the whole class. 3. Students used "scaffold cards" (e.g., "I need to understand" "My theory" "New information") to construct a KB Wall by making ideas public to the community. 4. The experimental students engaged in classroom meta-discourse to collectively reflect on KB Wall ideas by monitoring the trajectory of idea development and the features of progressive discourse.	√ √ √ √	√ √ √
Component 2: Developing problem-centered inquiry using Knowledge Forum (Lessons 5 to 7)	Prompting students to participate in the online discussion. Prompting students to reflectively analyze their Knowledge Forum discussion.	5. Students generated questions, built on ideas, and revised theories on Knowledge Forum view. 6. The teacher provided students the quantitative participation log data (e.g., number of notes created) to encourage students to contribute to their Knowledge Forum view. 7. The experimental students engaged in classroom meta-discourse to collectively reflect on the progress of their knowledge building effort in Knowledge Forum. Groups of students were also encouraged to reflect their online discussion weekly.	√ √ √	√ √
Component 3: Explicit reflection, inquiry, and comparison into knowledge building discourse and principles (Lessons 8 to 12)	Scaffolding students to collectively reflect on their online discussion from the perspectives of content knowledge and the nature of discourse. Linking the understanding of knowledge building principles and online discussions.	8. Students continued to inquire into different problems using Knowledge Forum. 9. The experimental students inquired into knowledge building principles and used graphics/concept maps to represent understanding of principles. 10. The experimental students conducted collaborative reflection on Knowledge Forum discussions by comparing different threads of Knowledge Forum discourse. 11. The experimental students engaged in classroom meta-discourse to reflect on and deepen the inquiry into the nature of discourse.	√ √ √ √	√
Component 4: Identifying key themes and deepening inquiry (Lessons 13 to 15)	Supporting students to identify gaps and develop high-level conceptualization of ideas and engage in further inquiry	12. Students continued inquiry on Knowledge Forum and classroom discussions. 13. The experimental students engaged in classroom meta-discourse by identifying core problems and themes for theory revision and further Knowledge Forum inquiry while the comparison students continued to work in Knowledge Forum.	√ √	√

Fig. 3 The four-component knowledge building design augmented by meta-discourse

talk using meta-discourse to help them reflect metacognitively on the trajectory of idea development, to identify goals, standards, and strategies of productive discourse through inquiry into knowledge-building principles, and to deepen core problems from KF discussion for sustained inquiry. The teacher employed a four-phase design commonly used in other knowledge-building classrooms (Chan, 2011) enriched with meta-discourse designs, which can be described in terms of the following components:

Component 1: Creating a collaborative knowledge-building classroom culture for productive inquiry (lessons 1–4). The teacher introduced the main topic (what is art?), and the students worked in groups to construct artefacts, generate ideas and questions, and make their ideas public for inquiry. For example, the student groups created a mind map that showed their understanding of art reflected as they conducted discussions and activities in small groups. The students also constructed a knowledge-building wall (KB wall) that visualized their ideas and questions in an analogous fashion to the KF, which made community knowledge visible and extendable (Fig. 1). Scaffold cards, such as "I need to understand" were provided to support their knowledge-building writing on the KB wall. Additionally, the experimental students engaged in meta-discourse, in which they reflected on their classroom discussions and what they had noticed from the KB wall discussion, a process that gave them the opportunity to monitor the trajectory of their idea development (e.g., "Initially, I thought… but now I think…") and the features of progressive discourse (e.g., "others can continue to build on and inquire further").

Component 2: Developing problem-centered inquiry using KF (lessons 5–7). The students worked with the teacher and selected several meaningful questions generated from the KB wall to continue their inquiry in KF. That is, they generated questions, co-constructed explanations, searched for information, and revised their ideas. The teacher

regularly showed the quantitative participation log data from KF (e.g., number of notes created, number of scaffolds used) to motivate the students to contribute to the community. The experimental students additionally engaged in classroom meta-discourse by reflecting on and inquiring into their KF discussions.

Component 3: Explicit reflection, inquiry, and comparison of knowledge-building discourse and principles (lessons 8–12). In lessons 8–12, the students continued to inquire into different problems using KF. The experimental students performed two collaborative tasks. First, the teacher introduced knowledge-building principles (Scardamalia, 2002), which were used by the teachers and students to reflect on core ideas and standards of knowledge building. This study employed four principles (i.e., epistemic agency, improvable ideas, community knowledge, and use of authoritative information) as standards for what constitutes good discourse and knowledge building. Each student group selected one of the principles and made drawings/mind maps to illustrate their understanding of the principles in relation to their KF work, followed by group sharing and meta-discourse. Second, the student groups examined the KF discussion note structure drawn from the databases of the two classes and made artefacts/drawings to reflect on the discourse patterns and generate different shapes (e.g., a "straight-line" or an "octopus" pattern) to describe their understanding of the nature of their KF discussion. Third, the teacher facilitated a meta-discourse with the entire class to help students reflect on and deepen their inquiry into the goals, characteristics, and processes of discourse (e.g., "What do you see in these two patterns?").

Component 4: Identifying key themes and deepening inquiry (lessons 13–15). Students continued their inquiry on KF and classroom discussions and engaged in more classroom meta-discourse by identifying promising themes to deepen their KF inquiries. Similar to the meta-discourse designs in other studies (e.g., Resendes et al., 2015), the students were engaged in meta-discourse in which they reflected on theories and explanations about domain knowledge regarding art. Classroom meta-discourse and KF writing were intertwined for reciprocal influence. The KF discourse and interesting questions/ideas became the basis for the classroom meta-discourse. In return, the meta-discourse generated new insights, and the students returned to KF to deepen their collective inquiry (see the Results section).

Instruction in the comparison class

The students in the comparison class inquired into the same topics and were taught by the same teacher as the experimental class. In component 1, both classes conducted the same activities, including group work for mind map creation and KB wall construction. The teacher facilitated a discussion with the comparison group on the ideas posted and domain knowledge of the discourse; however, there was no meta-discourse to help them reflect on the discourse processes/features of discourse or the development of collective ideas for theory-building. In components 2 and 3, both classes inquired in KF and were provided with quantitative participation log data (i.e., how many times they wrote on KF, and how often they read KF notes). The comparison students did not engage in classroom meta-discourse by collectively inquiring into knowledge-building principles or comparing KF discourse. In component 4, the two classes continued to inquire into different problems using KF. The experimental students engaged in classroom meta-discourse to identify themes for theory-building and deepening their inquiry, while the comparison students shared what they wrote on the topics, not emphasizing reflection for idea development.

Figure 3 summarizes the pedagogical design for the experimental and comparison classes. Both classes worked on the same topic in KF. Following the research design adopted by previous studies on knowledge building (e.g.,Resendes et al., 2015; Yang et al., 2020), we used a quasi-experimental design with a comparison class combined with in-depth process analyses and multiple data sources to rigorously test the effects of meta-discourse design while also capturing the processes simultaneously. We examined the role of students' meta-discourse and epistemic discourse understanding in promoting knowledge-building inquiry and knowledge advancement.

Data sources and analyses

Figure 4 shows a summary of our research focus, research questions, and analyses. The details of the data sources and variables for analysis are elaborated below.

Knowledge Forum engagement and productive collective inquiry

Database usage and Knowledge Forum (KF) participation We first provided basic data on student participation in KF using log data adapted from the Analytic Toolkit (Burtis, 1998). These measures included the number of KF notes created, the number of KF build-on notes, the percentage of KF notes read, and the number of KF scaffolds used. Scaffolds

Research focus	Research questions	Analyses
Differences of epistemic discourse understanding and domain knowledge	RQ1.How did the experimental and comparison students differ regarding their epistemic discourse understanding and domain knowledge with the meta-discourse intervention in the knowledge building environment?	• Analysis of epistemic discourse understanding using adapted AIR coding scheme; comparison between the two classes • Analysis of domain knowledge adapted from school marking scheme; comparison between the two classes
Student engagement in knowledge building: collective idea improvement; Knowledge Forum online discourse and development with questioning, theorizing, and community; relationships between Knowledge Forum engagement, epistemic discourse understanding, and domain knowledge	RQ2. How did the experimental and the comparison students engage in Knowledge Forum inquiry, and what were the relationships between the students' epistemic discourse understanding and knowledge building inquiry on Knowledge Forum?	• Descriptive data of database usage and Knowledge Forum participation • Analyses of productive discourse using (a) inquiry thread analysis for collective idea improvement; (b) KBDeX keywords total degree centrality for collective idea improvement (comparison between experimental and comparison classes); and (c) KBDeX keywords usage for collective knowledge building inquiry (comparison between different epistemic discourse understanding groups) • Analysis of productive discourse using discourse moves as units of analysis, discourse moves reflecting questioning, theorizing, and community; and comparison between classes • Analysis of relationships between epistemic discourse understanding and discourse moves using group comparison • Correlation analysis of epistemic discourse understanding, domain knowledge, Knowledge Forum participation, and Knowledge Forum high-level discourse moves • Regression analysis to examine the predictors of domain knowledge
Classroom dynamics of meta-discourse in a knowledge building classroom	RQ3. How did the students engage in meta-discourse reflecting on and inquiring into their discourse for epistemic discourse understanding and knowledge building?	• Qualitative analysis of students' engagement in meta-discourse using multiple data sources including classroom videos, field notes, Knowledge Forum writing, and student artefacts including group concept-maps and notes from Knowledge Building Wall

Fig. 4 Summary of research focus, research questions, and analyses

refer to the thinking prompts students used when writing on KF, which were designed from theory building (i.e., "My theory," "I need to understand," "New information") (see Fig. 1). Student use of these KF functions (write, read, build-on, scaffolds) provided a rudimentary measure of their participation in the knowledge-building inquiry.

Collective idea improvement and inquiry thread analysis The students' productive inquiry was examined based on their collective idea improvement (Fig. 2). KF discourse was parsed into inquiry threads—threads of community members' notes addressing key conceptual problems (Zhang et al., 2007). Each thread represented a problem that students inquired into. The students' KF discourse was classified into three discourse patterns (van Aalst, 2009) that characterized an increasing level of sophistication in knowledge building as knowledge creation: knowledge sharing (idea accumulation and sharing of opinions and information), knowledge construction (constructing ideas using explanations for problem-solving), and knowledge building (progressive discourse with sustained idea improvement, reflections for rise above and collective knowledge advancement) (see Table S1). Studies on knowledge building have used this scheme to examine collective knowledge advancement (e.g., Yang et al., 2020). A second rater coded 30% of the inquiry threads into the three patterns, and the interrater reliability based on the Cohen's Kappa was 0.83.

Collective idea improvement and KBDeX We also examined students' collective idea development and knowledge advances (Fig. 2) using the Knowledge Building Discourse Explorer (KBDeX) (Oshima et al., 2012), a social-semantic network analysis tool, to examine how the students engaged in collaborative online discourse to advance their collective knowledge. KBDeX examines temporal changes in students' discourse and interactions based on researcher- and teacher-generated content-related conceptual keywords reflecting domain knowledge. A list of keywords reflecting key domain knowledge was generated and students' discourse was examined in relation to these keywords. The premise of KBDeX is that a cluster of linked words in a network represents the community's idea (Oshima et al., 2012). Following previous knowledge building studies (Oshima et al., 2012), we used KBDeX-generated changes in keyword networks and the total value of degree centralities (TDC) (where a higher TDC value represents a denser network) to examine the extent of the class community's collective idea improvement and knowledge advancement.

Knowledge building discourse moves Students' productive inquiry was also assessed using knowledge building discourse moves (Fig. 2). Within each inquiry thread described above, the notes were coded to examine the students' discourse moves. The coding scheme employed was developed in prior knowledge building research using a theory- and data-driven approach (Chuy et al., 2011; Yang et al., 2016) to reveal the students' questioning, theorizing, and community processes (Fig. 5). A second rater coded 30% of all the KF posts, with interrater reliabilities of 0.92 for questioning, 0.83 for theorizing, and 0.87 for community (Cohen's kappa).

Epistemic discourse understanding (Pre- and posttests)

Students' epistemic discourse understanding (Fig. 2) was assessed and examined using the epistemic cognition AIR model (aims and values, standards, and reliable processes, Chinn et al., 2014). The epistemic discourse understanding test includes three open-ended questions: "What do you think is a good discourse?" (The standards that students use in

Codes	Sub-codes	Description	Examples
Questioning	Fact-seeking (Q1)	Questions seeking factual information.	"What are visual elements?"
	Explanation-seeking (Q2)	Questions seeking open-ended responses with explanations.	"How can we use visual elements to appreciate a piece of art?"
	Sustained inquiry (Q3)	Asking further questions based on previous ideas and thus deepening the discussion deeper.	"Art is innovative…but how can art represent emotion? (as a further question building on previous ideas)."
Theorizing	Simple claim (T1)	Simple (dis)agreement or repetition of a statement.	"Art can be freely designed." (as a repeat of a previous note)
	Proposing an explanation (T2)	Proposing an explanation that explains certain phenomena for the first time.	"Art includes various elements and combines different colors and shapes."
	Supporting an explanation (T3)	Supporting and justifying an existing explanation proposed by another student.	"Different colors can represent different meanings: e.g., blue represents melancholy."
	Improving an explanation (T4)	Improving an already existing explanation through elaboration, specifying details, and using new evidence.	"You mentioned that people think that art is useless, but art is an indispensable part of our lives…our clothing was designed by artists."
Community	Connection (C1)	Reference to their own or others' notes or quoting extra sources to advance community understanding.	"[My theory] Artists use various forms (e.g., painting, photography, and music) to combine different visual elements into a piece of artwork [New information] Visual elements include color, line, shape, texture, etc. Visual elements are the criteria to appreciate an artwork."
	Synthesizing (C2)	Synthesizing ideas from previous multiple notes by using the references function and identifying gaps to engage in a high-level conceptualization.	"I am wondering if art opens up new thinking in the world. Does art equal innovation? [My theory] I agree with your idea that art belongs to innovation. However, you also said that science is relevant to art that focuses on creativity, innovation... [My theory] I think that science focuses on inquiry rather than creativity. [I need to understand] What are the differences between creativity and inquiry? [My theory] Creativity focuses on building up while inquiry focuses on developing new things..."

Fig. 5 Coding scheme for analyzing discourse moves in Knowledge Forum inquiry threads (Red square refers to a reference note. Students use the references function in Knowledge Forum to quote notes from their previous discussion)

evaluating discourse), "What kinds of strategies can be used to improve a discourse?" (The reliable processes students use to achieve a good discourse), and "What is the goal of discourse?" (Students' aims when engaging in discourse) (adapted from Chinn et al., 2014). The coding scheme was developed through a theory- and data-driven approach (Table 1) adapted from the AIR model (Chinn et al., 2014) and knowledge-building discourse (van Aalst, 2009) to reveal the students' epistemic discourse understanding. A second rater independently coded 30% of the data, with an interrater reliability of 0.87 (Cohen's kappa).

Domain knowledge (Pre- and posttests)

Students' domain knowledge was examined using a written test ("What is your understanding of art?" "The following are two artworks. Can you appreciate the two artworks?"), in which the students described their understanding of art and art appreciation and evaluated the artworks. Their responses to domain knowledge were analyzed using a four-point scale that was adapted from the official curriculum and assessment guidelines to examine students' understanding of art and art appreciation (level 0: irrelevant responses; level 1: regarding artwork merely as pictures drawing and using fragmented words to appreciate the artwork; level 2: regarding artwork as a way to express ideas and using visual element

Table 1 Dimensions and levels of epistemic discourse understanding using AIR and knowledge building perspectives

	Level 1	Level 2	Level 3
Aims and goals	The goal is to exchange ideas arriving at answers; obtain new information from group members; improve individual learning	The goal is to make meaning and construct personal and joint understanding; arriving at more understanding and solving problems	The goal is to contribute and extend knowledge for group/ community; aiming for creative and sustained knowledge work not just solving problems at hand but aiming to improve collective/ group ideas and advancing collective knowledge at group/ community level; improving collective ideas and sustained inquiry together
Standards and characteristics	The characteristics of ideal discourse (good discussion) include having a general agreement with no argument; reaching a correct answer within a short time	The characteristics of ideal discourse (good discussion) include many interactions, meaningful discussion, good argument and problem-solving; good discussion can help us get more understanding and solve the problem	The characteristics of ideal discourse (good discussion) include collective discussion on problems that are important for the community; emergent of new/innovative ideas; advancing community understanding; collective idea improvement; higher level of understanding through sustained idea improvement advancement
Reliable processes and strategies	The reliable processes/strategies to achieve good discourse are to express and share ideas with active participation and involvement	The reliable processes to achieve good discourse are to engaging in constructive interaction, elaborating and questioning peers' ideas; using examples, evidence and explanations for arguments and problem solving	The reliable processes to achieve good discourse is to synthesize diverse ideas for rise above; reflect on the progress/trajectory of discussion to identify core problems; identify what gaps exist in current discussion; set goals to address emerging problem; when one problem has been solved (task not completed), use what is solved to generate new problem for emergent inquiry—one problem leads to other questions)

language to explain the artwork; and level 3: regarding artwork as an integrated subject and a process of investigation, and using visual element language to illustrate the artwork with detailed explanations. See Table S2). A second rater independently coded 30% of the data. The inter-rater reliabilities were 0.81 for understanding of art and 0.82 for appreciation.

Meta-discourse in classroom talk with students' artifacts

Fifteen hours of video-taped classroom observations were collected and transcribed with the classroom artifacts to examine how meta-discourse supports epistemic discourse understanding and knowledge building. Inventories of multiple data sources, including transcripts, field observation notes, artifacts, and relevant KF notes, were created and organized in relation to the pedagogical designs and learning intentions in the four phases (Fig. 3). The video and transcripts were carefully read and examined. Relevant and critical incidents pertaining to meta-discourse were identified from different phases. Specifically, the qualitative analysis of meta-discourse was guided by the relevant work discussed in the literature review encompassing metacognition, principle-based understanding, theory-building, and particularly how they related to developing the students' epistemic discourse understanding. These transcripts and video materials were also examined in relation to the students' KF writing at different times. The preliminary incidents and stories were presented to the research team for discussion and analysis, and we examined their alignment with theories and key constructs for meta-discourse. We followed our framework when examining classroom examples, including reflection on discourse processes, principles, domain knowledge, and idea development.

Results

RQ1. Changes in students' epistemic discourse understanding and domain knowledge

To address RQ1 on the effects of the meta-discourse intervention, we examined the differences in epistemic discourse understanding and domain knowledge between the two classes after the intervention.

Epistemic discourse understanding Figure 6 shows the percentage of different levels of epistemic understanding at pre- and posttests for the experimental and comparison students. Student scores at different levels (three-point scale) for all questions were computed as an overall score for analysis. A one-way ANCOVA was conducted using posttest epistemic understanding as the dependent variable and group (the experimental and comparison classes) as the independent variable, controlling for pre-test epistemic scores (experimental: $M = 1.37$, $SD = 0.56$; comparison: $M = 1.38$, $SD = 0.55$). The results indicated that the experimental students' posttest epistemic understanding scores ($M = 2.19$, $SD = 0.79$) were significantly higher than those of the comparison students ($M = 1.75$, $SD = 0.84$), $F(1, 56) = 4.450$, $p < 0.05$, partial $\eta^2 = 0.074$, indicating a medium effect. The results suggested that the experimental students obtained higher epistemic discourse understanding scores after intervention than their counterparts. For illustrative purposes, Fig. 6 also includes examples from several students from pre- and posttests.

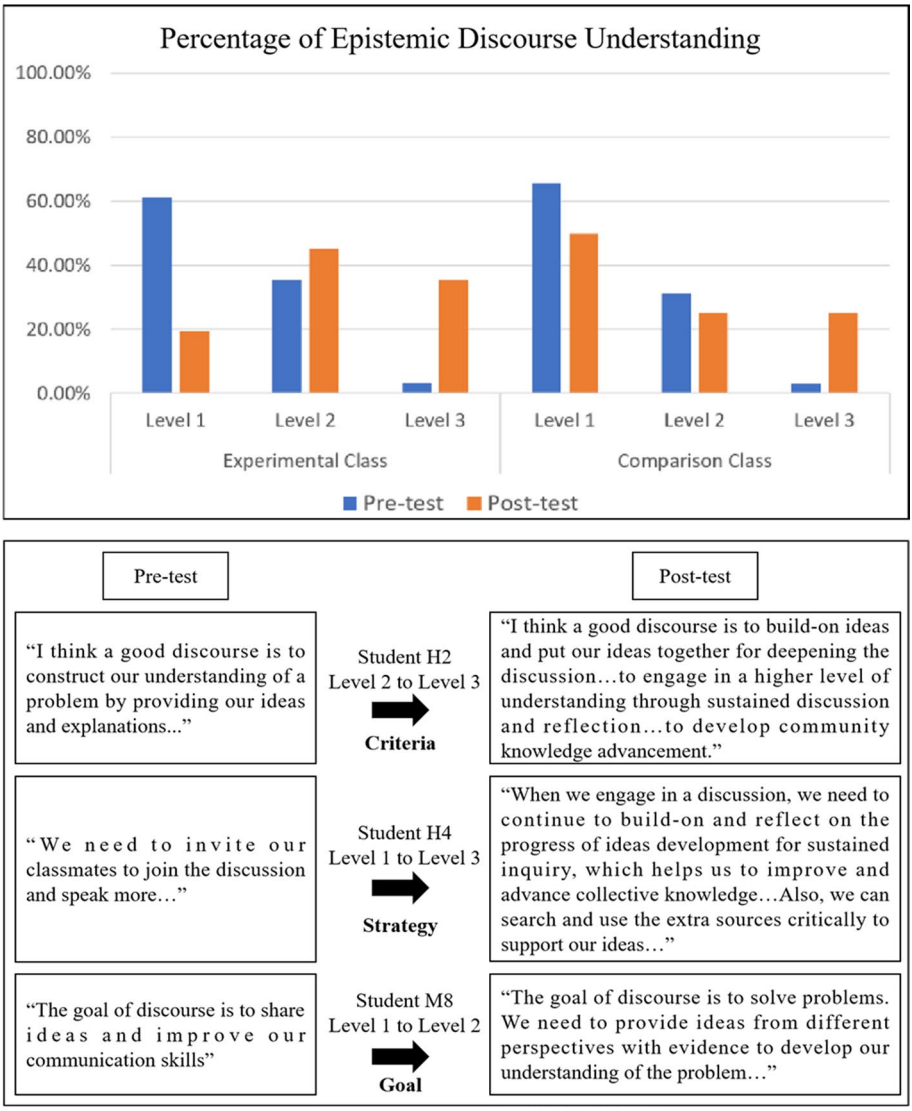


Fig. 6 Comparison of change in epistemic discourse understanding between two classes and examples of student work

Domain knowledge The means (and standard deviations) for pre- and posttest domain knowledge were 1.22 (0.47) and 2.13 (0.64) for the experimental class, and 1.34 (0.45) and 1.77 (0.44) for the comparison class. A one-way ANCOVA, using posttest domain knowledge as the dependent variable and controlling for pretest domain knowledge, showed a significant difference $F(1, 56) = 7.859$, $p < 0.01$, partial $\eta^2 = 0.123$ (indicating a medium effect), favoring the experimental group.

RQ2. Student engagement in Knowledge Forum inquiry and relationship with epistemic discourse understanding

To address RQ2, we provided basic database usage data and examined the differences in productive inquiry to assess collective idea development (thread analysis), discourse moves, and the KBDeX knowledge advances between classes. We then examined the relationship and contribution of epistemic discourse understanding to productive inquiry.

Productive inquiry in Knowledge Forum writing

Database usage and participation KF database usage showed that experimental students generated 232 notes. On average, they created 8.6 notes, built on 6.4 notes, read 44.1% of the community's notes, and used 6.9 KF scaffolds. The comparison students generated 266 notes. On average, they each wrote 8.3 notes, made 6.3 build-on notes, read 31.8% of the community's notes, and used 3.7 scaffolds.

Analysis of inquiry threads (collective idea improvement) KF discourse was parsed into inquiry threads and coded into three hierarchical discourse patterns. Table 2 presents the identified inquiry threads and coding results—two were coded as knowledge-sharing, five were coded knowledge-construction, and three were coded knowledge-building for the experimental class, versus six, three, and one, respectively, for the comparison class. These results suggested that the experimental students generated more inquiry threads coded as knowledge construction and knowledge building than the comparison students, reflecting that there was more collective idea improvement compared with their counterparts.

Discourse moves analysis Table 2 presents the distribution of discourse moves in the two classes. A one-way MANOVA on the KF discourse moves between the experimental and comparison classes was conducted. The results showed significant differences, Wilks' Lambda = 0.679, $F(9, 49) = 2.576$, $p = 0.016$, partial $\eta^2 = 0.321$, indicating a large effect. Follow-up univariate tests indicated significant differences on two high-level discourse moves—"supporting an explanation" $F(1, 57) = 6.699$, $p = 0.012$, partial $\eta^2 = 0.105$ (a medium effect) and "synthesizing" $F(1, 57) = 6.340$, $p = 0.015$, partial $\eta^2 = 0.100$ (a medium effect), favoring the experimental class.

Table 3 and Fig. 7 show the distribution of the discourse moves of the experimental and comparison classes for two periods. For coherence, discourse moves were grouped into high and low levels. We ran a one-way ANOVA, using the gain-score (the frequency of high-level KF discourse moves in Period 2 minus the high-level KF discourse moves in Period 1) of high-level KF discourse moves as the dependent variable. This analysis showed significant group differences, $F(1, 57) = 5.685$, $p = 0.020$ (a small effect) favoring the experimental students.

Differences in collective idea improvement between the two classes The collective knowledge advances of the students' KF discourse were examined using KBDeX measures that depict the connectivity and coherence of ideas. A network of ideas was generated by KBDeX based on students' online discussions and collective knowledge

Table 2 Frequency of categories of coding in the experimental and comparison classes

	Questioning			Theorizing				Community		Thread Quality
Thread	Q1	Q2	Q3	T1	T2	T3	T4	C1	C2	
Experimental Class										
#1 Art and artist	1	1	1	1	3	1	0	0	0	KS
#2 Purpose of art	0	2	3	1	10	1	0	0	1	KS
#3 Art and life	1	2	2	0	7	1	0	2	1	KC
#4 Re-creation	0	1	1	1	3	2	2	0	1	KC
#5 Definition of art	1	4	1	5	5	3	0	1	1	KC
#6 Plagiarism	0	20	1	3	17	3	0	1	0	KC
#7 Appreciation	0	2	6	4	9	6	0	0	0	KC
#8 Art problem-solving	0	0	5	4	9	3	2	0	4	KB
#9 Criteria of good art	0	3	1	0	7	2	3	1	5	KB
#10 Representation of art	2	8	6	10	18	2	1	2	3	KB
Total	5	43	27	29	88	24	8	7	16	
Mean	0.5	4.3	2.7	2.9	8.8	2.4	0.8	0.7	1.6	
SD	0.71	5.95	2.16	3.07	5.18	1.51	1.14	0.82	1.78	
Comparison Class										
#1 Definition of art	0	1	1	1	5	0	0	0	0	KS
#2 Purpose of art	0	1	1	0	8	0	0	0	0	KS
#3 Change of art	0	3	0	1	3	0	0	0	0	KS
#4 Good and bad art	0	3	2	1	7	0	0	0	0	KS
#5 Aesthetic	0	1	0	2	3	0	0	0	0	KS
#6 Art and imagination	0	2	1	0	5	0	0	0	0	KS
#7 Appreciation	1	5	4	6	12	0	0	0	0	KC
#8 Art and people	1	4	9	6	31	2	7	0	0	KC
#9 Characteristic of art	0	3	8	3	16	0	1	1	0	KC
#10 Value of art	8	6	11	10	43	3	1	1	1	KB
Total	10	29	37	30	133	5	9	2	1	
Mean	1	2.9	3.7	3	13.3	0.5	0.9	0.2	0.1	
SD	2.49	1.73	4.11	3.3	13.43	1.08	2.18	0.42	0.32	

KS knowledge sharing, *KC* knowledge construction, *KB* knowledge building.

can be represented by a network of ideas. We followed the approach in knowledge-building research by using total degree centrality (TDC) as an index to examine the students' collective knowledge advancement based on the increasing number of links between ideas (Oshima et al., 2012; Yang et al., 2020). The KBDeX-generated TDC changed from 4.73 to 5.27 to 12.17 for the experimental class, whereas the KBDeX-generated TDC also increased for the comparison class, but to a lesser extent (from 4.88 to 6.27 to 8.83) (Fig. 8). These results suggest that relative to the comparison students, the experimental students were working towards more coherent discussion integrating ideas and engaging more in collective knowledge work.

Table 3 Mean and SD of Knowledge Forum discourse moves in two periods

Knowledge Forum Discourse		Experimental Class				Comparison Class			
		Period 1		Period 2		Period 1		Period 2	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Low-level Knowledge Forum Discourse									
Questioning	Fact-seeking	0.19	0.40	0.00	0.00	0.28	0.46	0.03	0.18
	Simple claim	0.89	2.08	0.19	0.40	0.50	0.80	0.44	0.76
Theorizing	Proposing an explanation	1.67	2.00	1.59	2.47	2.31	2.16	1.84	1.80
High-level Knowledge Forum Discourse									
Questioning	Explanation-seeking	0.70	1.23	0.89	1.93	0.59	0.84	0.31	0.59
	Sustained inquiry	0.41	1.55	0.59	1.42	0.66	1.33	0.50	1.16
Theorizing	Supporting an explanation	0.22	0.42	0.67	1.36	0.06	0.25	0.09	0.39
	Improving an explanation	0.00	0.00	0.30	0.87	0.06	0.25	0.22	0.75
Community	Connection	0.11	0.58	0.15	0.46	0.03	0.18	0.03	0.18
	Synthesizing	0.15	0.36	0.44	1.09	0	0	0.03	0.18

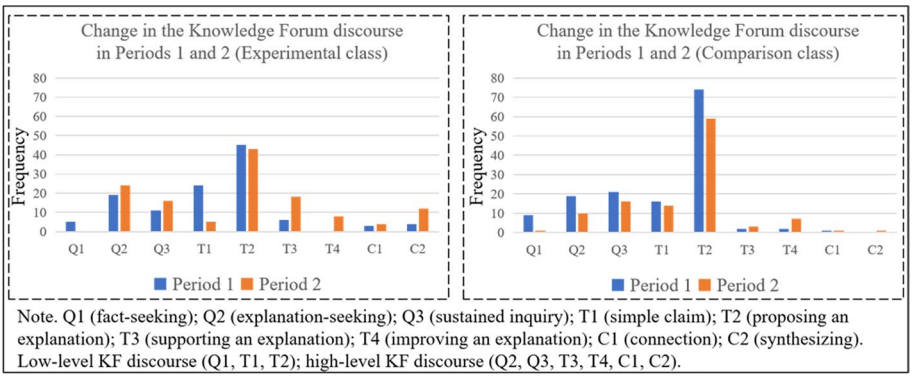


Fig. 7 Frequency of students' Knowledge Forum discourse moves in two periods

Relationships among epistemic discourse understanding, Knowledge Forum inquiry, and domain knowledge

We first examined whether students with high (versus low) epistemic discourse understanding differed in productive inquiry regarding KF discourse moves and collective ideas. Next, correlation and regression analyses were conducted to examine the role of epistemic discourse understanding on productive inquiry and domain knowledge.

Group differences (Epistemic discourse understanding) on discourse moves Students were divided into high- and low-score groups based on their posttest epistemic discourse understanding scores (students whose posttest epistemic understanding scores were above level 2 were grouped into high-score groups, while students whose scores were below or

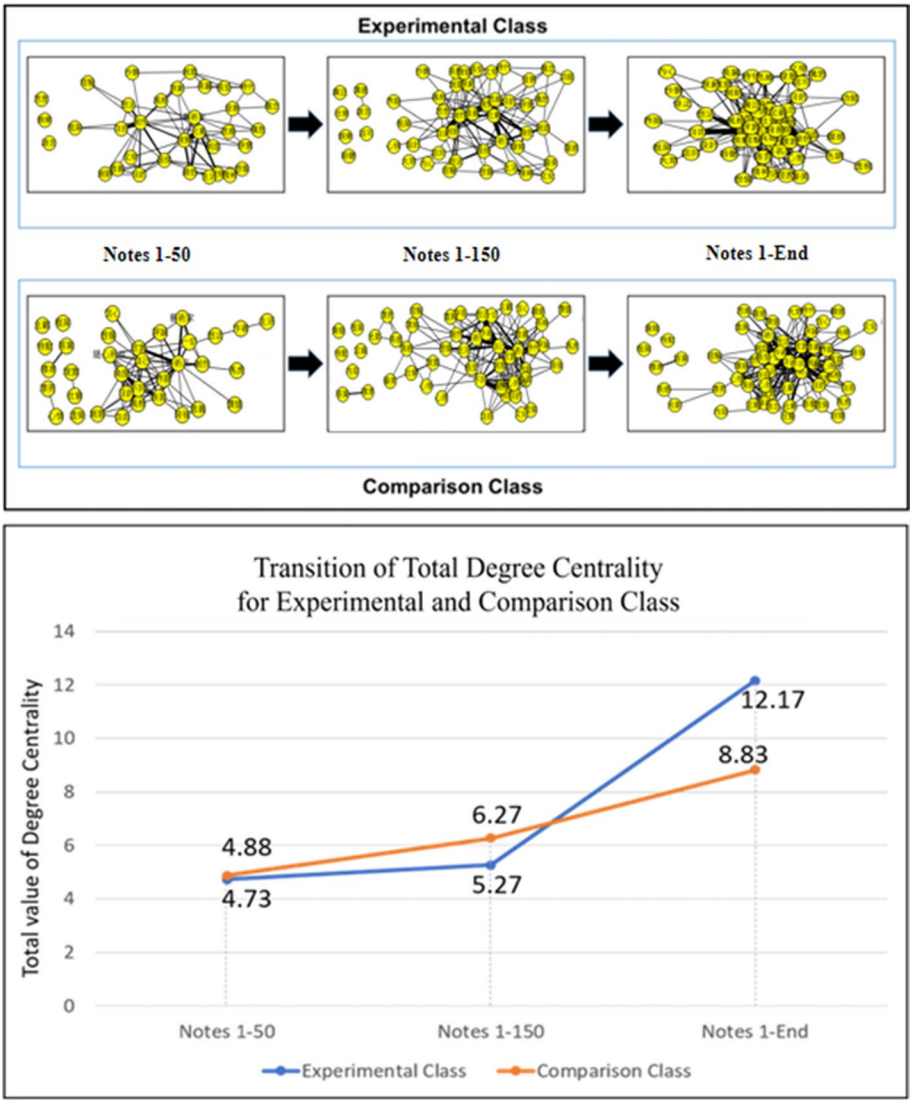


Fig. 8 Knowledge Forum keywords network change and total degree centrality

equal to level 2 were grouped into low-score groups, see Table 1 coding scheme). Table 4 presents the distribution of KF discourse moves between the high- and low-score epistemic understanding groups. A one-way MANOVA on the KF discourse moves between the high- and low-score groups showed a significant difference, Wilks' Lambda = 0.373, $F(9, 17) = 3.177$, $p = 0.019$, partial $\eta^2 = 0.627$, indicating a large effect. Follow-up univariate tests indicated significant differences favoring the high-level epistemic understanding group on three high-level discourse moves—"explanation-seeking" $F(1, 25) = 12.360$, $p = 0.002$, partial $\eta^2 = 0.331$ (a large effect), "supporting an explanation" $F(1, 25) = 8.978$,

Table 4 Mean and SD of Knowledge Forum discourse moves for high- and low-score epistemic understanding groups ("community" code belongs to high-level discourse moves)

Knowledge Forum Discourse		High-score group		Low-score group	
		M	*SD*	*M*	*SD*
Low-level Knowledge Forum Discourse					
Questioning	Fact-seeking	0.27	0.47	0.13	0.34
Theorizing	Simple claim	1.55	3.05	0.75	0.86
	Proposing an explanation	5.73	4.73	1.56	1.97
High-level Knowledge Forum Discourse					
Questioning	Explanation-seeking	3.45	3.53	0.31	0.60
	Sustained inquiry	2.09	4.37	0.25	0.45
Theorizing	Supporting an explanation	1.82	2.04	0.25	0.45
	Improving an explanation	0.27	0.65	0.31	0.34
Community	Connection	0.45	1.04	0.13	0.34
	Synthesizing	1.27	1.74	0.13	0.34

$p = 0.006$, partial $\eta^2 = 0.264$ (a large effect), and "synthesizing" $F(1, 25) = 6.723$, $p = 0.016$, partial $\eta^2 = 0.212$ (a large effect).

Differences in collective knowledge building inquiry We also examined using KBDeX whether students from high versus low epistemic understanding groups differed in their KF discussion in terms of using keywords for coherence. As discussed in the Methods, a list of keywords representing domain knowledge was generated, and they were highlighted if they had been used by the selected community. First, the students were divided into high- and low-groups using their posttest epistemic understanding scores (see classification criteria above). As Fig. 9 shows, the yellow and red balls in the KBDeX-generated keywords network represent all of the keywords used by the whole community in KF discussions, with red-highlighted balls representing keywords used by the high-/low-score

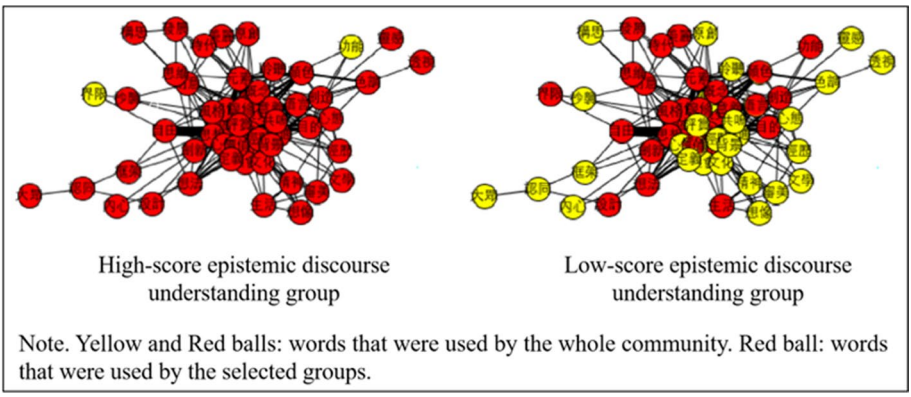


Fig. 9 Visualization of keyword usage between high- and low-score epistemic understanding groups in Knowledge Forum discourse

Table 5 Correlation between domain knowledge, epistemic understanding, Knowledge Forum participation, and high-level discourse moves (experimental class)

	1	2	3	4
1 Pre-epistemic understanding	–			
2 Post-domain knowledge	0.391*	–		
3 Post-epistemic understanding	0.619**	0.558**	–	
4 Knowledge Forum participation	0.324	0.486*	0.532**	–
5 High-level discourse moves	0.362	0.483*	0.547**	0.934**

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

Table 6 Hierarchical regression on Knowledge Forum (KF) discourse moves

	R	R^2	R^2 change	F change
Pre-epistemic understanding	0.362	0.131	0.131	3.772
Post-epistemic understanding	0.548	0.300	0.169	5.789*

*$p < 0.05$

epistemic discourse understanding groups. A comparison of the number of keywords the students used in the two groups (54 versus 33 keywords used, respectively) suggested that the students with higher epistemic understanding engaged more productively in knowledge building inquiry by using more keywords.

Correlation analysis Table 5 presents a correlation analysis of the relationship between different variables. For coherence of analysis, KF participation indices based on log data (notes created, built-on, and read, as well as scaffolds used) were combined using factor analysis. The principal component analysis reveals one factor with an eigenvalue greater than 1.00, called KF participation. It explained 61.76% of the variance (Eigenvalue 2.47). A common index of high-level discourse moves was created by combining high-level Questioning (explanation-seeking and sustained inquiry), high-level Theorizing (supporting and improving an explanation), and Community (connection and synthesizing).

Correlation analyses indicated significant relationships between different variables in the experimental class. Table 5 presents that pretest epistemic understanding is correlated with posttest epistemic understanding ($r = 0.619$) and posttest domain knowledge ($r = 0.391$). Significant correlations were also obtained among posttest epistemic understanding with KF participation ($r = 0.532$), high-level discourse moves ($r = 0.547$), and higher domain knowledge ($r = 0.558$). A similar correlation analysis conducted for the comparison class showed that the students' posttest domain and epistemic understanding were not correlated with KF engagement.

Regression analysis A regression was conducted to examine how pre- and posttest epistemic understanding predicted KF discourse moves (Table 6). Pretest epistemic understanding predicted 13.1% of the variance, and after post-epistemic understanding was added, an additional 16.9% of the variance was explained at a significant level ($p < 0.05$), which showed that post-epistemic understanding contributed to students' high-level KF discourse moves.

A hierarchical regression was conducted to provide an overall picture and to examine how epistemic discourse understanding, KF discourse moves and prior domain knowledge predict domain knowledge (Table 7). First, the prior domain knowledge was entered and explained 17.0% of the variance. Second, KF high-level discourse moves were added and explained an additional 15.4% variance. When posttest epistemic understanding was added, a further 9.7% variance was obtained, suggesting that high-level discourse moves and epistemic understanding contributed to students' posttest domain knowledge, over and above prior domain knowledge.

RQ3. Meta-discourse for epistemic understanding and knowledge building

To address RQ3, we presented the qualitative analysis of classroom discourse, students' artifacts, and KF writing to illustrate how students engage in meta-discourse reflecting on, and inquiring into their discourse for epistemic understanding and knowledge building. The meta-discourse analyses pertained to how students co-inquired with the teacher and reflected on the KF discourse in the classroom meta-discourse, including metacognitive, epistemic, and conceptual elements. Three meta-discourse themes emerged, guided by the literature and classroom discourse data.

Meta-epistemic reflection: Reflection on collaborative activities and processes

The first theme of meta-discourse is called meta-epistemic reflection and it involves both metacognitive and epistemic reflection into the discourse process. The students started with metacognitive reflection and moved onto epistemic aspects of the features of discourse.

The students were first prompted to reflect on their prior understandings for revision and improvement. Here is an example: the teacher invited students to reflect on their class discourse and how their ideas about art had changed (Fig. 10, top). Some students noted that they initially thought "beauty" was the most important criterion of good artwork, but later realized that the criterion could be "diversity" for meaning (line 6). Others reflected on their previous lack of understanding and how they now realized the need to use visual elements to comprehend the artist's perspective to understand the artwork (line 8). These conversations continued in the students' KB wall discussions.

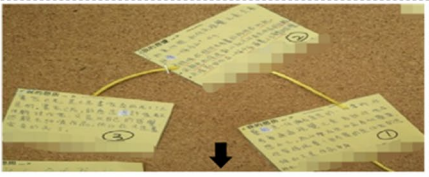
The students then moved their discussion to the KB wall, wrote their ideas on cards, built on them, and used strings to show the links (Fig. 10, middle). The KB wall is a physical representation that visualizes student ideas/questions/build-on analogous to KF. Students posted ideas (Fig. 10, bottom left) (e.g., "Artists use visual elements to express their ideas"; Note 1) and built on them through subsequent notes (Note 2), prompting others in the class community to wonder about art appreciation. The students put forth new ideas (e.g., "Death of the author"; Note 3) as an art discussion theme/problem. A similar

Table 7 Hierarchical regression on posttest domain understanding

	R	R^2	R^2 change	F change
Predomain knowledge	0.412	0.170	0.170	5.110*
High-level discourse moves	0.569	0.324	0.154	5.471**
Post-epistemic understanding	0.649	0.421	0.097	3.867**

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

1. Teacher (T): ***Can anyone reflect on what we discussed in the last series of lessons?***
2. S1: Visual elements.
3. T: Good. What else?
4. S4: We discussed the topic of what is art and how to appreciate a piece of art.
5. T: Good. Can anyone reflect on their initial idea about art and whether it changed after these lessons?
6. S2: ***Initially, I thought that*** '***beauty***' was the most important criterion of good artwork, ***but now I think*** the criterion should be '***diversity***', for example, a good artwork can make me learn something after reading it.
7. T: Anything else?
8. S12: ***Before these lessons***, ***I was not aware of what art is and did not understand how to use art to comprehend authors' thinking, but after these lessons***, I gained the understanding that we can use ***visual elements*** as tools to know what the author was intended to express in the artwork.

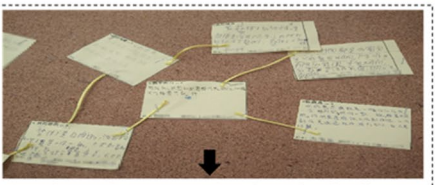


Question: "***What is your understanding of art?***"

Note 1: "Art is an interesting thing… ***Artists use visual elements to express their ideas*** when making an artwork…why should an ordinary piece of art be priced so high? Because the artwork represents the author's ideas instead of merely the painting."

Note 2: "***How can we use visual elements to appreciate art?*** For example, the thickness of the line and the shade of the color..."

Note 3: "***Death of the author***…it means that we shall focus on our criteria to appreciate an artwork instead of focusing on what the author would like to express through the artwork…"



Question: "***Can art (creation) have freedom?***"

Note 1: "Art is freedom, no two pieces are the same…"

Note 2: "There is no restriction in art creation...art equals innovation."

Note 3: "Every artwork is unique…"

Note 4: "Artists may have the same ideas, but they cannot create the same artworks"

Note 5: "***Do you mean re-creation***? Re-creation is a process that creates some new things based on the original artwork. It is not plagiarism."

Fig. 10 An excerpt of a classroom discussion (top), the KB wall with note cards and strings (middle), and excerpts from the note cards in the KB wall (bottom)

discussion thread on the KB Wall (Fig. 10, bottom right) built on another question, in which the students were wondering whether art offers the freedom to recreate art.

Following the KB wall discourse, the teacher asked students what they had noticed from the KB wall, thereby engaging them in tracing their idea development and noticing the

features of their discourse on epistemic aspects. This generated another meta-discourse; for instance, one student referred to the KB wall discussion, saying, "In the beginning, we inquired into the question of *what is art*; this question may have only one answer, but [we] can continue to build-on that and inquire further… Later, we deepened our discussion from authors' (artists) expressing their ideas through art to the death of the authors /artists (using our criteria) for art appreciation." (see Note 3, Fig. 10, bottom).

This example shows how the students reflected on their changing ideas of art (from something beautiful to something meaningful to the expressions of the artist's ideas), which helped them become more metacognitively aware of the evolution of their own ideas and that of the class. In the KB wall meta-discourse, they referred to collective and not just personal ideas (e.g., "it means we should focus on"). They also noticed and reflected on how they discussed suggesting their developing understanding of the notion of progressive discourse (e.g., "we first discussed this and later…" and "others can continue to build on that and inquire further"). The students engaging in this meta-discourse using metacognition and embedding collective activity and conceptual ideas may become more aware of the evolving ideas in the community and epistemic nature of discourse (not linear but involving diverse ideas). These reflections would have supported their growth in epistemic discourse understanding for productive inquiry.

Meta-epistemic principles: Reflections on principles and criteria

The second theme of meta-discourse is called meta-epistemic principles and it involves students explicitly inquiring into knowledge-building principles and comparing the KF discourse to support their reflection on the goals, standards, and processes of discourse.

Reflection on principles As the students generated more KF notes, they were introduced to several of the knowledge-building principles. Different groups made drawings to illustrate their understanding (Fig. 11), which was followed by group sharing and meta-discourse on the criteria for and characteristics of discourse.

For example, some students linked the principle of community knowledge to their prior experience of working on the KB wall, relating it to how they worked together to pursue the question of "what is art." Fig. 11 shows that the students wrote, "…our KB wall is a combination of knowledge contributed by the entire class … we discussed a question about '*death of the author*' … we provided responses … and new knowledge emerged." In this meta-discourse, when sharing their ideas with the class, they added "…we shared, built on, and challenged the ideas proposed by different students … all of us put our knowledge (like a drop of water) into the ocean, and it has become community knowledge with different ideas… through this process, new knowledge can be created." The students explicitly reflected on their collective knowledge building experience (discourse on the KB wall) of sharing, building on, and challenging ideas ("new knowledge emerges when many people think together"). This explicit inquiry into principles linking to their experience helped them develop the epistemic criteria of knowledge building for enriching their epistemic understanding.

Comparison of discourse for identifying criteria The students continued with their reflective inquiry into the discourse—they worked in groups browsing and comparing the KF databases from the two classes (classes G and H). Although they did not read all the KF

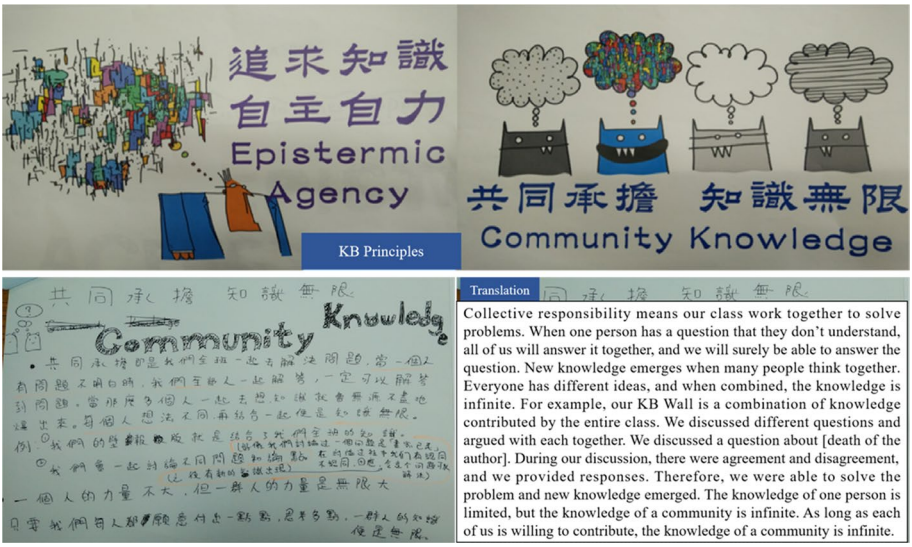


Fig. 11 An example of a group of students' drawing and reflection illustrating their understanding of the knowledge-building principle of community knowledge

notes, they used the structure of the KF discourse to guide their discussion. Students drew diagrams, wrote explanations, and came up with a "straight-line" or an "octopus" pattern to describe the nature of the KF work. As Fig. 12 shows, the students explained that one KF pattern is linear (one KF post followed by another post) while another had a key question that gave rise to more questions, and different students responded and raised more questions. Furthermore, the students were able to suggest different ways forward ("If everyone

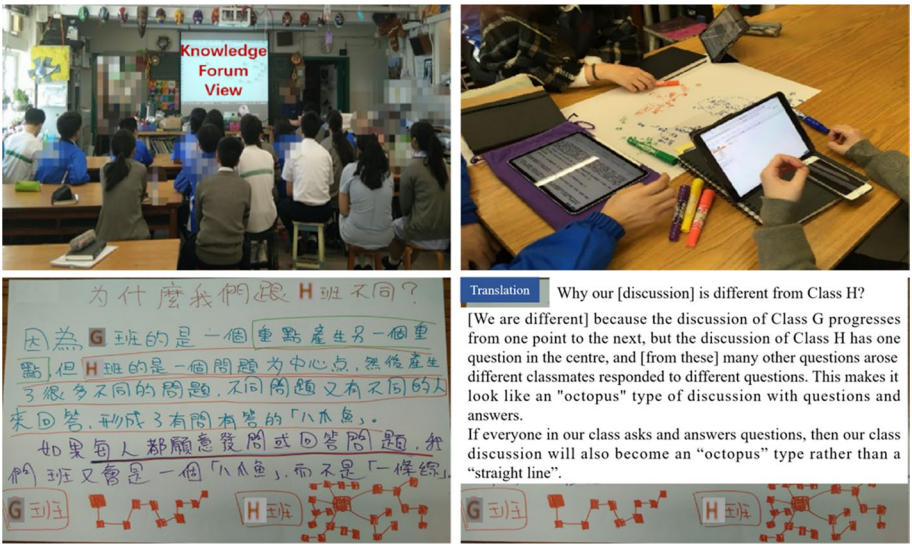


Fig. 12 The drawings and reflection on the comparison of KF discourse structure

in our class asks and answers questions, then our class discussion will also become an octopus shape rather than a straight line.") (Fig. 12).

Following the creation of these artifacts, the teacher and students continued with classroom meta-discourse to deepen their inquiry into the nature of discourse. The following is an example:

> Line 1. Teacher: What do you observe about the two patterns?
> Line 2. S4: 'Octopus' (Class H) vs. 'Straight-line' (Class G) shapes [Fig. 12] …We only focused on one question, and we did not think about it or discuss it from different perspectives.
> Line 3. Teacher: The 'octopus' shape, what more can you say about it?
> Line 4. S1: Our ideas just come one after another [linear form], while the other class had one initial idea followed by two to three ideas...
> Line 5. S4: Our initial idea had four build-on notes. Later, our build-on notes became a line in which one note was directly followed by another. However, the other class has two build-on notes for the initial note and later…they went deeper into their inquiry…We had only one question…and we did not inquire further…
> Line 6. Teacher: Can you explain more about how you can have more new questions in your Knowledge Forum discussion?
> Line 7. S4: Challenge. For example, when someone raises the idea that, 'artists use visual elements to create artworks', then a new question will emerge about the visual elements and art.

In this classroom meta-discourse, the students pointed out the gaps and they noted that they focused on only one question instead of different perspectives (line 2), and just having their ideas to come in a linear manner (line 4), as there was only one question and "we did not inquire further" (line 5). The teacher worked with the students to consider ways to move forward, which led to the new idea of using challenge to prompt new questions—relating to the problem about visual elements (line 7). This example illustrates how inquiry into KF writing enriched with artefacts and meta-discourse can help students reflect on their collective work, identify knowledge-building gaps, and suggest ways forward. Although the students used intuitive descriptions (e.g., an octopus shape), these meta-discourses on the features of productive and unproductive discourse could help students to develop the epistemic criteria of open, expansive, and community-based discourse in knowledge building by using contrasting patterns to spark understanding.

Meta-epistemic theory: Reflections on idea development

The third theme is called meta-epistemic theory and it involves metacognitive reflection for conceptual idea development enriched with epistemic aspects pertaining to theory building that is critical to knowledge building.

The following excerpt shows the students engaged in meta-discourse and reflecting on their KF discussion by improving ideas and inquiring further into emerging problems. The students were pursuing the question, "Can art solve problems?" on the KF discourse, which they extended with meta-discourse in the classroom.

Line 1. Teacher: 'Can art solve problems?' 'If you face a problem that is irrelevant to art, how can you solve it using art?' [The teacher worked with students to identify an interesting question on Knowledge Forum]
Line 2. S10: Art is everywhere. Animals, trees, and forms. Everything is art. [An initial theory but incomplete]
Line 3. S4: If you face a problem, e.g., math, how can you use art to solve the math problem? [Questioning the adequacy of the theory]
Line 4. Teacher: Good point. What do others think about math and art?
Line 5. S2: Symbols. We can use graphics to solve math problems...
Line 6. S4: Art is about inquiry and creation. Science is also relevant to art. [Initial theory is deepened and enriched]
Line 7. S10: Art is about creation. It is not the same as science, which focuses on inquiry. [Theory is challenged]
Line 8. S4: Art is about creation, but you must still engage in the inquiry process. [Further explanation]
Line 9. Teacher: Can anyone explain the difference between inquiry and creation?
Line 10. S10: Creation is about building something new and inquiry is about finding a new thing.
Line 11. S4: There is nothing new under the sun…When you make an inquiry, you will find something new. It is the same when we are creating, e.g., creating an airplane. When you see the birds, you can inquire about flight…and we can follow that to make something new like an airplane. [Theorization of art as both an inquiry and a creation]
Line 12. Teacher: What do you think about [what was said]?
Line 13. S10: Based on what you [S4] said, an inquiry is one of the ways to enhance creativity. [Refining into more usable theory]

The teacher initiated the meta-discourse by alerting the students to an ongoing KF problem ("Can art solve problems?" line 1). S10 gave a tentative theory/explanation conjecturing that "art is everywhere" (line 2), which prompted S4's question about how art can solve math problems (line 3). This question was followed by various explanations; S4 enriched the theory and pointed out the possible relationships between art and science (line 6). This idea was taken up by S10, who characterized art as a creation and science as an inquiry (line 7). These ideas were enriched further by S4, who inquired more into the relationship between creation and inquiry. The initial idea that art is everywhere for solving problems was deepened by explaining that both art and science involve creation and inquiry (line 11), and the students improved on the theories/explanations of how inquiry is a means to enhance creativity (line 13).

The students then returned to KF writing and continued to build on and deepen their inquiry. The classroom meta-discourse deepened students' inquiry into art and science for creativity and innovation, and new KF questions were posed, e.g., "[*My theory*] I think art is related to creativity, innovation…, etc.", S4; "[*I need to understand*] Art belongs under innovation. I think that art can open up new thinking in the world. Does art equal innovation?", S1).

Similar to metacognitive conversations/meetings (Yuan et al., 2022), this example demonstrates how meta-discourse supports students in engaging in a theory-building process to improve their explanations. The students generated initial explanations, and these were progressively deepened to explain and theorize about art and science in

relation to inquiry and creation. The students developed the meta-discourse processes of epistemic engagement in theory building via deepening the dialogue. The classroom meta-discourse helped students understand the epistemic and dialogic nature of discourse and also consequently helped enrich their KF progressive inquiry.

Analysis of classroom episodes

Using the three themes and the prototypical excerpts, we conducted an analysis of the classroom episodes for the distribution of meta-discourse for all 15 lessons of classroom discourse. Forty-four classroom episodes were identified using natural breaks with different pedagogical designs, classroom activities, and discussion sequences. We analyzed the 44 episodes using the three patterns in terms of the characteristics and features that most resembled the meta-discourse patterns. Analysis showed that ten episodes were classified as meta-epistemic reflection, eight as meta-epistemic principles, and three as meta-epistemic theory. This suggests that the examples are distinctive but not atypical; students were engaged in similar meta-discourse processes in this designed knowledge building environment.

In the comparison class, students engaged in regular classroom discussions without meta-discourse. Twenty classroom episodes were identified using natural breaks. We analyzed the 20 episodes and generated three themes, including (1) expressing ideas, sharing and engaging in class discussions exchanging ideas (students expressed and shared ideas about a topic, 12 episodes), (2) reviewing KF quantitative indices (the teacher showed and discussed with students about the quantitative log data, four episodes), and (3) sharing KF writing on what is interesting focusing on ideas and content (students shared what they wrote in KF, four episodes) (see Table S3 in the Supplementary File). The total word-count proportions were 61.41% teacher talk and 38.59% student talk in the comparison class.

The analyses of meta-discourse in the experimental class suggesting high student agency were corroborated with general patterns of student engagement and talk distribution. The total word-count proportions were 54.89% teacher talk and 45.11% student talk, suggesting a high level of student engagement and agency. This is a high proportion of student talk in comparison with other intervention approaches, such as dialogic accountable talk orchestrated by teachers (Chen & Chan, 2022). General participation and talk distribution analysis provided corroborating evidence that the students had agency and took responsibility to engage in the classroom discussion by using meta-discourse—the collective inquiry and reflection into discourse may have helped students to develop epistemic discourse understanding for productive inquiry in knowledge building.

Discussion

Substantial advances have been made in examining and advancing discourse in CSCL. Still, relatively less attention has been given to examining students' meta-level understanding of discourse for promoting productive inquiry. This study investigated the role of a knowledge-building environment using KF, enriched through meta-discourse in which students reflected on and inquired into their discourse for promoting epistemic discourse understanding and productive inquiry. We first provide a summary of the key findings: First, the findings illustrate the characterization of students' discourse understanding (the aims, standards, and reliable processes). We found that the experimental students who

engaged in meta-discourse processes developed a more sophisticated epistemic discourse understanding and domain knowledge than the comparison class (RQ1). Second, we found that the experimental students had a deeper engagement in both collective idea improvement and discourse moves compared with their counterparts, further illustrating the positive role of the designed environment. Epistemic discourse understanding predicted KF discourse moves, and both contributed to domain understanding after controlling for pre-domain knowledge (RQ2). Finally, we examined how meta-discourse supported students' epistemic understanding and productive inquiry (RQ3). The qualitative analysis illustrated the dynamics and process of meta-discourse with three emerging themes: meta-epistemic reflection on collaborative activity, meta-epistemic reflection on principles, and meta-epistemic theory and reflection on conceptual ideas. In the following, we discuss the nature, roles, and dynamics of epistemic discourse understanding and meta-discourse for productive inquiry and implications for CSCL and knowledge building.

Characterization and roles of epistemic discourse understanding

This study examined students' epistemic discourse understanding and investigated its role in productive knowledge-building inquiry. We adapted the AIR model of Chinn et al. (2014) to examine the goals of knowledge-building discourse (aims), the characteristics of productive knowledge-building discourse (standards/ideals), and the strategies for achieving productive knowledge-building discourse (reliable processes). The findings showed different levels of discourse understanding about knowledge building in line with knowledge-creation discourse (van Aalst, 2009). At the lower level, some students considered the goal of discourse to be information sharing, a good discourse as one that has no arguments, and active participation and interaction as reliable processes/strategies for achieving a good discourse. Other students considered the epistemic goal of discourse to be the co-construction of knowledge, a good discourse as one that has constructive interactions and useful strategies involving different questions and explanations for problem solving. However, at the higher level, some students considered the epistemic goals of discourse to be aligned with knowledge building as collective idea improvement and community advancement; a good discourse as one that has emergent and sustained progressive discourse and reliable processes to include the synthesizing of diverse ideas, identifying gaps, using rise above, and sustaining inquiry by solving one question to raise new questions for community advancement.

These identified levels of epistemic discourse understanding are related to productive knowledge-building inquiry, as shown by the empirical findings. Primarily, sophisticated epistemic understanding (toward a collective and sustained pursuit focus) was associated with more productive collective inquiry (collective knowledge advancement), high-level discourse moves (questioning, theorizing, and community), and contributions to domain knowledge. These findings are consistent with the interpretation of how epistemic discourse understanding influences productive knowledge-building inquiry. When students think that working collaboratively in CSCL is simply about sharing information, they may focus on the exchange; if they think discourse involves the construction of understanding, they may focus on interactions and meaning making. Only when students develop epistemic goals valuing discourse for its contribution and community advances are they more likely to engage in rise-above strategies/processes. This study adds to the literature that shows that understanding the goal of argumentation contributes to performance beyond argumentation skills (Kuhn et al., 2008) and that developing epistemic criteria of models

scaffolds students' learning to construct good scientific models (Pluta et al., 2011). Consistent with these findings, our results showed that developing epistemic discourse understanding involving goals, standards, and processes/strategies is important in productive knowledge-building inquiry. This study extends epistemic cognition to CSCL discourse using the AIR framework (goals, criteria, and processes). Just as understanding that the epistemology of science is essential for science learning beyond learning science content and ideas, it would be helpful to examine epistemic discourse understanding beyond focusing on discourse content and collaborative activity.

Developing epistemic discourse understanding, including goals, characteristics, and processes, supports students' meta-cognitive awareness and provides epistemic standards and community norms for emergent knowledge building. Epistemic beliefs and actions are intertwined (Sinatra, 2016), similar to epistemic fluency and epistemic activity (Goodyear & Zenios, 2007). More sophisticated beliefs would lead to deeper discourse action, and the resultant deeper collaborative discourse may lead to reflections on epistemic discourse understanding for continued development. Epistemic cognition has also been increasingly shown to be situated in practice, and these intertwined relationships and development could be enriched in designed CSCL environments.

Meta-discourse and the dynamics and mechanisms for knowledge building

This study examined how a designed knowledge-building environment, enriched with meta-discourse, influenced students' epistemic discourse understanding and productive inquiry. The quantitative findings indicated that the experimental students demonstrated a deeper inquiry (including thread analysis, discourse moves, and keywords network analysis by KBDeX) and moved further toward sophisticated views of discourse that aligned with knowledge building than the comparison students. These findings provide evidence for the effects of the environment that employs meta-discourse for productive inquiry.

Qualitative analyses help to reveal how meta-discourse involving metacognitive, epistemic, and conceptual components supports productive inquiry and knowledge advancement. Three interrelated themes emerged, drawn from the literature enriched with empirical findings: (1) meta-epistemic reflection emphasizes students' metacognitive and epistemic reflection on collaborative activity, the evolution of ideas, and the progressive nature of inquiry emerging in the community (e.g., changes from the initial to current ideas, one answer to multiple and expansive inquiries); (2) meta-epistemic principles emphasize students' explicit inquiry into the epistemic criteria of discourse (knowledge-building principles) and identification of features of discourse to revise their discourse; and (3) meta-epistemic theory with students engaging in theory-building efforts pursuing idea development and deepening inquiry (e.g., from "can art solve problems" to an inquiry into "art and science and creativity"). Overall, the students engaged in the meta-discourse to reflect on the what, why, and how of their collaborative discourse, thereby deepening their collective inquiry and the epistemic meanings of discourse, which are the essence of knowledge building.

These findings related to meta-discourse are consistent with various past studies that have examined the role of reflective activities on argumentation skills (Felton, 2004; Iordanou, 2022), student discussions related to group activity (Kuhn et al., 2020), and metacognitive conversations about conceptual idea development (Yuan et al., 2022). This study enriches this line of research on reflection on discourse and demonstrates that meta-discourse focuses on the collective not just individuals. As shown in the examples, we found that students alluded to evolving ideas in the community, the features

and principles of discourse, discourse gaps, and the ways to fill them, theory-building efforts, and collective activity related to knowledge-building work. In different ways, these students worked collectively to develop the meta-level understanding needed for productive knowledge-building inquiry. Meta-discourse helped them to become aware of the metacognitive, epistemic, and conceptual elements of discourse to further community knowledge building.

We also discussed the importance of meta-discourse in knowledge building using KF. Central to knowledge building is KF, the technology with different affordances designed to instantiate the complex knowledge-creation goals and emergent process (Scardamalia & Bereiter, 2014; see Fig. 1). Knowledge-building discourse for creative work is ever-deepening as students probe deeply, generate questions, and co-construct explanations for revising their theories for emergent inquiry. Although there are many advantages of emergent inquiry for creative work, KF has some limitations. As an open system, it is common for ideas to become isolated and fragmented, and students may not easily follow new ideas that have been developed in the community. The advantages also pose disadvantages for students who find it challenging to keep track of the discourse. Meta-discourse, which involves students' reflection on discourse, can help organize the flow of discourse housed within KF (Zhang et al., 2020). It can also serve the purpose of rise-above synthesis to integrate disparate and promising ideas for higher-order conceptualization, which is a distinctive characteristic of knowledge building. Meta-discourse that develops during knowledge building is important for CSCL and particularly relevant for building new knowledge through discourse as it emerges and progresses in large communities.

Drawing on the study findings, we discussed the dynamics and mechanisms of how meta-discourse supports epistemic discourse understanding and emergent knowledge building relating to metacognitive, epistemic, and conceptual processes. First, we found that meta-discourse, in which students talk about their discourse (online and offline), supported metacognition in the social and collective contexts. Students articulated what they had learned personally and as a class (e.g., what is on the KB wall), compared their past and new understandings, as they identified problems and posted more questions for continuing inquiry. These metacognitive reflections were not just individual based but were also articulated in groups and communities; they went beyond individual reflection to include ideas that the community considered or advanced. Knowledge building often involves a prolonged period (weeks/months) relative to that required for metacognition in other popular types of group activities. Meta-discourse is particularly useful in helping students to develop a conceptual landscape of their community discourse (e.g., What is interesting? What has our community discussed?) for developing higher-level conceptualizations and sustained inquiry.

Second, the meta-discourse in this design involves epistemic components relating to goals/aims, standards/characteristics, and reliable processes/strategies. The qualitative findings illustrated how students engage in meta-discourse using knowledge-building principles to discuss their inquiry. Such meta-discourse provides opportunities for helping students become aware of the goals and value of discourse, the criteria for productive discourse, and the comparison between different discourse structures. This awareness helps in understanding what processes/strategies can help them arrive at a more productive inquiry. Students often engage in CSCL without knowing their goals, expectations, and criteria; metacognitive and epistemic awareness can support their collective agency for taking the discourse to a higher level. In addition, the goals, standards, and processes discussed and questioned in a social context could influence others in the group/community. Specifically, meta-discourse not only influences the discourse activity itself but also contributes to

students' new ways of understanding discourse for developing community norms to support ongoing productive knowledge-building inquiry.

Third, meta-discourse also involves conceptual aspects and idea development (domain knowledge), in which students focus on theory building; that is the essence of knowledge building. The example showed how students engaged in a discourse on an intriguing problem ("Can art solve problems?", p. 36), which interlinks KF and classroom meta-discourse. Meta-discourse is primarily about developing knowledge building in the community, and students need to experience theory-building with idea development. There are concerns that knowledge building focuses too much on KF writing; classroom meta-discourse integrated with KF writing widens the possibilities of theory-building to develop ideas from different perspectives and modalities. Meta-discourse provides opportunities for students to make their epistemic practice of theory-building more explicit, as they ask emergent questions, construct rise-above explanations, and improve their ideas collectively.

Implications for CSCL and knowledge building

This study has provided conceptual and empirical insights into developing meta-level understanding with epistemic dimensions to promote CSCL and knowledge-building discourse. The CSCL literature has made substantial progress in examining and supporting collaborative discourse. This study is one of the few systematic CSCL studies demonstrating how meta-level understanding or meta-knowledge involving students' epistemic discourse understanding and meta-discourse can provide an additional layer for promoting collaborative discourse. This study contributes to CSCL enriching the notion of meta-level understanding as a basis for collaboration (Kuhn et al., 2013), and shows the intertwining roles of epistemic discourse understanding and meta-discourse in line with what has been called meta-knowing (goals/criteria) and meta-strategic knowledge (reflective inquiry) in a CSCL context (Kuhn et al., 2008). The present study contributes to the CSCL literature on designing a knowledge-building environment, augmented with a meta-discourse design, to promote students' epistemic discourse understanding, productive inquiry, and knowledge advancement.

Although this study was conducted in a knowledge-building environment, its findings also have implications for examining epistemic discourse understanding in the broader CSCL context. Decades of epistemic cognition research have demonstrated that understanding the nature of science is essential for doing science beyond learning science ideas (Sandoval, 2012, 2014). Likewise, as demonstrated by the findings, students' understanding of the goals, standards, and strategies of different kinds of CSCL discourse (e.g., collaborative argumentation) could be beneficial beyond discourse activities. In collaborative activity, students do not engage in discourse alone, they also need to know the what, why, and how of the collaborative discourse processes. Our findings showing the intertwined epistemic discourse understanding with evolving meta-discourse processes for productive inquiry may also help extend new areas of CSCL inquiry into socializing epistemic cognition. CSCL is concerned with the collective, not individual, work. If students view group discussion and interaction as a way to promote individual understanding, information sharing, and interactions for task completion, they would not see a way or a need to pursue collective understanding for deep collaborative work. It would be fruitful to further examine how students develop epistemic understanding and epistemic practice in CSCL as a way of bridging beliefs and actions of collaboration.

This study has further developed the notion of meta-discourse, which is discourse about discourse, with students reflecting on and inquiring into their discourse involving metacognitive, epistemic, and conceptual elements. Furthermore, it includes them considering what they have accomplished and identifying knowledge gaps for further inquiry. Just as metacognition is a higher-level process for cognition, meta-discourse supports rise-above and a higher-level conceptualization of discourse in knowledge building. Metacognition has been extensively studied in CSCL, and generally, it focuses on specific group and discourse activities (Järvelä et al., 2016; Kuhn et al., 2020). Meta-discourse enriches metacognition by highlighting students' reflection on discourse for prolonged inquiry and organizing the flow of discourse for emergent understanding at the community level. As CSCL is extended from studying group collaboration to community collaboration (Yuan et al., 2022), meta-discourse, which is advocated for knowledge-building research, could provide more possibilities for reflecting on community advancement.

This study also has implications for enriching the knowledge-building research on meta-discourse in which student agency and rise-above processes are emphasized (Resendes et al., 2015; Zhang et al., 2012). We have identified the possible mediating role of epistemic discourse understanding, enriching the influence of meta-discourse. Current knowledge-building research has shown the role of meta-discourse but needs to clarify how it exerts an effect. Through explicit reflection and discourse, these processes could enrich and modify students' understanding of knowledge-building discourse, which would have a reciprocal influence on their knowledge advancement. Meta-discourse directly influences students' engagement in deeper discourse and possibly influences student epistemology and community norms for more sustained effects on knowledge building. Epistemic understanding and epistemic action are intertwined, and their possible reciprocal bi-directional effects should be further examined.

The findings of the study also have design implications for knowledge building and CSCL. This study contributes to new ways of designing principle-based knowledge-building environments. Knowledge-building research has usually focused on how teachers use principle-based approaches to design knowledge-building environments (e.g., Chen & Hong, 2016). This study extends the possibility for students to reflect on and inquire directly into the principles and characteristics of discourse, which are essential in developing an understanding of what knowledge building is about. Designing classroom discussions in which students talk about the goals, criteria, and strategies of discourse could help them understand and develop knowledge-building norms, thereby enriching and sustaining collective inquiry. There are also implications for creating open, expansive, and epistemic-rich CSCL environments and cultivating students' meta-discourse and dialogic capacity for agency in charting productive knowledge building. This study also deepens our understanding of how students and teachers co-inquire and engage in different types of meta-discourse that help inform classroom knowledge-building talks.

Limitations and future research

The study has several limitations suggesting the need for future research. First, it employed a quasi-experimental design, and it needs to be acknowledged that there are complex factors that are difficult to control in classroom-based research. Nevertheless, both classes show improvements (e.g., coherence of ideas in KF discussion), which suggests that the teacher has provided good support to both. Comparison groups can provide useful data and

have been employed in knowledge-building research (Resendes et al., 2015). Second, while the experimental students have obtained higher epistemic understanding scores, there may be concerns with "teaching to the test" effects when the students discuss the nature of discourse in the classroom. Caution has been taken to avoid using the same question stems, and there is evidence that students were not just recalling some presented information; qualitative analyses suggest students' shared deepening understanding of discourse in their meta-discourse.

Third, KBDeX network structure analysis of students' collective discourse showed more coherence and connections and different keywords used by students with different epistemic understandings. More in-depth analyses of these groups are needed to investigate the patterns of epistemic change in connection to collective growth using different methods. Fourth, we analyzed meta-discourse using prototypical episodes qualitatively to examine the processes; and continuing work is now being undertaken to analyze and code students' and teachers' specific meta-discourse activities. Combinations of qualitative and quantitative analyses would help characterize different facets of meta-discourse processes and to test the mediating roles of epistemic discourse understanding. Fifth, the analysis of students' epistemic discourse understanding into three levels is based on the theoretical lens of knowledge building. It needs to be acknowledged that in different CSCL environments, productive collaborative discourse may have different meanings, and these are fruitful areas of investigation. Finally, the small sample size limited our statistical analysis, and future studies could address this issue using larger samples.

Conclusions

Discourse is central to CSCL, but what students think about discourse and how they talk about the goals and the nature of discourse for productive inquiry and knowledge building has not been systematically examined. CSCL has focused on examining the collaborative discourse process (Cress et al., 2021). However, limited attention has been given to examining "discourse about discourse" that involves a meta-level reflection on the discourse process. The epistemic cognition literature has examined students' understanding of the nature of knowledge/knowing, but the specific study in CSCL environments on socializing epistemic cognition is limited. This study was adapted from the AIR model (aims, ideals, reliable processes/strategies; Chinn et al., 2014) and three modes of discourse (van Aalst, 2009) to characterize students' epistemic discourse understanding in knowledge building and to investigate how meta-discourse can promote epistemic discourse understanding and productive inquiry.

This study provides conceptual and empirical considerations for enriching CSCL interactions by incorporating meta-level reflection and epistemic processes for productive knowledge building. We designed an epistemically rich knowledge-building environment in which knowledge-building inquiry on KF was interwoven with classroom meta-discourse. The comparison using multiple measures demonstrated that in this design, meta-discourse enriches the contribution of student epistemic discourse understanding to productive inquiry and knowledge advancement. We identified different types of meta-discourse highlighted in several episodes, including metacognitive, epistemic, and conceptual reflection on discourse. Similar episodes with these characteristics were identified throughout, corroborated by the evidence of high proportions of student talk reflecting collective agency in dialogue.

This study has theoretical and design implications for the examination of epistemic processes and meta-discourse emphasized in knowledge building (Bereiter et al., 2019; Bereiter & Scardamalia, 2016). Current CSCL research focuses on supporting the discourse activity itself; this study highlights the examination of meta-level understanding involving epistemic discourse understanding and meta-discourse as a foundation for promoting collaborative activity. Developing students' understanding of the goals, standards and processes of discourse supports metacognitive awareness and provides epistemic standards and community norms for CSCL. Meta-discourse is an important concept in knowledge building. Reflection on discourse can encompass reflections on collaborative activity for collective metacognition, the goals and strategies of discourse for community norms, and sustained theory-building advancement. It is increasingly recognized that reflection on discourse is essential, and the findings suggest CSCL inquiry could be enriched via discourse about discourse and the investigation of meta-discourse processes.

While this study was conducted in a knowledge-building context, examining students' understanding of the epistemic criteria for different kinds of collaborative discourse may be fruitful in CSCL. This could involve, for example, investigating students' understanding of what constitutes argumentative or problem-solving discourse and helping students to talk about their group/collective activity with criteria to help them develop agency for continued collaboration. Technology and analytics have been shown to enrich meta-discourse processes (Resendes et al., 2015; Yang et al., 2022; Zhang et al., 2020) to help students develop collective agency for productive inquiry. Further investigations are needed to examine meta-discourse designs and processes using different technology-enhanced approaches to support epistemic discourse understanding for promoting knowledge building and CSCL.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11412-023-09403-2.

Data availability The data is available on request from the corresponding author.

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