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Discourse Moves and Emotion in Knowledge Building Discourse and Metadiscourse

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This paper explores the possibility that knowledge building metadiscourse-discourse about knowledge building-can produce a positive feedback loop, with positive emotional state and knowledge advancement serving to increase each other. Grades 2 and 3 students' utterances over several months were analyzed as a unit of study, starting with identification of each discourse move and corresponding emotion, defined as a state. These states were then analyzed over time, with a focus on metadiscourse sessions in which students reflected on earlier discourse to identify questions and ideas to be pursued in greater depth. Each discourse move-emotional state was analyzed to determine frequency, transition from one state to another, and spread of each state such as "reflection and positive" and "proposing new directions for inquiry and curiosity." These two states were among the most frequently occurring in the metadiscourse sessions and virtually absent in other discourse sessions. Transition rates indicated that reflection tended to trigger more reflection, and proposing a new direction led to more proposals for new directions. Sequential pattern analysis suggested subsequences specific to metadiscourse sessions. Overall, results indicate that engaging in metadiscourse contributes to students' productive KB and positive emotions.

Keywords: Knowledge Building, discourse, metadiscourse, emotion, idea improvement, discourse move, young students

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INTRODUCTION

Emotions and cognitive decision making are central to human response to the dynamic environments they face (Afraimovich et al., 2011), forming interconnections (Oatley et al., 2014) involving participation and coordination of overlapping brain centers (Afraimovich et al., 2011). Cognitive judgment influences emotional responses with emotional appraisals forming the base for coordinated responses (Feldman Barrett et al., 2019). To better understand how emotions are framed and contextualized within learning activities and environments, researchers increasingly study emotion and cognition as unified and interconnected actions (e.g., Chevrier et al., 2019; Hod and Katz, 2020; Isohätälä et al., 2020a,b; Vogl et al., 2020).

Productive collaborative learning requires students to be aware of and coordinate their cognitive, emotional, and metacognitive resources and processes (Hadwin et al., 2018; Järvelä et al., 2019). Knowledge Building (KB), emphasizes students' collective social and cognitive responsibility to advance community knowledge (Scardamalia and Bereiter, 2014). Such endeavors involve students' engagement in knowledge building metadiscourse, discourse about knowledge building, in which they make decisions, form goals, identify and remedy understanding gaps, and discuss future inquiry directions (Zhang et al., 2015). Engaging in high-level cognitive and metacognitive work requires a broad and reflective view of their discourse, treating discourse as an object for formative assessment, inquiry, and refinement (Resendes et al., 2015). Metadiscourse allows students to work on ideas they think are important and valued and take greater control over learning than they usually do. The control-value theory (CVT; Pekrun, 2006; Pekrun and Perry, 2014) suggests students may experience more positive emotions in metadiscourse sessions. CVT assumes that subjective controls (i.e., the extent to which a student perceives causal influence over actions and outcomes) and values (i.e., how important and attractive they think the actions and outcomes are) influence students' emotions during learning tasks. This framework for understanding the generation and influencing factors of emotions in learning settings guides researchers to design environments to support students' positive emotions. For instance, this study did so by engaging students in KB metadiscourse sessions that were likely to enhance students' control of learning and the value of their collaborative inquiry.

Students who participate in collaborative learning, including KB, experience cognitive and emotional interactions (Isohätälä et al., 2020a,b). Previous studies suggest that engaging in metadiscourse will help sustain and deepen KB (e.g., Resendes et al., 2015; Yang et al., 2016; Tao and Zhang, 2018; Zhang et al., 2018). What remains unknown are the effects of engaging in metadiscourse on students' emotions. Furthermore, studies indicate that metacognitive processes usually mediate the effects of emotions on learning outcomes (e.g., D'Mello et al., 2014; Mega et al., 2014; Obergriesser and Stoeger, 2020). KB discourse and metadiscourse unfold over time, and it is important to study the temporal dimension of students' learning process (Chen et al., 2017; Zhu et al., 2019b). Therefore, this study considered students' emotions and KB discourse moves together to understand when students' control over learning was supported at different levels in discourse and metadiscourse, how their discourse moves and emotion states differed, and the transitions and sequences of the states. Considering the discourse move and corresponding emotion of each utterance as a paired unit allowed us to generate insights of how cognition reflected in a discourse move and emotion co-occur, and change over time, which was not possible in previous analyses which studied cognition and emotion separately or examined relationships (e.g., Chevrier et al., 2019; Buono et al., 2020). Research into the co-occurrence of cognitive-emotional states is needed to further our understanding of emotions that promote or impede learning with implications for designing more positive socioemotional environments for collaborative inquiry learning. This study has theoretical and methodological novelty. Theoretically, it addresses the research gap concerning limited understanding of students' discourse moves and emotions in discourse and metadiscourse sessions. Methodologically, this study considers the discourse move and emotion coding of an utterance as a whole (i.e., state) and investigates frequency, transition, and spread.

LITERATURE REVIEW

Knowledge Building and Discourse Moves

Knowledge Building advocates for students' collaborative responsibility to advance community knowledge (Scardamalia and Bereiter, 2014), to better prepare them to engage with a society wherein knowledge is continuously refined, and new knowledge quickly emerges. Advancing community knowledge involves pursuing more coherent explanations that encompass more new facts and a deepening understanding of why theories work (Scardamalia, 2002; Thagard, 2007). When an experimental idea is published in natural science, like biology, scholars worldwide can test and build on it. Similarly, in KB, students' ideas and theories are seen to have a public life: they are open to testing, questioning, criticizing, putting up alternatives, and improving (Popper, 1972; Bereiter, 1994; Scardamalia et al., 1994; Philip, 2009).

Ideas are improved through progressive KB discourse and metadiscourse in offline KB talks and online platforms such as *Knowledge Forum* (KF). Usually, a class of students and teachers form a KB community. As shown in **Figure 1**, in KB talks (Reeve et al., 2008), students and teachers sit in a circle to discuss community norms, questions, ideas, and theories that they think are important to share, discuss, and research. The community may also decide what ideas to focus on and what experiments, field trips, and other investigative activities to pursue. KB discourse can also occur online in KF—the technology built specifically to support knowledge-creating interactions (Scardamalia, 2004). In KF, Students are encouraged to record the important ideas, resources, or examples they have discussed in KB talks to deepen their understanding of these issues. Within KF (see **Figure 2**), students can post ideas as notes onto a public space called a "view." They can co-author, revise, read, reference, build on, and annotate notes as ways of building community knowledge. When writing notes, students can use scaffolds such as "my theory," "I need to understand," "a better theory," and "constructive uses of authoritative sources." These scaffolds can be co-constructed by the teacher and students to facilitate student thinking and writing.

Different measures have been developed to study students' KB discourse and metadiscourse. For example, Zhang et al. (2009) used the "epistemic complexity" and the "scientific sophistication" measures to code students' scientific understanding. The epistemic complexity of ideas indicates students' efforts to produce theoretical explanations and elaborations on community ideas. Measures of scientific sophistication assess the extent to which students move from

FIGURE 1 | An example of Knowledge Building talk.

an intuitive to a scientific understanding. Yang et al. (2016) classified students' notes into three categories: question, idea, and community. The question category is further distinguished into fact-seeking, explanation-seeking, and metacognitive questions. The idea category includes simple claim, elaboration, explanation, and metacognitive statement. The community category includes negotiating a fit and synthesizing note. Hmelo-Silver and Barrows (2008) categorized the statements generated in medical students' KB discourse into collaboration and complexity. The collaboration category consists of new ideas, modifications, agreement, disagreement, and "meta," while complexity includes the simple, causally elaborated, and elaborated levels. This study integrated and adapted these coding schemes to analyze students' discourse moves in their discourse and metadiscourse sessions.

Furthermore, it is critical to study the transitions and temporal sequences of discourse moves of collaborative learning, especially for KB which emphasizes students' idea improvement. Knowledge construction, collaborative problem solving, and idea improvement occur over time (Reimann, 2009; Knight et al., 2017). An idea (e.g., a question, a piece of information, or an explanation) needs to be understood in its context (i.e., previous ideas) to evaluate how it contributes to idea improvement. Using lag-sequential analysis and frequent sequence mining, Chen et al. (2017) analyzed the sequential patterns among students' contribution types (i.e., discourse moves) in KB. They found that productive threads were characterized by more transitions among notes coded as questioning, obtaining information, working with information, and theorizing. In contrast, merely opinion-giving did not contribute much to idea improvement. In a collaborative inquiry learning context, Zhu et al. (2019b), indicated that when groups successfully solved their problems, their discourse was characterized by a higher probability of transitions from proposition generation to orientation, from interpretation and conclusion to experimentation, and from proposition generation

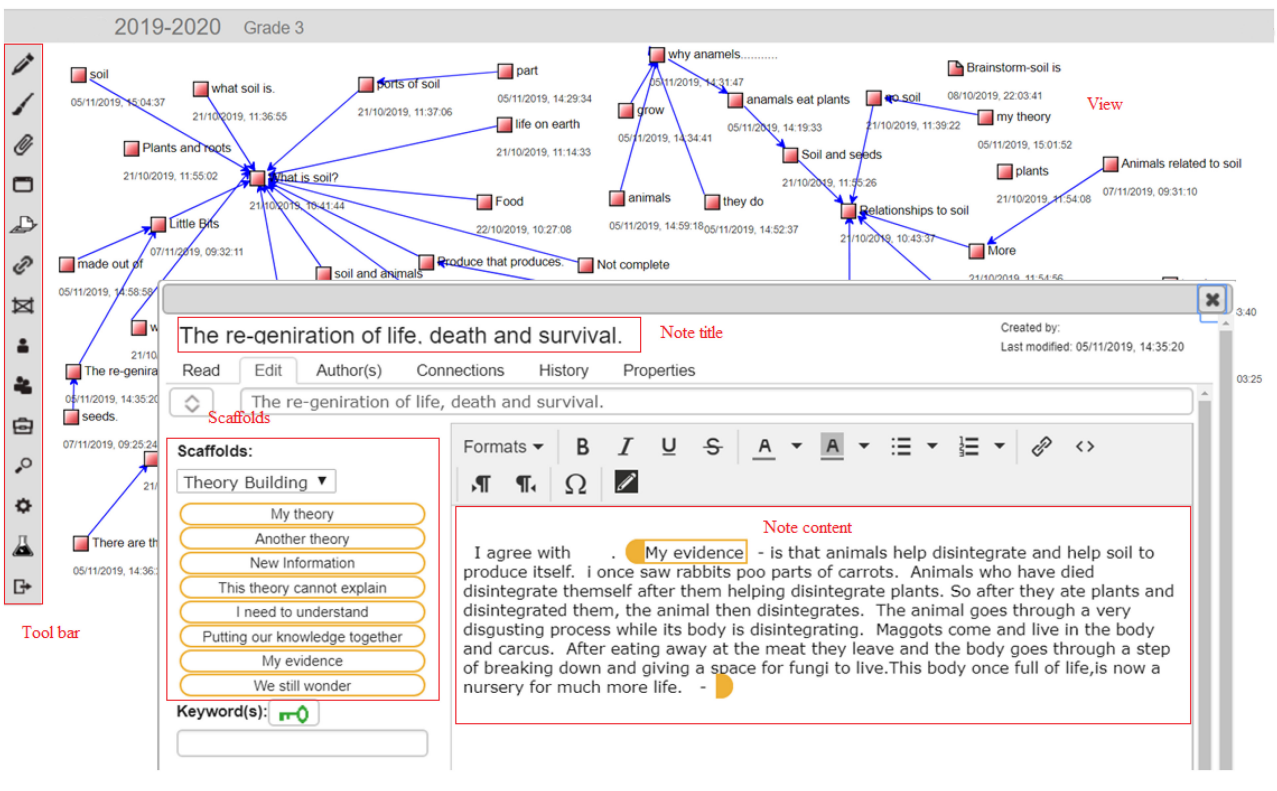

FIGURE 2 | Grade 3 Knowledge Forum view showing a note open for editing (student misspelling was not corrected).

to sustaining mutual understanding. These results suggest that students in groups who solved problems successfully tended to ensure that everyone in their group had a shared understanding of the relationship between the variables. However, existing studies (e.g., Chen et al., 2017; Zhu et al., 2019b), have been focused on analyzing online discourse, leading to a limited understanding of how offline discourse may unfold over time.

Emotion and Emotion Transitions in Learning

Emotions emerge as part of a stimulus-appraisal process (Fiedler and Beier, 2014), wherein an individual engages with an object (e.g., environment, person, memory) and passes a judgment on it. This series of judgments can happen on a conscious or unconscious level and are affected by various personal factors and dynamic processes of collaborative inquiry (Bakhtiar et al., 2017). The social nature of that interaction precipitates an emotional response that can then be analyzed based on the circumstances surrounding the individuals and the response/judgment they bring to that set of circumstances. It is important to note that emotions, especially in performance-based learning environments, do not simply emerge without cause. Cognitive psychology describes how the appraisal process ties together the causal reasoning, deliberation, goal appraisal, and planning processes that surround emotions, which are mediated through the experience of emotions (D'Mello and Graesser, 2012). The cognitive mechanisms in our mind help transform the appraisals and actions surrounding a situation into emotions that can be externally expressed (Shuman and Scherer, 2014) in the form of a physical indicator (e.g., an action, reaction, physical gestures, movement).

Various theories have emerged to describe how individuals emotionally respond to their environments. These theories include emotion regulation in achievement settings (ERAS; Harley et al., 2019), the component process model (CMP; Scherer, 2009), and the CVT (Pekrun, 2006; Pekrun and Perry, 2014). These models share similarities in how they situate emotions to the time and place where an individual makes a judgment regarding a stimulus or environment, which then results in an emotional expression. These emotion theories, especially the CVT and ERAS, allow researchers to describe how emotions emerge in a host of achievement-oriented environments (Loderer et al., 2020), and describe the emergence of emotions as an appraisal of two components: (1) control and (2) value. Subjective control refers to a student's perceived causal influence over actions or outcomes (e.g., expectations that persistence at studying can be enacted and can lead to success, Skinner, 1996). Subjective value denotes the student's perceived valence of actions and outcomes (e.g., the perceived importance of success). As described above, in the KB context, students' authentic ideas and epistemic agency are emphasized, conveying value and control. By enabling students to reflect on their community discourse status, identify understanding gaps, and make inquiry plans, metadiscourse further provides them with opportunities to work on ideas they think are of importance and value and take greater control through reflecting on earlier work. As such, we argue that KB contributes to students' positive emotions, and metadiscourse sessions are more likely to foster positive emotions than the first-pass discourse sessions.

Thornton and Tamir's (2020) three-dimensional mental state model, which frames humans' experiences of thoughts and feelings, helps explain the transitions of mental dynamics. The researchers synthesized and verified that a mental state could be represented with three dimensions: (1) rationality, (2) social impact, and (3) valence. Rationality is about the degree of cognition (e.g., agency, competence, reasoning) involved in a state. Social impact describes the intensity and sociality of a state, for example, how impactful a state is on social relationships. Valence indicates the positive or negative extents of a state. Thornton and Tamir (2020) suggested that a mental state is more likely to transit to a near state in the mental space. The emotional transitions that individual learners make while engaging in KB change their appraisal of their ideas and environments, therefore necessitating the need to understand how emotions co-develop with ideas.

Metadiscourse

Metadiscourse engages students in metacognitive conversations about their ongoing collaborative inquiry. In metadiscourse, students take collective responsibility for high-level cognitive work such as making decisions, forming goals, identifying and remedying understanding gaps, and discussing future inquiry directions (Zhang et al., 2015). Several studies have shown the positive impact of metadiscourse on students' community knowledge advancement (e.g., Resendes et al., 2015; Lei and Chan, 2018; Zhang et al., 2018). However, metadiscourse is rarely observed in inquiry-based learning without intentional support (Scardamalia, 2002; van Aalst, 2009). Researchers have been studying how to support metadiscourse or reflective assessment with pedagogical and technical designs. For instance, Hewitt and Woodruff (2010) integrated a wiki page that held a permanent and group-authorable summary of the discourse in KF to help students maintain a meta-level collective understanding of the progress. Chen et al. (2015) designed a *Promising Ideas Tool* that helps students select, aggregate, and display the ideas that they think can lead in the most productive directions. Resendes et al. (2015) investigated grade 2 students' ability to engage in productive discussions of their community knowledge status with the support of two group-level feedback tools: a tool that displays the overlapping and different words used in students' notes and authoritative sources, and a tool that shows the frequency of KF scaffolds used in notes. Yang et al. (2016) used two questions to guide the reflection of 20 grade 11 students on their community knowledge: *Are we a community that collaborates*? and *Are we putting our knowledge together*? Tao and Zhang (2018) and Zhang et al. (2018) examined how Idea Thread Mapper (ITM), a time-based inquiry-structuring tool (Chen et al., 2013), helped teachers and students to monitor their community status and decide which threads to focus on. In Lei and Chan's (2018) study, the students wrote group e-portfolios as their KB unfolded as a way of engaging in collaborative reflective assessment. These designs have informed the metadiscourse design of the current study.

Self-regulation and metacognition are two constructs very relevant to metadiscourse. Three mechanisms describe the process of self-regulated learning: (1) assessing the effectiveness of strategies that students employ to help them meet their learning goals, (2) modifying plans, and the effort they exert to meet those modified plans, and (3) engaging in effective and meaningful self-reflection and having a sufficient mechanism by which to do this (Azevedo and Aleven, 2013). Socially shared regulation learning that encourages students to negotiate and achieve shared goals, plans, and strategies as a group (Järvelä and Hadwin, 2013) is more relevant to this study context—students taking collective responsibility to build knowledge. Metacognition is the thinking process about one's thoughts (Clarebout et al., 2013). This process is driven by the interaction of metacognitive knowledge, experiences, and strategies, which help the learner to be able to objectively think about and monitor their abilities and goals, and in turn can inform other processes critical to learning, such as self-regulation.

These self-regulated and metacognitive processes mediate the effects of emotions on learning outcomes and reinforce positive processes that can help learners achieve success. For instance, Buono et al. (2020) study with 150 6- to 9-year-old students indicated that students' planning fully mediates the effect of frustration on their narrative storytelling scores, and frustration is significantly related to fewer planning behaviors. Mega et al. (2014) showed that positive emotions only foster undergraduate students' learning when mediated by self-regulated learning and motivation. D'Mello et al. (2014) found that confusion can contribute to learning when appropriately induced, regulated, and resolved. Järvenoja et al. (2019) explored which challengers triggered students' socially shared emotional regulation during collaborative learning and which emotional regulation strategies emerged. They found that socially shared emotional regulation is an established part of regulation when collaborative learning is challenged. Obergriesser and Stoeger (2020) conducted a temporal analysis to investigate how elementary students' enjoyment and boredom predict their effective use of learning strategies and vice versa. They found that students' self-reported enjoyment positively predicted their effective use of learning strategies, while boredom did not; in turn, learning strategies neither predicted enjoyment nor boredom. However, these studies were mainly conducted at the individual learning level. Few studies have investigated how metacognition may influence emotions and cognition at the collaborative level.

Conceptual Framework and Research Questions

Previous research suggests the interconnection of cognition and emotion, the importance of studying the sequential patterns of discourse move and emotions in the KB context, and the impact of metadiscourse and relevant self-regulation and metacognition on cognition and emotions. Furthermore, the three-dimensional mental state model suggests a state tends to transit to similar states, suggesting discourse move-emotion states would spread in KB communities in which students take collective responsibility to advance their knowledge and engage in various cognitive and emotional interactions. KB, as suggested by its principles (including real ideas, authentic problems, and epistemic agency), emphasizes students working on ideas they care about and driving their inquiry by engaging in high-level cognitive work such as negotiating shared goals and making plans. Although this high-level cognitive work may occur at all levels, KB metadiscourse sessions provide students with more opportunities to discuss the ideas and problems they care about and how to work on these issues by reflecting on their current KB discourse, identifying understanding gaps, proposing future inquiry directions, and making plans to further advance their community knowledge. This may help students to perceive the relevance and value of learning and take more control over their learning. According to the CVT, students would feel increased positive emotions and decreased negative emotions in metadiscourse sessions.

We conjecture that students' discourse moves-emotion states in KB discourse and metadiscourse sessions differ, as do the transitions of these states. As shown in **Figure 3**, a conceptual framework of discourse move-emotion states in KB discourse and metadiscourse sessions was developed to guide this study. This study aimed to investigate the following three questions:

1. What are the frequently occurring discourse move-emotion states in discourse and metadiscourse sessions?
2. What are the transition patterns of students' discourse move-emotion states in KB discourse and metadiscourse sessions?
3. How do discourse move-emotion states spread in KB discourse and metadiscourse sessions?

METHODS

Participants and Research Context

Twenty-two 7- to 9-year-old students participated in this study, starting in January 2019, and ending in December 2019. The participants were from one private school in a large metropolitan city. Two of the students left the class at the end of grade 2, and two new students joined in grade 3. In grade 2, there were eleven girls and eleven boys; in grade 3, 12 girls and 10 boys. The school had a well-established inquiry program with ethnic and cultural diversity of the city represented in the student population. The students engaged in KB talks when they were in Junior Kindergarten and began using KF at the end of grade 1. Therefore, most of the students were familiar with KB talks and KF.

The following descriptions of the grade 2 and 3 teachers, Emily and George, were based on email responses to questions regarding when they started teaching, when they adopted Knowledge Building, and how they understood and practiced KB. Both teachers had been engaged in KB, although their work in the current study represented their first attempt to implement it in grade 2 and grade 3 classrooms. Their initial introduction to KB was in their previous roles as Teacher Librarian, Technology Integrator, and Physical Education teacher. Emily is a female teacher who started teaching in 2013 after receiving a master's

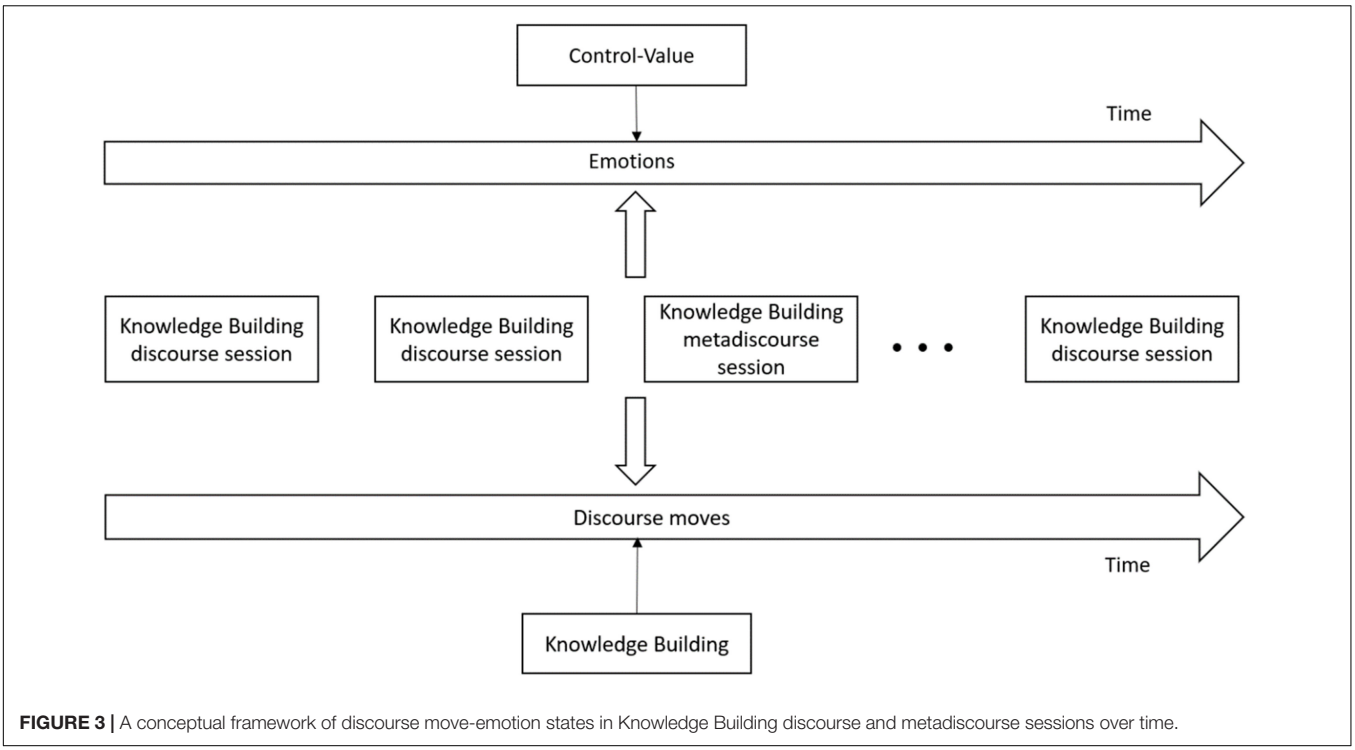

FIGURE 3 | A conceptual framework of discourse move-emotion states in Knowledge Building discourse and metadiscourse sessions over time.

degree in Child Study and Education. She had been teaching for 6 years when the study started in 2019. Emily became familiar with KB as a teacher candidate. Her role as a Teacher Librarian and Technology Integrator engaged her in the world of KB as part of her job chairing meetings between teachers and KB researchers. She came to learn about the KB principles and how to apply them in multiple ways in a classroom setting. She adapted what she learned from others into her teaching in the library before she became a grade 2 teacher. As Emily reflected, she believed that KB could occur in many capacities and across many curricular areas. In her class, children were constantly asking questions and she was to help children ask rich, deep questions—moving beyond surface-level ideas that could be easily answered, to questions that required investigation. She and the children gathered as a community to respond to experiences they had or to unpack a question that was posted by a member of the community. As they engaged in their learning together, they often paused and reflected on what they had learned thus far and discussed what they would like to learn next, what they might still be wondering about, and how they could further gather information. Children moved from constantly saying, "I know" to then saying, "maybe" when they were sharing an idea. This showed their growth in understanding that there were many possible answers and their idea was one of many.

George is a male teacher who started teaching in 2010. He developed his understanding of KB in different teaching roles in the school. For example, when George started as a Physical Education teacher, he thought of Physical Education as exclusively teacher-directed, requiring an 'expert' to impart knowledge to students to ensure things are done correctly and safely. However, through observing and reflecting, he shifted the Physical Education program to include greater student voice and agency to make the learning more meaningful for students. It was George's first year of teaching grade 3 when the study was conducted. He believed everyone in the KB community had things to offer and could bring diverse ideas, and KB made learning about the process, not just producing a product. By placing ideas at the center of learning, the community openly discussed their theories, questions, and goals, becoming metacognitive about the learning journey itself. He thought KB allows them to explicitly think about the process of learning in ways he had never thought of before joining the school.

Discussions on which this research is based lasted for about 4 months in grade 2 starting in January 2019, and two-and-a-half months in grade 3 starting in October 2019. In grade 2, the students mainly worked on Growth and Changes in Animals and related topics, and in grade 3, they studied Soils in the Environment. The outbreak of COVID-19 in the city in March 2020 forced an end to the KB in grade 3 although the students and teachers were planning to conduct their soil and seed experiments in the spring. Therefore, the relatively shorter KB period does not indicate students' disengagement.

Curriculum and Pedagogical Design

The KB talks were labeled discourse and metadiscourse sessions based on their focus. Discourse sessions represent classroom talks such as working with information, constructing theories, discussing observations and readings. Metadiscourse sessions were talks specially designed to reflect on earlier discourse and assess their overall state of understanding, feelings, and future inquiry directions. Of course, discourse and metadiscourse are interrelated and may happen simultaneously. However, we designed monthly metadiscourse sessions in which the students intensively reflected on their previous discourse sessions and

planned their following discourse. The reason for doing so was because metadiscourse may not take place naturally given students' slowly developing metacognitive skills and challenges in regulating collaborative knowledge construction (Järvelä et al., 2016). KB principles such as collective responsibility, embedded and transformative assessment, epistemic agency, and rise above were especially highlighted and guided the design of metadiscourse sessions (Scardamalia, 2002). Next, we elaborate on the design of discourse and metadiscourse sessions.

Discourse Sessions

In both grades 2 and 3, the students engaged in face-to-face KB discourse (see **Figure 1**), in which they discussed questions that they cared about with the facilitation of their teachers. In grade 2, the students were curious about what kind of living environment salmon need, how to create a diagram of the life cycle of Atlantic salmon, the difference between ideal and current salmon habitats, what they could do to protect the environment, etc. The grade 3 students focused on researching what soil is, how soil develops different colors, how plants and animals relate to soil, and how and why different soils are made.

Various learning opportunities supported the students in researching questions and sustaining interest. In the beginning, some anchors were used to explore students' interests and curiosity. For instance, in grade 2, a salmon tank was set up in the classroom to hatch salmon eggs (see **Figure 4**), which enabled students to observe the growth and change of salmon. In grade 3, the students collected soil samples around the school and their neighborhoods (see **Figure 5**). In grade 2, creating a new diagram to display the life cycle of Atlantic Salmon drew the students' interest when they noticed the discrepancies between different resources. Another main research strand was building ideal and current salmon habitats. In grade 3, the students studied the soil samples to check their components, colors, hardness, and other properties. They also did experiments with the soil samples, for instance, shifting the soil samples and putting the soil samples into water. The classes went on field trips or invited knowledgeable people to their classrooms. For instance, the grade 2 cohort invited educational staff from the World Wildlife Fund, Toronto Zoo, Toronto and Region Conservation Authority, and the School of the Environment at the University of Toronto to discuss salmon, animals, waste, water contamination, and microplastics with the students. The grade 3 students visited the Humber Arboretum to learn, observe, and experiment with soils. The students read relevant books, watched videos, and annotated information for evidence, which also inspired new questions. In both grades, the students wrote, read, and built ideas in KF to record, sustain and improve their discourse.

FIGURE 4 | Setting up Salmon tank in grade 2 classroom.

FIGURE 5 | A grade 3 student collecting a soil sample.

Metadiscourse Sessions

In grades 2 and 3, the students engaged in metadiscourse about once every month. The students mainly discussed, reflected upon, and summarized what they had learned, what they still wondered about, and how they could improve ideas and build a more supportive and positive socio-emotional environment. We used several methods to support metadiscourse sessions.

In grade 2, questions such as "What have you learned about salmon? How have your ideas about salmon changed? What do you still wonder about salmon? How did you feel during this work?" guided students' metadiscourse. Furthermore, we used the Time Machine Tool embedded in the KF to support students' discourse. This tool can replay the development of KF views and help the students to recall their idea building. As the following excerpt from a grade 2 metadiscourse session shows,

the students built on each other's ideas regarding future inquiry directions after discussing how their understanding had changed (student name information was unavailable for this session). The students not only referred to previous discussions proposing new directions for inquiry but also suggested alternatives. Eventually, they decided to first design salmon habitats in the KF or using paper, and then build ideal and current salmon habitats using materials.

> "Adding onto Tom and Will, I think half the class can make an ideal habitat. And the other half can make what exists right now."
> "I was thinking, basically like Emma's, we could make it on the computer and then we could try and make it in reality."
> "I like Emma's idea, but I don't wanna do it on the computer cause it's hard."
> "I think it would be cool if the red group did something, like let's say the bad, like what we shouldn't do, and then the blue group did what we should do."

In the middle of grade 3, the students reflected on the discourse move distribution chart of their community in grade 2 (see **Figure 6**) and discussed what stood out to them in the bar graph. They noticed they had a lot of information but less "putting our knowledge together" and discussed why and what to do next:

> Sophia: But I notice that putting our knowledge together has the least and information has the biggest.
>
> Noah: Information is the stuff we know. If we try to put knowledge together, it's hard to do that. Harder than just writing down information.

Later, the students individually reflected on and wrote about things that made them frustrated. Their writing was collected, and the data was compiled using a bar graph. Then, the students reflected on the graph, which represented collective elements that made the class frustrated. The students were asked to choose one of the things that they could work on to make the community more friendly. They were also asked not to monitor others to avoid bullying possibilities.

Data Sources

The data included in this study were video recordings of 32 discourse sessions (about 5 h in grade 2 and 8.5 h in grade 3) and 8 metadiscourse sessions (about 1.3 h in grade 2 and 1.4 h in grade 3) in grades 2 and 3. All the videos were first transcribed verbatim. All the metadiscourse sessions conducted in grades 2 and 3 were included for analysis as well as all of the discourses sessions if the video was not shorter than 14 student utterances in each video transcript. **Figure 7** shows the number of students who spoke at least once in the discourse and metadiscourse sessions, indicating 8–19 students participated in each session. In 75% of the sessions, at least half of the students participated. The frequency of the fourth bar is zero because the students' name information was unavailable in the grade 2 teacher's notes when the first author was absent that day. We checked the utterances and removed the ones that did not carry ideas, but simply comments such as "yes," "yeah," "no," "I know." The utterance of each speaking turn was considered as a unit. Finally, we included 2,409 student utterances in 32 discourse sessions and 513 student utterances in 8 metadiscourse sessions in this study.

Data Analysis

Figure 8 shows the study protocol for this research. The same discourse move coding scheme was employed to analyze each utterance in the discourse and metadiscourse sessions. It

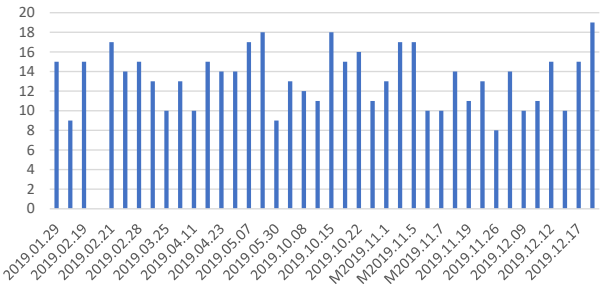

FIGURE 7 | Number of students participating in discourse and metadiscourse sessions.

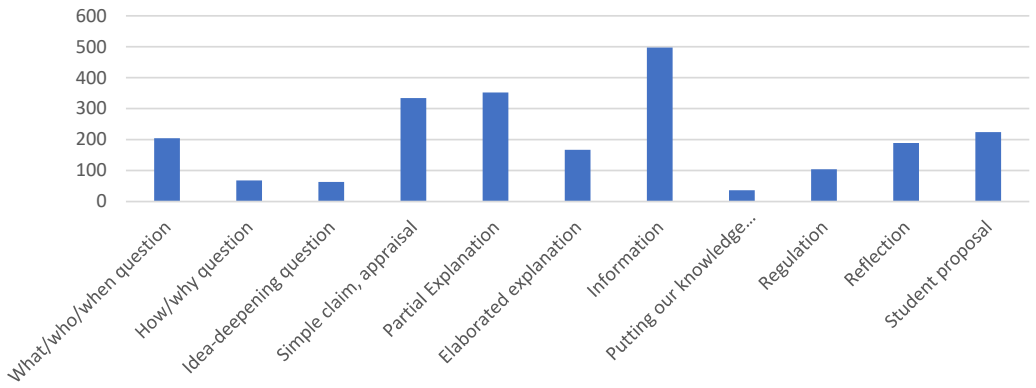

FIGURE 6 | The distribution of students' discourse moves in grade 2 that grade 3 reflected on.

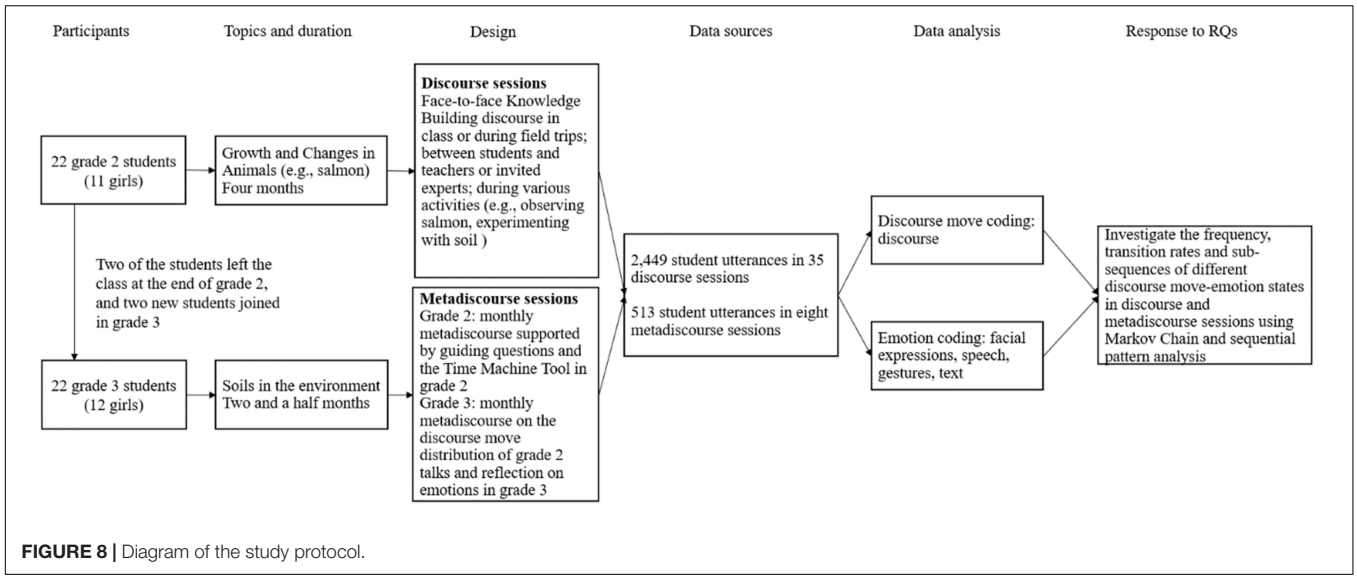

FIGURE 8 | Diagram of the study protocol.

should be noted that because KB emphasizes idea improvement and emotions are also influenced by previous utterances, we coded each utterance in context rather than as an independent speaking turn. For instance, we coded questions that extended previous discourse by seeking deeper explanations or more specific information as "idea-deepening/elaborating question(s)." Similarly, paraphrasing previous explanations were not considered "elaborated explanation(s)." We did not separate discourse and metadiscourse coding schemes but considered all the indicators as discourse moves. The discourse move scheme was adapted from our previous studies (Zhu et al., 2019b,a). **Table 1** shows the discourse moves and descriptions. There are seven discourse moves: question, simple claim/appraisal or information, partial explanation or integration, elaborated explanation or integration, proposing new directions for inquiry, reflection, and regulation. Proposing new directions for inquiry and reflection are indicators of metadiscourse but can also happen in the discourse sessions.

Similarly, the same emotion coding scheme (see **Table 2**) was applied to each utterance clip in the discourse and metadiscourse sessions. Individuals' spoken words, gestures, facial expressions, voice, or punctuation were considered when coding the emotions. The multi-faceted coding approach for analyzing emotions was adapted from our previous studies (Zhu et al., 2019b,a). As shown in **Table 2**, there are five emotional states: positive, negative, curiosity, surprise, and unidentifiable.

Regarding grade 2 data, two researchers coded 432 units, accounting for 21.90% of grade 2 records. The agreement was 77.78% for discourse move coding, and 86.34% for emotion coding. The disagreements between the two researchers were discussed and resolved. Because in the large project to which this current study belongs, two researchers coded grade one students' utterances in terms of discourse moves and emotions and reached agreements of 85.60 and 91.44%, respectively. We considered the researchers might have reached their best practice in terms of shared understanding and coding validity. Therefore, the first author coded the remaining data.

We considered the discourse move and emotion coding of each utterance as a pair. There were 32 discourse move-emotion states in total, as there was no occurrence of "reflection and surprise," "partial explanation or integration and surprise," or "proposing new directions for inquiry and surprise." To answer the first question on the frequently occurring discourse move-emotion states, we ranked the 10 most frequently occurring discourse move-emotion states in the discourse and metadiscourse sessions. Then for each discourse move-emotion state that ranked top 10 in both the discourse and metadiscourse sessions, we conducted a Chi-square test to examine whether there is significant difference in the percentage of the state between the two different kinds of sessions.

Concerning the second research question, we conducted a Markov Chain analysis using the TraMineR package (Gabadinho et al., 2011) to investigate the transitions of the 10 most frequently occurring discourse move-emotion states in discourse and metadiscourse sessions separately.

The transition-rate analysis can produce information about the changes in states that occurred most frequently among the discourse and metadiscourse sessions (Yang et al., 2018; Zhu et al., 2019b). For instance, given two states ("student proposal and positive" and "partial explanation or integration and positive") represented as (s_i, s_j), the transition-rate analysis calculates the probability of a change from "student proposal and positive" to "partial explanation or integration and positive" at a given position. We can define $n_t(s_i)$ as the number of sequences that end with "student proposal and positive" (s_i) at position t, and $n_t^{t+1}(s_i, sj)$ as the number of sequences with "student proposal and positive" (s_i) at position t and "partial explanation or integration and positive" (s_j) at position t+1. M is the maximum sequence length of different KB sessions. Then, the transition rate $p(s_j|\ s_i)$ between "student proposal and

TABLE 1 | The categories and descriptions of discourse move coding scheme.

Discourse move categories	Descriptions
Questions	Different kinds of questions that seek facts, evidence, explanations, or more specific details.
Simple claim/appraisal or information	Discourse moves that do not require lots of cognitive efforts such as providing opinions without any elaboration or justification, restating previous ideas or mentioning of personal experiences or other sources.
Partial explanation or integration	Producing an explanation, adding details to ideas or previous ideas but may contain some scientific flaws; connecting or comparing ideas contributed by students without explanations.
Elaborated explanation or integration	Elaborating the reasons, relationships/comparison, processes, or mechanisms of how things work; connecting or comparing ideas with judgments/examples/details and reasoning.
Proposing new directions for inquiry	Suggesting how to conduct their inquiry or what they should research.
Reflection	Evaluating their work or interactions, sharing their learning experiences, challenges, feelings, etc.
Regulation	Managing time, deciding speaking turns, discussing community norms, and other issues that are directly related to idea building.

TABLE 2 | The categories and descriptions of emotion coding scheme.

Emotion categories	Description
Positive	An indication of happiness, excitement, or satisfaction talking about ideas fluently, with increasing volume or expressing disagreement explicitly.
Negative	An indication of unhappiness, not understanding, tiredness, or disinterest.
Curiosity	An indication of willingness and interest to explore ideas or express requests.
Surprise	An indication of feeling surprised because of unexpected ideas or phenomena.
Unidentifiable	There are not enough clues to identify the emotion.

positive" (s_i) and "partial explanation or integration and positive" (s_j) is:

$$p(s_j|s_i) = \frac{\sum_{t=1}^{M-1} n_t^{t+1}(s_i, s_j)}{\sum_{t=1}^{M-1} n_t(s_i)}$$

Furthermore, we compared the transition difference to examine what discourse move-emotion states characterize students' metadiscourse sessions in KB communities.

Concerning the third question about the spread of discourse move-emotion states, we conducted sequential pattern mining of the states in the discourse and metadiscourse sessions. Sequential pattern mining identifies a set of sub-sequences that occur above a set frequency threshold, namely, confidence (Zhu et al., 2019b). We used the ArulesSequences Package for R, which implements the SPADE algorithm, to identify the frequent sub-sequence (Zaki, 2001). The length of a sub-sequence can be one or more. Confidence is computed as the possibility of sub-sequences appearing in the input database. We use the sequences in **Table 3** to illustrate the process of sequential pattern mining. In this study, the results of the sequential pattern mining are a series of sub-sequences consisting of different discourse move-emotion states. For instance, the sequence {SP} is a sub-sequence of SID 1, 2, 3, and 4, and its confidence, namely, the probability of occurrence, is 1 (4 out of 4). The sequence {SP}, {PEU} is only a sub-sequence of SID 3 and 4, and its confidence is 0.50. If we set 0.80 as the threshold, {SP} will be picked up as a sub-sequence of the four sequences in **Table 3**, but {SP}, {PEU} will not. This study set 0.80 as the confidence value to identify sub-sequences that occurred in most sessions. We compared the difference between the sequential states in the discourse and metadiscourse sessions. Finally, we selected representative students' utterances to illustrate the sequential patterns.

TABLE 3 | An example sequence dataset.

Sequence ID (SID)	Sequence
1	<{SP}, {SU}, {QC}, {PEU}>
2	<{SP}, {SP}, {PEP}, {PEU}>
3	<{SP}, {PEU}, {QC}>
4	<{SP}, {SP}, {PEU}, {QC}, {QC}>

RESULTS

Most Occurring Discourse Move-Emotion States in Discourse and Metadiscourse Sessions

Table 4 shows the 10 most occurring discourse move-emotion states in grades 2 and 3 discourse sessions, accounting for 85.97% of utterances. **Table 5** shows the 10 most frequently occurring discourse move-emotion states in the metadiscourse sessions of grades 2 and 3, accounting for about 78.17% of all states. In the discourse sessions, the percentage of simple claim/appraisal or information and unidentifiable (21.92%) is significantly higher than that in the metadiscourse sessions (10.53%) [χ^2 (df = 1, N = 2,922) = 4.00, $p < 0.05$], suggesting students' relatively lower cognitive efforts in the discourse sessions. Furthermore, "proposing new directions for inquiry and positive," "proposing new directions for inquiry and unidentifiable," and "proposing new directions for inquiry and curiosity" are among the most occurring states in the metadiscourse sessions, indicating

TABLE 4 | The descriptive data of the 10 most occurring discourse move-emotion states of discourse sessions.

Discourse move-emotion pair	Frequency	Percentage	Cumulative percentage
Simple claim/appraisal or information and unidentifiable	528	21.92	21.92
Simple claim/appraisal or information and positive	477	19.80	41.72
Question and curiosity	305	12.66	54.38
Partial explanation or integration and positive	222	9.22	63.60
Partial explanation or integration and unidentifiable	152	6.31	69.91
Elaborated explanation or integration and positive	135	5.60	75.51
Proposing new directions for inquiry and positive	78	3.24	78.75
Regulation and curiosity	67	2.78	81.53
Regulation and unidentifiable	59	2.45	83.98
Regulation and positive	48	1.99	85.97

TABLE 5 | The descriptive data of the 10 most occurring discourse move-emotion states in metadiscourse sessions.

Discourse move-emotion pair	Frequency	Percentage	Cumulative percentage
Simple claim/appraisal or information and positive	71	13.84	13.84
Reflection and positive	70	13.65	27.49
Simple claim/appraisal or information and unidentifiable	54	10.53	38.01
Question and curiosity	46	8.97	46.98
Partial explanation or integration and positive	34	6.63	53.61
Proposing new directions for inquiry and positive	31	6.04	59.65
Proposing new directions for inquiry and unidentifiable	27	5.26	64.91
Elaborated explanation or integration and positive	23	4.48	69.40
Partial explanation or integration and unidentifiable	23	4.48	73.88
Proposing new directions for inquiry and curiosity	22	4.29	78.17

students' high level of cognitive work and epistemic agency in the metadiscourse sessions. Overall, students had significantly higher percentage of proposing new directions for inquiry in the metadiscourse sessions than in the discourse sessions [χ^2 (df = 1, N = 2,922) = 8.1, $p < 0.005$]. When students were proposing ideas, they tended to express positive or curious emotional clues. Similarly, the students reflected on their learning more frequently (i.e., reflection and positive, 13.65%) in the metadiscourse sessions, while reflection and positive was not even among the 10 most-occurring discourse move-emotion states in the discourse sessions. In contrast, the students regulated more in the discourse sessions (i.e., regulation and curiosity, regulation and unidentifiable, regulation and positive, in total 7.22%), whereas non-regulation relevant states ranked top 10 in the metadiscourse sessions. These results suggest that in the metadiscourse sessions, students tended to discuss what their thinking was, what they learned, and what they should research in the future. In contrast, in the discourse sessions, the students were likely to manage time, decide speaking turns, and discuss community norms and other issues that were not directly related to idea building.

The Transition Rate of Discourse Move-Emotion States in Discourse and Metadiscourse Sessions

Figure 9 shows the transition rates among the 10 most occurring states in the discourse and metadiscourse sessions. Only transition rates above 0.15 are displayed to make the diagram more readable (see **Tables 6**, **7** for the complete matrices). In the discourse sessions, "simple claim/appraisal or information and positive" and "simple claim/appraisal or information and unidentifiable" have more central roles in the transition visualization, indicating most states had a higher chance of being led or followed by these two states. In contrast, in the metadiscourse sessions, several states, such as "partial explanation or integration and positive," "partial explanation or integration and unidentifiable," and "simple claim/appraisal or information and positive," have more influential roles in the transition network. This difference suggests that, compared to the discourse sessions, in the metadiscourse sessions, more states tended to lead to or follow students' more advanced cognitive contributions (i.e., partial explanation or integration).

Furthermore, in the metadiscourse sessions, if the current state is "reflection and positive," there is a 0.53 chance for the next state to be "reflection and positive," suggesting that a student's reflection tended to trigger subsequent reflection. When students reflected on their learning, they were likely to have positive feelings. Similarly, if the current state is "proposing new directions for inquiry and curiosity," there is a 0.73 possibility for the next state to be "proposing new directions for inquiry and curiosity." If the current state is "proposing new directions for inquiry and positive," there is a 0.29 possibility for the next state to be "proposing new directions for inquiry and positive." The chance for "proposing new directions for inquiry

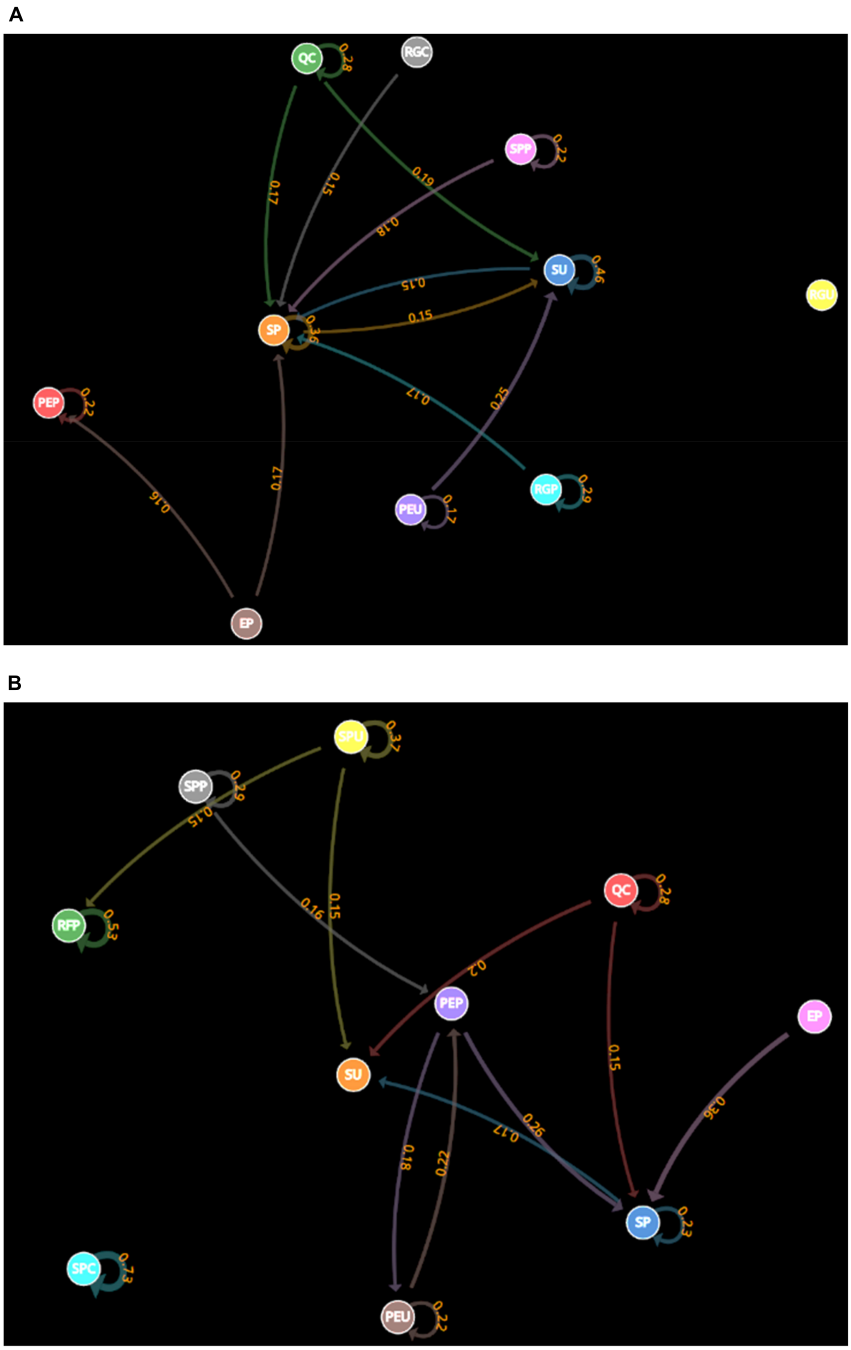

FIGURE 9 | Markov Chain analysis results of the 10 most occurring states. **(A)** Discourse sessions. **(B)** Metadiscourse sessions. SP, simple claim/appraisal or information and positive; SU, simple claim/appraisal or information and unidentifiable; RFP, reflection and positive; QU, question and curiosity; PEP, partial explanation or integration and positive; PEU, partial explanation or integration and unidentifiable; EP, elaborated explanation or integration and positive; SPP, student proposal and positive; SPU, student proposal and unidentifiable; SPC, student proposal and curiosity; RGC, regulation and curiosity; RGU, regulation and unidentifiable; RGP, regulation and positive.

and unidentifiable" to transit to itself is 0.37. These results suggest that in the metadiscourse sessions, the students tended to consecutively propose new directions for their inquiry, which indicates different students might have offered various ideas regarding their future collaborative inquiry.

The following excerpt illustrates how students (the name information was unavailable because of data collection issues) proposed ideas, discussed what they wanted to work on, and built on each other's ideas with generally positive emotions. Finally, they agreed to make ideal and

TABLE 6 | The transition matrix of the 10 most occurring states in discourse sessions.

	SU	SP	QC	PEP	PEU	EP	SPP	RGC	RGU	RGP
SU	0.46	0.15	0.08	0.05	0.07	0.03	0.01	0.02	0.02	0.01
SP	0.15	0.36	0.12	0.10	0.02	0.03	0.04	0.02	0.02	0.02
QC	0.19	0.17	0.28	0.04	0.04	0.04	0.03	0.03	0.02	0.01
PEP	0.12	0.11	0.10	0.22	0.09	0.12	0.01	0.01	0.00	0.02
PEU	0.25	0.08	0.13	0.13	0.17	0.10	0.01	0.01	0.01	0.01
EP	0.12	0.17	0.07	0.16	0.14	0.10	0.01	0.02	0.05	0.01
SPP	0.06	0.18	0.09	0.09	0.01	0.01	0.22	0.03	0.03	0.00
RGC	0.13	0.15	0.12	0.01	0.03	0.07	0.03	0.06	0.12	0.03
RGU	0.06	0.09	0.12	0.14	0.08	0.11	0.00	0.06	0.14	0.02
RGP	0.02	0.17	0.10	0.04	0.06	0.08	0.00	0.04	0.06	0.29

SU, simple claim/appraisal or information and unidentifiable; SP, simple claim/appraisal or information and positive; PEP, partial explanation or integration and positive; PEU, partial explanation or integration and unidentifiable; EP, elaborated explanation or integration and positive; QC, question and curiosity; SPP, proposing new directions for inquiry and positive; RGC, regulation and curiosity; RGU, regulation and unidentifiable; RGP, regulation and positive.

TABLE 7 | The transition matrix of the 10 most occurring states in metadiscourse sessions.

	SP	SU	RFP	QC	PEP	PEU	EP	SPP	SPU	SPC
SP	0.23	0.17	0.03	0.08	0.11	0.01	0.11	0.04	0.03	0.01
SU	0.13	0.09	0.04	0.07	0.07	0.02	0.04	0.11	0.07	0.00
RFP	0.07	0.06	0.53	0.04	0.07	0.00	0.00	0.01	0.01	0.00
QC	0.15	0.20	0.07	0.28	0.00	0.04	0.02	0.02	0.04	0.00
PEP	0.26	0.06	0.00	0.03	0.06	0.18	0.12	0.06	0.06	0.00
PEU	0.13	0.04	0.04	0.09	0.22	0.22	0.00	0.04	0.04	0.00
EP	0.36	0.05	0.09	0.05	0.14	0.00	0.09	0.09	0.00	0.00
SPP	0.10	0.13	0.03	0.03	0.16	0.10	0.00	0.29	0.06	0.00
SPU	0.00	0.15	0.15	0.04	0.00	0.11	0.00	0.04	0.37	0.07
SPC	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.05	0.05	0.73

SP, simple claim/appraisal or information and positive; SU, simple claim/appraisal or information and unidentifiable; RFP, reflection and positive; QC, question and curiosity; PEP, partial explanation or integration and positive; PEU, partial explanation or integration and unidentifiable; EP, elaborated explanation or integration and positive; SPP, proposing new directions for inquiry and positive; SPU, proposing new directions for inquiry and unidentifiable; SPC, proposing new directions for inquiry and curiosity.

current salmon habitats and create a book about animals in salmon habitats.

We should make a book about all the predators because they probably have a lot of predators. There are probably a few of them, and we could all draw one.

> I also like Daniel's idea, and I want to know how the first ocean became?
> Adding onto Tom and Will, I think half the class can make an ideal habitat. And the other half can make what exists right now.
> I was thinking, basically like Emma's, we could make it on the computer, and then we could try and make it in reality.
> My idea is the same as Sophia's, to make a book about all the different things. I also want to learn about, I want to make a book, and it's all about different types of fish that are like salmon and have the same predators. Maybe they may get lampreys.
> What more can we do to protect the salmon? Like where the birds don't know.
> Another idea? I had an idea that we take the map, and I thought it would be interesting if we could see which parts are the best for Atlantic salmon.
> So, looking at the waterway using Google earth?

In **Figure 9**, there are no transition links from other states to the "elaborated explanation or integration and positive" state because the possibilities are smaller than 0.15. However, as shown in **Table 6** , in the discourse sessions, "elaborated explanation or integration and positive" had a higher chance to follow states such as "partial explanation or integration and positive" (0.12), "partial explanation or integration and unidentifiable" (0.10), "elaborated explanation or integration and positive" (0.10), and "regulation and unidentifiable" (0.11). These results suggest that "elaborated explanation or integration" is usually built upon itself or "partial explanation or integration," which conveys a notion of progressive KB discourse. As shown in **Table 7**, in the metadiscourse sessions, "simple claim/appraisal or information and positive" and "partial explanation or integration and positive" were more likely to lead to "elaborated explanation or integration and positive," with transition rates of 0.11 and 0.12, respectively. Furthermore, there is a 0.09 possibility for an "elaborated explanation or integration and positive" to lead to another "elaborated explanation or integration and positive." These results not only indicate progressive KB discourse, but also suggest that positive emotions tend to lead to positive emotions within KB communities.

The Spread of Discourse Moves and Associated Emotions in Discourse and Metadiscourse Sessions

The sequential pattern analysis shows that when the threshold was set as 0.8, 333 state sequences were identified in the discourse sessions, while 274 state sequences were discovered in the metadiscourse sessions. To investigate their difference, we filtered the state sequences that only occurred in the discourse sessions and metadiscourse sessions, respectively. As a result, 223 state sequences were specific to discourse sessions, while 166 state sequences were unique to metadiscourse sessions. Given the frequent occurrence of "simple claim/appraisal or information and positive," "simple claim/appraisal or information and unidentifiable," and "question and curiosity" and their combinations in discourse and metadiscourse sessions, we further examined the state sequences that include at least another type of state. In the metadiscourse sessions, we found 84 state sequences that include other states such as "proposing new directions for inquiry and unidentifiable," "partial explanation or integration and unidentifiable," "partial explanation or integration and positive," and "reflection and unidentifiable." **Table 8** shows some examples of these specific sequences. However, in the discourse sessions, none of the sequences include other states.

Overall, the specific sequences of metadiscourse sessions suggest progressive KB discourse and the spread of similar emotions, with "simple claim/appraisal or information and positive," "simple claim/appraisal or information and unidentifiable," and "question and curiosity" leading to more advanced cognitive contributions (i.e., "partial explanation or integration and unidentifiable," "partial explanation or integration and positive") or metacognitive contributions (i.e., "proposing new directions for inquiry and unidentifiable," "reflection and unidentifiable"). For instance, the longest specific sequence in metadiscourse sessions is <{SP}, {SP}, {PEP}, {PEU}, {QC}> ⇒ <{QC}>, indicating students' idea improvement from simple claims to partial explanations to continuous questions and the spread of positive emotions and curiosity within the thread.

TABLE 8 | Examples of specific discourse move-emotion sequences in metadiscourse sessions.

Sequence ID	Specific sequences	Confidence
1	<{SP},{SU},{SU}> ⇒ <{SPU}>	0.88
2	<{SP}> ⇒ <{RFU}>	0.88
3	<{SP},{SU}> ⇒ <{PEU}>	0.88
4	<{SP},{SU},{QC}> ⇒ <{PEU}>	0.88
5	<{SP},{SP},{PEP}> ⇒ <{PEU}>	0.88
6	<{SP},{PEU}> ⇒ <{QC}>	0.88
7	<{SP},{SP},{PEU},{QC}> ⇒ <{QC}>	0.88
8	<{SP},{PEP},{PEU},{QC}> ⇒ <{QC}>	0.88
9	<{SP},{SP},{PEP},{PEU},{QC}> ⇒ <{QC}>	0.88

SP, simple claim/appraisal or information and positive; SU, simple claim/appraisal or information and unidentifiable; SPU, proposing new directions for inquiry and unidentifiable; PEP, partial explanation or integration and positive; PEU, partial explanation or integration and unidentifiable; QC, question and curiosity; RFU, reflection and unidentifiable.

The following quotes illustrate an example of sub-sequence <{SP}, {SU}, {SU}> ⇒ <{SPU}>. When the grade 2 students talked about when might be the best time for the class to go to the river to see the salmon that were hatched in their classroom but later released, Amy, Emma, and Lucas provided information based on their observations or experiences or made simple claims. Then, Mia proposed that the class should visit at the end of the school year because it is closer to summer. Their emotions were mainly positive and unidentifiable.

> Amy: The summer. Because usually when I was there for a walk, I saw a huge salmon.
> Emma: Fall.
> Lucas: Because they migrate upstream.
> Emma: To lay their eggs.
> Mia: Maybe at the end of the school year because it is closer to the summer.

The sequence <{SP}> ⇒ <{RFU}> also occurred frequently in the metadiscourse sessions. For instance, when the grade 3 students discussed what makes them upset, they reflected:

> Lucas: wait! There is one thing I notice.
> Amy: People don't like being tapped. If you're talking to each other, that just interrupts you. You feel like you are ignored, and nobody wants to listen to you.

The sub-sequences <{SP}, {SU}> ⇒ <{PEU}>, <{SP}, {SU}, {QC}> ⇒ <{PEU}>, and <{SP}, {SP}, {PEP}> ⇒ <{PEU}> show how various turns of "simple claim/appraisal or information and positive" may lead to "partial explanation or integration and unidentifiable." When the grade 2 students talked about what would happen if they touched a salmon egg, and how salmon take their eggs, Noah talked about his wondering and simple claim and Rose responded with a partial explanation, as shown in the following quotes:

> Noah: I wondered if the eggs were squishy.
> Noah: It would be like flat.
> Rose: Imagine, imagine, imagine a ball like bubble gum. And imagine a salmon egg taking the form of bubble gum.
> Rose: Um, how a salmon will take an egg, take an egg, um…

The sub-sequences <{SP},{PEU}> ⇒ <{QC}>, <{SP},{SP}, {PEU},{QC}> ⇒ <{QC}>, <{SP},{PEP},{PEU},{QC}> ⇒ <{QC}>, and <{SP},{SP},{PEP},{PEU},{QC}> ⇒ <{QC}> are about how "simple claim/ appraisal or information and positive" led to one or more "partial explanation or integration" and was then followed by continuous questions. For instance, when the grade 3 students tried to classify and integrate their questions regarding soil after observing their collected soil samples, Emma, Jackson, and Tom provided different integration ideas, which were followed by Misha's further questions.

> Emma: Because it's kind of, it's kind of in both categories.
> Jackson: But both categories don't fit together.
> Tom: And "how did the first seed come to life," you forgot to attach them.

Emma: I think "what is soil" and "how do soil make trees grow" should go to [. . .]
Emma: It's kind of on that topic. Wait, wait.
Misha: I have a question. Why did you say soil is earth, if we don't have soil [. . .]? I don't get it.

DISCUSSION

This study examined how students' discourse move-emotion states develop over time in discourse and metadiscourse sessions. Researchers considered the discourse move and emotion coding of each utterance as a pair and compared the 10 most frequently occurring states in discourse and metadiscourse sessions. In addition, transitions from the most occurring states to subsequent states in the discourse and metadiscourse sessions were computed. The results indicate that students' reflections and proposing new directions for inquiry occurred more in the metadiscourse sessions; students usually felt positive when reflecting on their learning or proposing future inquiry directions. Furthermore, a student's reflection tended to trigger subsequent reflections. Proposing new directions for inquiry led to more proposals of future inquiry directions. This study represents one of the first to consider both students' cognition and emotion in KB discourse and metadiscourse sessions in which students reflected on their collaborative inquiry and future inquiry directions. Several findings are worth discussing.

This study suggests that when students were given the chance to take a wide and reflective view of their learning and engage in metadiscourse, they could reflect on what they had learned, how their thinking had changed, and how they hoped to deepen their inquiry. When students proposed ideas about future inquiry, they tended to show positive expressions, be curious about whether they could do certain things or work in the ways they proposed. In some cases, their emotions were not identifiable, but overall, enjoyment was significantly related to students' cognitive use of learning strategies at the intraindividual level (Obergriesser and Stoeger, 2020). Students' positive and curious emotions during the metadiscourse sessions may be related to their control over learning and the value they perceived in it (Pekrun et al., 2017). This interpretation aligns with Chevrier et al.'s (2019) study, which suggests that students tend to be more curious, and less surprised or bored if they have more constructivist beliefs and a mature understanding of the nature of science.

Students' discourse moves, such as proposing ideas and reflecting on learning, tended to be contagious amongst the community members. Proposing new directions for inquiry or reflections may be triggered by teachers' questions or a student proposal, with other students then building on with their various ideas. Thornton and Tamir (2020) found there is a higher chance for a mental state to transit to a similar state. These results suggest the importance of supporting students' metadiscourse because, unlike other states that might occur more naturally in discourse, metadiscourse might need to be facilitated as people's metacognitive skills develop slowly (Pressley and Ghatala, 1990) and they need support to regulate their collaborative knowledge construction or KB (Järvelä et al., 2016).

Similarly, the high transition rates between similar emotions suggest that positive emotions tended to be contagious in learning communities in which students felt safe and comfortable expressing their ideas. This may be explained by the emotional contagion theory (Hatfield et al., 1993), which posits that emotions may be amplified when they are expressed and used to coordinate group performance. As previously discussed, students' enjoyment is related to how competently and effectively they employ learning strategies (Pekrun, 2006; Obergriesser and Stoeger, 2020). Positive feelings can motivate students to continue and deeply engage in ongoing activities and deeply process information (Fredrickson, 2001). Positive emotions function as internal signals to continue or approach and have long-lasting consequences on individual growth and social connection (Fredrickson, 2001). Further research can build on this study and further examine the effects of positive emotions in a learning community.

The findings of this study show the differences in students' discourse move-emotional states, transition rates, and sequential patterns between discourse and metadiscourse sessions, and highlight the importance of intentionally and purposefully engaging students in metadiscourse sessions. Students' metacognitive contributions (e.g., proposing new directions for inquiry, reflection), which play important roles between learning and emotion, usually do not naturally occur and need to be intentionally scaffolded in metadiscourse sessions. Metacognition may help students manipulate cognitive resources that can be taken up by high arousal emotions. Some studies (D'Mello et al., 2014; Buono et al., 2020; Obergriesser and Stoeger, 2020) have shown that students' metacognition (i.e., self-regulated learning) mediates the relationships between learning and emotions. Negative emotions, in particular (e.g., confusion, boredom, frustration), can be regulated to play different roles in learning. However, in the literature, students usually learn at the individual level rather than the collaborative level, and therefore, they mainly need to plan, monitor, control, and reflect on individual learning (Pintrich, 2000). Future research should extend this direction by studying how to support students to collaboratively regulate the negative emotions in their KB communities.

LIMITATIONS AND FUTURE DIRECTIONS

This study has several limitations. First, we considered the data collected in grades 2 and 3 together and equally because our purpose is to investigate the discourse move-emotion state patterns in discourse and metadiscourse sessions rather than comparing grades 2 and 3. However, students' cognitive development should not be ignored. Second, in this study, we only analyzed students' discourse. However, in classrooms, teachers' discourse mediates students' discourse and influences the sequential patterns. Further research may include teachers' discourse in analyses. Third, although the nuanced discourse move-emotion states enable us to examine the subtle difference between states, similar states also distribute and hide some transition patterns. For instance, if only considering discourse

moves but ignoring emotions, in the discourse sessions there is a transition chain from question to simple claim/appraisal or information (transition possibility 0.36), to partial explanation or integration (0.24) and elaborated explanation or integration (0.22). However, when including emotions in the analysis, different types of emotions distribute the transition rates and make the progressive KB discourse less visible. Finally, we did not investigate less-occurring emotions such as surprise and negative. Based on several recent studies on self-regulated learning and emotions (e.g., D'Mello et al., 2014; Buono et al., 2020; Obergriesser and Stoeger, 2020), negative emotions need more attention and regulation. Further research may qualitatively examine these emotions to examine their roles in KB discourse.

CONCLUSION

Knowledge Building process can trigger students' various emotions as they experience cognitive equilibrium, disequilibrium, and conflict when negotiating ideas and advancing community knowledge (Yang et al., 2022). The importance of emotion in its own right and in relation to learning has been increasingly recognized over the past two decades (Polo et al., 2016). However, emotion has been rarely investigated in the KB context, and in relation to students' cognition, especially discourse moves. The CVT indicates the benefits of supporting students' subjective control and value on their positive emotions, which suggests students might experience more positive emotions in KB metadiscourse sessions that provide students opportunities to discuss what ideas they think are valuable and to take greater control over learning than in earlier KB discourse sessions. Drawing these gaps and literature support, this study integrated KB, metadiscourse, emotions, and students' subjective control and value appraisals. We found that when providing the participants (as young as grade 2) with chances to engage in metadiscourse, they could take the opportunities to engage in high-level cognitive work. Positive emotions and knowledge work spread, lifting not only individuals but also the community. Therefore, teachers should facilitate students to engage in metacognitive activities to support their positive emotions and productive KB.

AUTHOR'S NOTE

GZ is an assistant professor at the National Institute of Education, Nanyang Technological University. She has Learning Sciences, Educational Technology, and Curriculum and Pedagogy backgrounds. Her research interests include student agency, socio-emotional interactions, learning analytics, Knowledge Building, and Computer-Supported Collaborative Learning (CSCL).

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DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because these data will be made available to other researchers on a case-by-case basis. Requests to access the datasets should be directed to GZ, gaoxia.zhu@nie.edu.sg.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the University of Toronto (U of T) Research Ethics Boards (REBs). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

GZ designed and implemented the study, collected and analyzed the data, and drafted the manuscript. MS supervised and co-designed the study, and provided guidelines through the process. MMo helped write part of the study and provided the constructive feedback. MMa and RN co-designed and implemented the study in their classrooms. ZL assisted the data analysis. All authors contributed to the article and approved the submitted version.

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