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Exploring emotional and cognitive dynamics of Knowledge Building in grades 1 and 2

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Abstract

Emotions have a powerful effect on learning but results regarding the nature of the impact are inconsistent and little is known about effects with young students, as participants are usually university students. This study aims to explore the emotional and cognitive dynamics of young students in both online and offline Knowledge Building. Classroom transcripts and online discourse collected for 45 grade 1 and 2 students over seven to 8 weeks were analyzed. Based on the total number of spoken and written words, the participants were classified into high- and low-participation groups. Multimodal learning analytics including speech emotion analysis, sentiment analysis, and idea improvement analysis were used in a mixed method research design incorporating co-occurrence patterns of emotions and idea improvement of students at different participation levels. High-participation students expressed significantly higher frequencies of emotions recorded as neutrality, joy, curiosity, and confidence compared to low-participation students. High-participation students were more likely to elaborate reasons, describe relationships and mechanisms surrounding ideas they explored, and to introduce new ideas and concepts into community resources. Surprise, challenge, and neutrality can be beneficial since students tended to express these emotions when producing explanation-seeking questions, new ideas, explanations, and regulation. Personalized support to students with different participation levels is proposed, to create a more discursively connected community. Future directions include collecting more diverse data to better understand students' emotions and to provide teachers and students with real-time data to support Knowledge Building as it proceeds.

Keywords Idea improvement · Multimodal learning analytics · Speech emotion analysis · Knowledge Building · Discourse analysis · Learning community · Online and offline discourse

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1 Introduction

In the last two decades, significant shifts in learning theory and practice have extended of the study of cognition to incorporate emotional factors and learning as a collective rather than exclusively individual enterprise (Polo et al. 2016; Sinha et al. 2015). Social practices, cognitive change, and emotional behaviors are three critical components related to knowledge construction and knowledge creation (Baker et al. 2013). Knowledge Building, an approach that aims to foster sustained creative work with ideas, requires students to take collective responsibility to improve ideas. Knowledge Building as a pedagogical practice engages students within knowledge building communities in which idea improvement is the norm for engagement (Scardamalia 2002; Scardamalia and Bereiter 2006). Effective collaboration is a social dialogic process that requires knowledge and skills (Kirschner and Erkens 2013). Social-emotional and cognitive dynamics must operate in concert to support student engagement and knowledge creation in knowledge building communities. The social-emotional dynamics refer to students' subjective feelings, expressive actions and physiological reactions (Cahour 2013). Interacting with others and ideas (e.g., reading, referencing, providing constructive feedback, and building on ideas) is thought to reflect the cognitive dimension with a focus on personal and collective knowledge advancement. Knowledge building communities seek to establish conditions for student well-being in contexts where community members are engaged in knowledge creating dynamics such as identifying weaknesses in ideas, exploring idea diversity with attention to promising ideas, and achieving more coherent theories (Scardamalia and Bereiter 2014; Thagard 2007).

How emotions and learning interact is under active investigation, with findings indicating that positive emotions such as enjoyment and pride promote learning (e.g., Csikszentmihalyi 1990; Pekrun 2000; Pekrun et al. 2017). These emotions seemingly increase learners' motivation, facilitate deep learning, and allow cognitive resources to be focused on learning tasks (Pekrun et al. 2017). Mega et al. (2014) suggest that positive emotions only benefit learning when it is mediated by self-regulation and motivation. Increasingly researchers are exploring the influence of negative emotions on learning and uncovering complex relationships. On the one hand, negative activating emotions (e.g., anger and anxiety) might trigger worries and feelings of failure (Pekrun et al. 2017). On the other hand, under a specific circumstance, negative emotions might trigger extrinsic motivations to invest effort, and confusion may be an indicator of learning and knowledge construction (e.g., D'Mello et al. 2014; Worsley and Blikstein, 2015).

The majority of studies conducted into the relationship between emotions and learning have focused on university students (Putwain et al. 2018). How younger students' emotions affect their cognitive performance has been given little attention even though there is a call to foster K–12 students' socio-cognitive engagement in advancing knowledge across all areas of the school curriculum (Bielaczyc et al. 2013; Brown and Campione 1996; Scardamalia and Bereiter 2006).

Knowledge Building represents a model of community engagement in knowledge work to enable an inclusive knowledge society. Knowledge creation is supported from the earliest ages, with students as members of knowledge building communities taking collective responsibility for advancing community knowledge. The current investigation explores socio-cognitive dynamics within knowledge building communities featuring both face-to-face and online discourse, as elaborated below. Focus on socio-cognitive dynamics in community contexts represents a new challenge in the study of emotions in school contexts. To provide detailed accounts of student engagement, classroom discussions in grades 1 and 2 were video recorded and online discourses were captured to provide detailed accounts of student contributions, build-on, references and other discourse forms in online community spaces. A mixed method research design was used incorporating multimodal learning analytics including speech emotion analysis, sentimental textual analysis and idea improvement analysis. These were applied to the full dataset to investigate: (1) how emotions co-occur with idea improvement, and (2) how students at different participation levels develop ideas. Suggestions are provided for personalized support to help students engage in more productive knowledge work.

2 Literature review

2.1 Community models for learning and knowledge creation

Bielaczyc et al. (2013) argue that different community models of education–for example Knowledge Building (Scardamalia 2002; Scardamalia and Bereiter 2006), Fostering Communities of Learners (Brown and Campione 1996), and Mathematics Classrooms as described by Lampert (2001)—share characteristics. According to their analysis shared features include (1) classroom investigations and discussions are driven by students' ideas, questions, and strategies; (2) students play epistemic games by generating questions, gathering information, doing experiments, exchanging ideas, and refining community ideas; (3) teachers scaffold students' participation and facilitate students' discourse and shared understanding; and (4) social structures—such as classroom norms and ways of participating in community activities and accessing technical tools— are considered as parts of a systematic whole, rather than discrete entities. It is not easy to implement community models, in part because the shift may differentially result in discomfort for teachers and students given many issues surrounding respect, authority, the refining of ideas, the expression of disagreement, and the presentation of alternative opinions raised by community interactions (Bielaczyc et al. 2013). This issue calls for attention to the feelings of students in learning communities.

Knowledge Building is a socio-constructivist approach with theory, pedagogy, and technology aligned to support students in taking collective responsibility for advancing the knowledge of their community (Scardamalia and Bereiter 1994, 2014). Knowledge Building aims to foster knowledge creation, with individual learning resulting from student ideas at the center of Knowledge Building discourse (Philip 2009). To create knowledge ideas must live in the world, not merely in the minds of individuals; ideas must be tested, questioned, criticized, and improved

(Popper 1972). Collective responsibility for community knowledge is highlighted since students are likely to achieve more when they combine their efforts instead of working individually or cooperating via division of labor (Broadbent and Gallotti 2015). Embedded and transformative assessment supports work as it proceeds. Design principles rather than specific procedures guide the implementation of classroom Knowledge Building practices. Teachers see themselves as “doing my part in a profession that is making progress on formidable and important problems” (Bereiter 2002, p 398).

In Knowledge Building Circles (also referred to as “Knowledge Building talk,” see Reeve et al. 2008) teachers and students sit in a circle to help convey that everyone is equally central in discourses used to explore interest in a topic, to discuss issues important to advancing community ideas, to listen respectfully to others, and to interact actively to advance community knowledge. Knowledge Building Circles can be held as often as the community thinks is appropriate and can take diverse forms. In the classes in this study, it typically took place once or twice a week. When a class is engaged in Knowledge Building, they may begin with a Knowledge Building Circle to discuss community norms, questions, ideas, and theories that members think are important to share, discuss, and research. The community may also make decisions regarding what ideas to focus on and what experiments, field trips and other investigative activities to pursue. Then they may work in Knowledge Forum—the technology built specifically to support knowledge creating interactions (Scardamalia 2004). Students are encouraged to record the important content that they have discussed in Knowledge Building Circles so that they can build on ideas, read notes of peers, provide references for new information regarding authoritative resources to deepen their understanding of issues. As elaborated below, they work as a community to advance their understanding. Knowledge Building Circles can take place among all class members or smaller groups while the remaining students are engaged in Knowledge Forum or other activities. What is important is that all community members share ideas and build on them.

Students can join different communities in Knowledge Forum to achieve various purposes. In a given community, students can post their ideas as notes onto a public space called “view.” They can revise their notes, co-author notes, and read, reference, build on, and annotate notes to build their knowledge. The interface of Knowledge Forum shows lines to display connectedness created by building on and referential relationships. When writing notes, students can use “epistemic markers” provided by the system such as “my theory,” “I need to understand,” “a better theory,” and “constructive uses of authoritative sources.” These markers can be co-constructed by the teacher and students to facilitate student thinking and writing. All participants are free to arrange notes on views and to create new views. An important feature of Knowledge Forum is the “rise-above” note. It allows users to achieve “increasing high-level accounts and to create the coherence that drives them toward deeper understanding” (Zhang et al. 2009, p 11) from diverse existing ideas; it supports this by encouraging students to bring their notes together into a higher-order structure that provides an integrative account of the notes it contains. It supports “new syntheses” out of “diversity, complexity and messiness” (Scardamalia 2002, p 76).

2.2 Emotions and learning

Emotions are constructed by individuals or groups in social contexts (Lutz and Abu-Lughod 1990); they exist in person–environment interactions, not just within an individual or environment (Schutz et al. 2006). Emotions consist of (1) subjective feelings, which correspond to individuals' consciousness of what they feel, (2) bodily reactions in response to physical states—for example, an acceleration of the heartbeat or a heating of the skin—and (3) expressive behavior, including facial expressions, changes in body posture, and discourse reflecting emotions and sentiment (Cahour 2013).

Although various types of emotions have been identified, studies often examine achievement emotions. Achievement emotion is caused by an activity or outcome that is evaluated by the subject according to some external or internal standard of quality (Pekrun 2000). Pekrun (2000), in his exploratory study, found that joy, hope, relief, pride, anger, anxiety, boredom, and dissatisfaction were the most frequently reported achievement emotions by university students. Grawemeyer et al. (2017) used a sub-set of achievement-emotions—including enjoyment, surprise, frustration, and confusion to determine what kind of feedback should be provided to learners using their tutoring platform. Worsley and Blikstein (2015) examined the frequency of transitions among confusion, surprise, neutrality and joy that students expressed when participating in a collaborative, hands-on task in engineering design.

It is not surprising that emotions and learning interact and that results of studies into their relationship are inconsistent, given disparities in contexts and populations. Some research indicates that positive emotions promote learning, while negative emotions undermine learning. For instance, Pekrun and his colleagues (2017) suggest that positive emotions (e.g., enjoyment and pride) can positively influence students' academic achievement by increasing their motivation, facilitating deep learning, and helping them to focus their attention and cognitive resources on learning tasks. Csikszentmihalyi (1990) argues that when students are in a state of heightened engagement (referred to as "flow"), they tend to learn optimally. Mega et al. (2014) showed that only when emotions are mediated by self-regulated learning and motivation can positive emotions foster academic learning. In contrast, negative activating emotions (e.g., anger and anxiety) might spark irrelevant thoughts—such as worries and feelings of failure or trigger extrinsic motivations to invest effort (Pekrun et al. 2017). Baker et al. (2010) suggest that negative emotions (such as boredom) are related to poor learning.

Studies also indicate that negative emotions can contribute to learning; for example, D'Mello et al. (2014) suggest that confusion might promote learning. Worsley and Blikstein (2015) highlighted the importance of confusion as an indicator of knowledge construction and a surprise mediator of cognitive disequilibrium. Specifically, their results indicated that being in or transitioning to an expression of confusion was related to good learning outcomes; being in or transitioning to an expression of surprise was associated with less desirable learning performance. In exploring the relationship between students' participation in cognitive tutoring activities and their performance on standardized tests, Pardos et al. (2013) found that learning gains were negatively associated with emotions like boredom and confusion. In scaffolded tutoring, however, boredom positively correlates with performance. Engaged concentration and frustration positively correlated with improved learning outcomes (Pardos et al. 2013). Grafsgaard et al. (2013) studied the relationship between units of facial action, affective outcomes, and learning gains. They found that raising one's outer brow negatively correlated with learning gains, that lowering one's brow positively correlated with frustration, and that dimpling one's mouth positively correlated with frustration and learning gains.

Inconsistent results may be explained in several ways. First, the researchers used different methods to analyze their participants' emotions. For example, Pekrun et al. (2017) and D'Mello et al. (2014) used students' self-reports to determine their subjective feelings. Grafsgaard et al. (2013) determined participants' feelings from their expressive behaviors, including their facial expressions, changes in posture, and gestures. Emotions are transient and fast, changing and varying frequently (Csikszentmihalyi and Hunter 2003). For this reason, different methods might capture emotions differently. Second, some factors were considered by some researchers but not by others. For example, Mega et al. (2014) investigated the mediating roles of self-regulated learning and motivation, while Pardos et al. (2013) studied how the presence of scaffolds in tutoring influenced the role of boredom and confusion on learning. These results suggest that the influence of emotions on learning—and especially the influence of negative emotions, such as boredom, frustration, and surprise—can be regulated.

2.3 Multimodal learning analytics

Complex and open-ended learning environments provide opportunities for learning but also make it difficult to collect and analyze learning data. When students engage in such learning environments, they have many opportunities to interact with their peers and teachers, to generate unique and personalized or collective artifacts (such as robots and computer programs), and to solve real-world problems. While beneficial in many ways, community environments make it more difficult to collect data on students' learning and to track their trajectories (Blikstein and Worsley 2016). For instance, to extend their learning beyond the classrooms, students may use computer-mediated learning systems, or go on fields trips. Given the difficulty of collecting and analyzing data on unstructured learning occurring in diverse places and different times, most educational work in data mining and learning analytics has utilized data generated by computer-supported learning systems (Blikstein and Worsley 2016). As a result, what happens in face-to-face environments, how face-to-face and online learning are integrated, and how students work across different media have yet to be investigated. Understanding both classroom and online discourse (Lossman and So 2010) and movements across face-to-face and online learning spaces is critical.

Multimodal learning analytics–employing multiple sources of data (e.g., video, logs, text, artifacts, audio, gestures, biosensors)–could offer new insights into learning and bring together multiple techniques—including text analysis, speech analysis, affective-state analysis, and action and gesture analysis. Multimodal analytics aims to generate a comprehensive understanding of complex learning issues in "realistic, ecologically valid, social, mixed-media learning environments" (Blikstein and Worsley 2016). Records are easy to collect from both face-to-face activities and online systems, and the resulting text provides a rich source of information on different types of explanations, various topics being discussed, and affective feelings. Speech contains linguistic, textual, and prosodic features that can be used to predict students' reading proficiency, fluency, and emotions. Text and speech are the two primary sources of data collected and analyzed in this study.

Different techniques—including sentiment analysis, speech emotion recognition, facial expression recognition, surveys, interviews, and biosensors—can be used to measure emotions. Emotions and opinions are usually extracted from discourses and texts via sentiment analysis (Loia and Senatore 2014). For instance, Arguedas et al. (2016) used a sentiment-analysis tool to assess the emotions of twelve high school students from their discourse in Wikis, chats, and forum debates. Information conveyed via text, via how words are spoken, and via the incorporation of different emotions may influence the meaning of the content (Koolagudi and Rao 2012). Non-linguistic cues may contain expressions of emotions (Koolagudi and Rao 2012). Features of speech—such as the excitation source, the vocal tract, and prosodic features—can be used to analyze different sets of emotions (Koolagudi and Rao 2012).

In recent years, multimodal data—such as vocal expressions, facial expressions, body expressions, and physiological signals—have increasingly been used to build technology that recognizes an individual's emotional state (Ranganathan et al. 2016). These modalities have different statistical properties. Combining features may provide useful ways to represent data and to improve the accuracy with which various emotions are identified. Another advantage of multimodal data is that some feelings may only be recognizable in one modality, thus uncovering additional emotional expressions (Keltner and Cordaro 2017). For instance, sympathy is signaled via touch and voice, but less so via facial expressions or text (Goetz et al. 2010). Adopting a multimodal analytical framework, Sakr et al. (2016) investigated how students' emotional engagements unfolded as they used iPad technologies to interact with stimuli in situ history learning. Emotions like empathy, care, protection, respect, pity, and excitement were identified via a grounded analysis in the videos they recorded. Grafsgaard et al. (2014) used multimodal data, including nonverbal behavior and task actions, to predict the learning and affect of university students. Their results revealed that engagement and frustration can be predicted by facial expressions and gestures; learning can be predicted by facial expressions and posture. However, these studies did not investigate how learning and affect correlate. In the current study, we used mainly non-linguistic, prosodic features to measure the emotions that students expressed in classroom videos, and we used sentiment analysis to analyze students' online textual discourse.

Regarding idea improvement analysis, researchers (e.g., Resendes et al. 2015; Yang et al. 2016; Zhang et al. 2009) use thematic analysis to identify inquiry threads of ideas contributed by students. An "inquiry thread" is a conceptual thread in notes addressing a common issue (Zhang et al. 2007). Different coding schemes may be used to code inquiry threads to assess students' idea improvement. For example, Zhang et al. (2009) used measures of "epistemic complexity" and "scientific sophistication" to code students' scientific understanding. The epistemic complexity of a student's ideas is a measure of their efforts to produce theoretical explanations and elaborations on community ideas. The "scientific sophistication" dimension assesses the extent to which a student has moved from an intuitive to a scientific understanding. Hmelo-Silver and Barrows (2008) categorized statements into two major dimensions: "collaboration" and "complexity." The former consisted of new ideas, modifications, agreement, disagreement, and "meta," while the latter included the levels of "simple," "causally elaborated," and "elaborated." Yang et al. (2016) used the categories "question," "idea," and "community" to analyze notes contributed by Grade 1 students. Among them, "questions" included fact-seeking, explanation-seeking, and metacognitive questions. "Ideas" contained simple claims, elaborations, explanations, and metacognitive statements. "Community" were about negotiations of fit and synthesizing notes. In this study, we integrated these coding schemes and coded the classroom-video transcripts and online textual notes of two learning communities.

2.4 Summary and research questions

The importance of emotion in learning represents an active area of research with new multimodal learning analytics that offers possibilities for studying complex learning in increasingly natural and diverse learning situations. The current investigation takes advantage of these means to explore the emotions of younger participants (grades 1 and 2) as they engage in knowledge building. Toward this end, we collected classroom videos and online discourse to explore

1. The extent to which different types of emotions co-occur with idea improvement, with a focus on students at different participation levels.
2. The means used by students at different participation levels to work with ideas, with implications for personalized support for their work.

3 Methods

A mixed method research design featuring both qualitative and quantitative methods was adopted to collect and analyze data (Creswell and Clark 2017). Qualitative analysis was conducted to code students' emotions and idea improvement in classroom discussion and online notes. Qualitative analysis of individual discourse was also used to explore types of personalized support that might be provided to students at different participation levels. Quantitative methods were used to analyze differences between high- and low-participation in terms of emotions and idea improvement performance (independent sample T-tests were used). To explore emotion-idea improvement co-occurrence in high- and low-participation groups principal component analysis was used. Participants, course design, and data collection and analysis are described in detail below.

3.1 Participants

This study was conducted at a primary school in Toronto, Canada. The school is committed to ethnic and economic diversity and gender balance. Collaboration, sharing, and a culture of inquiry are pervasive in the school as reflected in classroom work and school meetings including the principal, vice principal, teachers, and researchers. The grade 1 and 2 teachers engaged in this study had experience with Knowledge Building pedagogy and technology; the participants were 23 grade 1 and 22 grade 2 students (the combined group included 6–8 years old children). There were 23 girls and 22 boys in the two classes. School and the university's review boards gave ethical approval to this project.

3.2 Course design

The study lasted 7 weeks for the grade 1 class. The teacher and students aimed to understand a scientific topic—the life stages of butterflies. The main ideas that the students explored throughout the study were caterpillars turning into chrysalises, body part caterpillars spin webs from, chrysalises turning into butterflies, how butterflies get their color, why newborn butterflies are wet, and where butterflies live. The study lasted 8 weeks for the grade 2 class. In the grade 2 class, the teacher and the students worked on a mathematics topic: shapes. This study represented an attempt to use Knowledge Building in the study of mathematics (they had already been using it in a wide range of other subjects including science and social sciences). While the students mainly explored the definition of a shape, shape design, 2D and 3D shapes, they also discussed "why do we share knowledge?" at the beginning of the study.

In this study, Knowledge Building Circles and Knowledge Forum time occurred once or twice a week for both classes. Each session lasted for about 1 h. Classes usually began with the teacher and the students discussing a topic or theme on butterflies or shapes for about 10 min in a Knowledge Building Circle (see Fig. 1). Then the group would continue their conversation in Knowledge Forum (as shown in Fig. 2) by entering their ideas discussed in the Knowledge Building Circle for further refinement. The Knowledge Building Circle and Knowledge Forum discourses were integral parts of a class. Ideas from previous sessions would often be re-introduced for further discussion during subsequent Knowledge Building Circles.

The teachers in both classes also provided students with physical tools (see Fig. 3) to support their learning. In the grade 1 class, the teacher and the students raised butterfly larvae so that they could closely observe the growth of butterflies. In the grade 2 class, two-dimensional and three-dimensional shapes were provided to help the students sort shapes and understand dimensions.

Fig. 1 An example of Knowledge Building Circle discussion (a photo published online by the school was used to protect the identity of the participants)

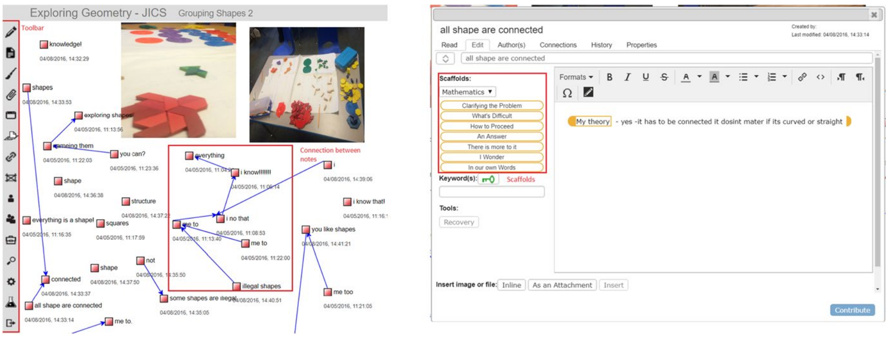

Fig. 2 The interface and functions of Knowledge Forum

3.3 Data collection and analysis

Figure 4 shows a diagram of the study protocol of the current research. In both classes, two strands of data were collected: video recordings of the Knowledge Building Circles and textual discourses recorded via Knowledge Forum. From the grade 1 class, 85 min of discussion in Knowledge Building Circles were collected. From the grade 2 class, 150 min of videos were collected. The videos were then transcribed. As is shown in Fig. 1, students' online discourses were recorded via Knowledge Forum in the form of notes and relationships of notes (e.g., reading, building on, referring to). From the grade 1 class, 104 Knowledge Forum notes were collected. From the grade 1 class, 215 Knowledge Forum notes were collected. In both grade 1 and grade 2 classes, the students were ranked

Fig. 3 Physical artifacts to support students' understanding in grades 1 and 2

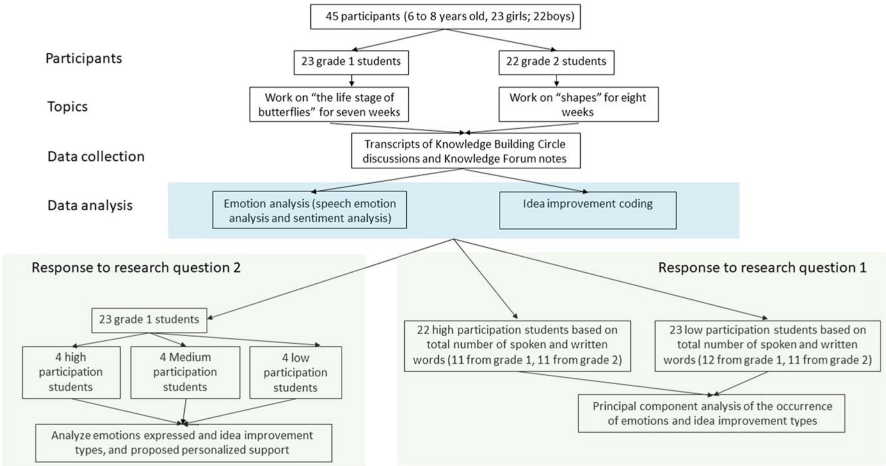

Fig. 4 Diagram of the study protocol

based on the total number of spoken and written words in face-to-face and online platform discussions.

As shown in Fig. 4, this study involves two layers of analysis. The first analysis addressed the first research question: To what extent do different types of emotions co-occur with idea improvement at different participation levels? Protocols were coded for emotion and idea improvement. Speech emotion analysis was used to analyze classroom videos and sentiment analysis to analyze online discourses. Content-analysis coding was used to analyze the transcripts of classroom videos and online discourses for idea improvement. In each class, 11 students (basically half of the students at each grade level) were assigned to the "high participation" group.

The remaining students were assigned to the “low-participation group” (11 in one class, 12 in the other, for a total of 23 students). Then for the high-participation and low-participation groups, a principal component analysis was conducted to investigate the extent to which various emotions co-occurred with idea improvement. The second analysis addressed question 2: By what means do students at different participation levels work with ideas and what are the implications for personalized support? Using grade 1 as a case, we selected students with different participation levels (i.e., high participation, medium participation, and low participation) and qualitatively analyzed how they worked on idea threads, and the emotions and idea improvement types they displayed. On the basis of the results, we suggested ways in which the teachers could provide personalized support to help different students to better improve their ideas. Overall, analyses consisted of speech emotion analysis, semantic analysis, idea improvement analysis, principal component analysis, and qualitative analysis. In the following subsections, we introduce these approaches and instruments in detail.

3.3.1 Emotion coding of classroom videos and online notes

We recorded the times at which each student started and stopped speaking in the classroom videos. Then, two researchers who had experience working in Knowledge Building contexts and were familiar with the dataset worked closely to openly tag about 20% of the video data for emotions, referring to the achievement-related emotions identified by Pekrun et al. (2017). Six emotional states were identified: joy, confidence, curiosity, surprise, neutrality, and challenge. These six states were coded in all of the video recordings analyzed by the two researchers. All disagreements between the two researchers were discussed and resolved.

Using the grounded theory approach (Glaser and Strauss 2017) and referring to the achievement-related emotions (Pekrun et al. 2017), an emotion-coding scheme was developed to code the emotions students indicated in their online textual notes. As Table 1 shows, the coding scheme included four emotional states: joy, curiosity, neutrality, and challenge. The emotional states of frustration, boredom, gratitude, and disgust were not considered because of their low rate of occurrence. Using this coding scheme, the two researchers independently identified the emotions indicated in the online notes.

3.3.2 Coding scheme for idea improvement

The transcripts of the classroom discussions and the online discourses were studied to determine the extents to which the students improved their ideas. Researchers (e.g., Resendes et al. 2015; Yang et al. 2016; Zhang et al. 2009) use thematic analysis to identify threads of ideas in diverse notes before coding each note. In this study, we separately identified the conceptual issues addressed in the student notes for grade 1 and 2. Then, the notes in each thread were coded using a refined “coding framework for a content analysis of discourse in each inquiry thread” (Yang et al. 2016). The refined scheme is shown in Table 2. In each grade, two researchers used

Table 1 Coding framework for sentiment analysis of discourse in each inquiry thread

Emotion type	Description	Example
Joy	An indication of students' happiness and satisfaction with what the community has achieved, and with themselves. Students may use emoji, words, or punctuations to convey this	Shapes can be almost anything There is a lot of shapes in the world… :) I saw shapes very cool shapes, very cool!!!!!!!!!!!!! I liked it Good idea
Curiosity	An indication of students' willingness and interest to explore and understand some ideas	Tell me more Are those shapes? I need to understand what 2D means
Challenge	Indicating that students do not understand some ideas/need help with some ideas, or do not agree with some ideas	I do not know what you mean I do not know what are those I don't know what numeric means
Neutrality	No indication of any of the emotions above	

Table 2 Coding framework for idea improvement analysis of Knowledge Building Circle and Knowledge Forum discourse

Coding categories	Sub-categories	Description	Example
Questions	Fact-seeking	Questions on the definition of terms or concepts, or seeking factual Information	I wonder—what equilateral means?
	Explanation-seeking	Questions seeking open-ended responses with elaborative explanations	What does this have to do with geometry?
Ideas	Simple claim, appraisal, or paraphrase	Opinions without any elaboration or justification, indicating shared or different opinions or understanding, a restatement of the previous idea	My theory—I agree I like it too. My theory—I think it is cool that you make shapes with other shapes. My theory—you can make shapes with shapes.
	Partial explanations or elaboration request	Expressing alternative ideas with partial explanations; requesting the previous author to elaborate; adding details to previous ideas. The explanations may include some misunderstanding	Tell me more. My theory—because I think if you did not share ideas most people would not have important stuff Anything is a shape if it has points, sides, corners; it could be anything! :)
	Explanations	Reasons, relationships or mechanisms elaborated. The explanations are scientific	My theory—some of them do not have to have corners, but not all shapes have to have sides This note was responded to: all shapes have to have sides points and corners
	New ideas	Introducing ideas/concepts that do not previously exist in the community with elaboration or justification	My theory—anything can be a shape it does not have to have a name to be a shape
Community	Regulation	Regulating community norms such as title writing, spelling, responding behaviors, turn taking, etc	My theory—that the same title as S17
	Synthesis	Connecting or comparing different ideas	My theory—many shapes have many little shapes inside the big shapes I cannot find anybody that said nooooo!!!!!!!!!

the scheme to independently code the transcripts of the classroom videos and online notes.

Although all types of idea improvement are important in building knowledge, they differ in the epistemic efforts required and the extent to which they help advance community ideas. For instance, it is easier to express opinions without offering any elaboration or justification than it is to elaborate on one's reasons or describe relationships or mechanisms. It is easier to restate previously expressed ideas than it is to contribute new ideas to a community. The cognitive effort involved in contributing each idea improvement type is considered as a criterion of classifying idea improvement types to different levels. In this study, we considered "explanations", "new ideas" and "synthesis" as advanced idea improvement types, defined "partial explanations or elaboration request", "explanation-seeking questions", and "regulation" as medium level idea improvement types, and treated "fact-seeking questions" and "simple claim, appraisal, or paraphrase" as low-level idea improvement types. This scheme was used to compare the contributions of students at different participation levels.

3.3.3 Principal component analysis

Principal component analysis (PCA) is a multivariate technique that extracts the most important information of several inter-correlated quantitative dependent variables and displays the patterns of similarity of the observation (Abdi and Williams 2010). For both the high-participation group and the low-participation group, we conducted a principal component analysis to investigate the extent to which individual emotions correlated with performance in idea improvement. For each student, the frequency of each emotion was the total number of individual speaking turns and online notes coded as expressing a specific emotion. Similarly, the frequency of each type of idea improvement was calculated by counting its occurrence in the transcripts of the classroom discussions and in the online notes of each student.

3.3.4 Qualitative analysis of work in idea threads

Based on the total number of words that each student contributed in face-to-face and online discourse, four high-, four medium, and four-low participation students were identified from the grade 1 class. Qualitative analysis was used to show how these students worked in idea threads and which types of emotions and idea improvement were displayed. If there was a student-contributed explanation in a thread, raters conducted one further qualitative analysis to identify the inquiry thread as either "productive" or "in need of improvement" (Chen et al. 2017). To be rated as productive, students needed to extend their initial simple claims or partial explanations to demonstrate idea improvement; for example, by adding evidence or identifying an improved theory or explanation. If students showed no evidence of going beyond their initial understanding of a question or theories of a thread, this thread will be considered as needing further improvement. For each student at each participation level, we then compared the number of threads and productive threads they were involved in, the emotions they expressed, and the types of idea improvement they demonstrated. Based on the results, we propose types of personalized support should be provided to them.

4 Results

4.1 Co-occurrence of individual emotions and idea improvement

4.1.1 Descriptive data of emotions and idea improvement types

For grade 1, the overall agreement between the two researchers on emotion coding was 90.0% for the classroom videos and 99.0% for the online notes. For grade 2, the overall agreement between the two researchers was 88.9% for the classroom videos and 71.6% for the online notes. The difference in emotion coding accuracy for the online notes of grade 1 and 2 can be attributed to how the students wrote their notes. The grade 1 students tended to write in a very neutral way (e.g., "They shed their skin and get a cocoon and turn into butterflies"), which made it easy for the two researchers agree on a "neutrality" rating. In contrast, the grade 2 students used a lot of emojis and punctuation (e.g., "It is a form that is called a shape!"), forcing raters to make judgments regarding the emotion underlying the emojis and punctuation marks. To assess the overall difference between the emotions of the students in the high-participation group and in the low-participation group, we conducted an independent sample *T* test in which the six types of emotions identified in the Knowledge Building Circles and Knowledge Forum were dependent variables and participation level was the independent variable. As Table 3 shows, in both the high-participation group and the low-participation group, neutrality, joy, and confidence occurred most frequently, while surprise, curiosity, and challenge were relatively rare. The students in the high-participation group demonstrated significantly higher frequencies of neutrality ($p=0.00$), curiosity ($p=0.05$), and confidence ($p=0.01<0.05$), and marginally higher frequency of joy ($p=0.06$). The students in the two groups expressed similar levels of challenge ($p=0.12$) and surprise ($p=0.68$). Overall, the results suggest that the students in the high-participation group tended to express their positive emotions (e.g. joy and confidence) and feelings of neutrality more frequently.

For grade 1, the overall agreement between the two researchers on coding the video transcripts and online notes for idea improvement was 90.8%. For grade 2, their agreement was 94.7%. An independent T test was conducted for the frequencies of different types of idea improvement in the high-participation and low-participation groups. The results are shown in Table 4. Overall, the means for the different types of idea improvement demonstrated by the high-participation group were higher than the means for the different types of idea improvement demonstrated by the low-participation group. In both groups, "simple claim, appraisal, or paraphrase" and "partial explanations or elaboration request" occurred most frequently, and the sum of their percentages was higher in the low-participation group. In contrast, the students in the high-participation group contributed significantly more

Table 3 Descriptive statistics of emotions by students in the high and low-participation groups

	Mean		*p* value	Percentage (%)		SD	
	High-participation	Low-participation		High-participation	Low-participation	High-participation	Low-participation
Joy	4.26	1.73	0.06	15.31	17.86	5.55	2.85
Curiosity	0.74	0.18	0.05	2.66	1.86	1.14	0.59
Challenge	1.26	0.55	0.12	4.53	5.68	1.86	1.06
Neutrality	17.39	6.32	0.00	62.51	65.22	12.83	3.77
Confidence	4.04	0.82	0.01	14.52	8.46	5.33	1.81
Surprise	0.13	0.09	0.68	0.47	0.93	0.34	0.29

Table 4 Descriptive statistics for idea improvement of students in high and low-participation groups

	Mean		p value	Percentage		SD	
	High-participation	Low- participation		High-participation	Low-participation	High-participation	Low-participation
Simple claim, appraisal, or paraphrase	13.78	5.59	0.00	48.40	46.39	8.54	3.43
Partial explanations or elaboration request	6.09	4.00	0.14	21.39	33.20	4.75	4.54
Explanations	3.87	1.23	0.01	13.59	10.21	4.38	1.49
Explanation-seeking questions	0.65	0.27	0.11	2.28	2.24	0.94	0.55
Fact-seeking questions	1.43	0.23	0.01	5.02	1.91	2.11	0.53
New ideas	1.57	0.32	0.01	5.51	2.66	1.88	0.89
Regulation	0.91	0.32	0.03	3.20	2.66	1.16	0.48
Synthesis	0.17	0.09	0.50	0.60	0.75	0.49	0.29

"explanations" ($p = 0.01$) and "new ideas" ($p = 0.01$) than their counterparts in the low-participation group. These results suggest that compared to the students in the low-participation group, the students in the high-participation group were more likely to elaborate their reasons and describe relationships and mechanisms of ideas concerning shapes and butterflies. They also suggest that the students in the high-participation group were more likely to introduce ideas and concepts that did not previously exist in their communities. "Explanation-seeking questions", "regulation" and "synthesis" were rarely demonstrated in any group, but observed more frequently in the high-participation group. The students in the high-participation group asked significantly more "fact-seeking questions" ($p = 0.01$) than did the students in the low-participation group.

4.1.2 Co-occurrence of emotions and idea improvement in the high-participation group

Principal component analysis was applied to the six types of emotions and eight types of idea improvement to determine how they co-occurred at the individual level in the high-participation group. As Table 5 shows, five components had eigenvalues greater than 1. In total, these five components explained 76.57% of the variance. The first component explained the most variance (17.94%), the second component explained 16.70%, the third component explained 16.44%, the fourth component explained 15.98%, and the fifth component explained 9.51%.

As described above, five components explained most of the variance. As shown in Table 6, the first component consisted of the emotional variables surprise and challenge and the idea improvement variable "explanation-seeking question." This suggests that for the high-participation students, those who felt surprised and challenged were likely to seek open-ended responses with elaborative explanations. The second component includes confidence, and the idea improvement variables "fact-seeking questions" and "partial explanations or elaboration request." It indicates that among the high-participation students, those who felt confident tended to seek information, to express alternative ideas with partial explanations or to ask speakers/authors to explain. The third component consisted of the emotional variable neutrality and the idea improvement variables "explanations" and "new ideas." It suggests that among the high-participation group, the students who expressed neutrality in speaking and writing tended to elaborate their reasons, describe relationships and mechanisms, and introduce ideas and concepts that did not previously exist in the

Table 5 Variance explained by the components in the high-participation group

Component	Eigenvalues	% of variance	Cumulative %
1	2.51	17.94	17.94
2	2.34	16.70	34.64
3	2.30	16.44	51.08
4	2.24	15.98	67.06
5	1.33	9.51	76.57

Table 6 Principal component analysis results of emotions and idea improvement types in the high-participation group

	Component				
	1	2	3	4	5
Explanation-seeking questions	0.86				
Surprise	0.77				
Challenge	0.73				
Fact-seeking questions		0.84			
Confidence		0.82			
Partial explanations or elaboration request		0.62			
Neutrality			0.89		
Explanations			0.81		
New ideas			0.71		
Simple claim, appraisal, or paraphrase				0.75	
Regulation				0.74	
Joy				0.74	
Curiosity					0.92

Table 7 Variance explained by the components in the low-participation group

Component	Eigen values	% of variance	Cumulative %
1	3.29	23.50	23.50
2	2.49	17.80	41.30
3	1.92	13.73	55.02
4	1.68	11.99	76.02
5	1.25	8.94	75.96

community, which represents knowledge work that requires high-level cognitive efforts. The fourth component included joy and the idea improvement types "simple claim, appraisal, or paraphrase" and "regulation." This result indicates that among the high-participation group, the students who were joyful tended to express ideas without opinions and to regulate classroom norms, such as title writing and spelling. The fifth component included only curiosity.

4.1.3 Co-occurrence of emotions and idea improvement in the low-participation group

For the low-participation group, we applied a principal component analysis to the six emotion types and the eight idea-improvement variables to determine the extent to which different emotions and types of idea improvement correlated. For five of the components, the eigenvalues were greater than 1. As Table 7 shows, the eigenvalue of the first, second, third, fourth, and fifth component was 3.29, 2.49, 1.92, 1.68 and 1.25, respectively. These component explained 23.50%, 17.80%, 13.73%, 11.99% and 8.94% of the variance, respectively. In total, the five components explained 75.96% of the variance.

As mentioned above, for the low-participation group, five of the components contained most of the information related to the correlation between emotions and types of idea improvement (see Table 8). The first component consisted of challenge and the idea-improvement types "new ideas," "explanations," "regulation," and "simple claim, appraisal, or paraphrase." This result suggests that in the low-participation group, the students who felt challenged were likely to introduce new ideas/concepts, elaborate their reasons, describe relationships and mechanisms, regulate community norms, express opinions without evidence, and restate previously mentioned ideas. The second component included joy and neutrality and the idea-improvement variables "partial explanations or elaboration request" and "explanation-seeking questions." This indicates that among the low-participation group, the students who felt joyful and neutral tended to express alternative ideas with partial explanations and to ask questions that could trigger open-ended and elaborated responses. The third component included curiosity and "fact-seeking questions," suggesting that among the low-participation group, students who felt curious tended to ask "what," "when," "where," and "who" questions, but not "why" and "how" questions. The fourth component consisted of confidence and "synthesis," suggesting that among the low-participation group, the students who felt confident tended to connect and to compare different ideas.

Table 8 Principal component analysis results of emotions and idea improvement types in the low-participation group

	Component				
	1	2	3	4	5
New ideas	0.85				
Explanations	0.79				
Challenge	0.78				
Regulation	0.64				
Simple claim, appraisal, or paraphrase	0.62				
Partial explanations or elaboration request		0.83			
Joy		0.72			
Explanation-seeking questions		0.68			
Neutrality		0.61			
Curiosity			0.94		
Fact-seeking questions			0.92		
Synthesis				0.84	
Confidence				0.57	
Surprise					0.92

4.2 Working patterns of students with different participation levels and proposed personalized support

In total, the grade 1 students worked on 51 idea threads directly related to the scientific topic—the life stages of butterflies. Nineteen of these threads were productive, and in these threads, the students improved their explanations by giving reasons and describing relationships and mechanisms related to various questions about butterflies. As Table 9 shows, the four students in grade 1 who participated most actively engaged in the threads. Among them, G1_S9, G1_S12, and G1_S18 engaged in seven, six, and seven productive idea threads, respectively, while G1_S21 only engaged in two productive threads. All four students demonstrated substantial participation in classroom discussion. G1_S9, G1_S18, and G1_S21 wrote substantial numbers of notes online, while G1_S12 did not write online. G1_S9 expressed joy, curiosity, confidence, surprise, neutrality, and challenge and all eight types of idea improvement. G1_S12 displayed joy, confidence, and neutrality and "simple claim, appraisal, or paraphrase," "partial explanations or elaboration request," "explanations," and "new ideas." G1_S18 expressed joy, curiosity, challenge, neutrality, and confidence as well as "simple claim, appraisal, or paraphrase," "partial explanations or elaboration request," "explanations," "explanation-seeking questions," and "new ideas." G1_S21 demonstrated every type of idea improvement except "regulation," and they expressed joy, curiosity, challenge, neutrality, and confidence. Overall, the selected students who participated frequently expressed diverse emotions and types of idea improvement. In particular, they all provided explanations and new ideas, suggesting that they all directly contributed to the productiveness of idea threads and to the community knowledge and that they initiated some new threads.

To illustrate how the students who participated the most worked collectively on an idea thread, a productive idea thread featuring most of the selected participants is provided below:

T (Reading): "The monarch only flies during the day. When it rains, the butterfly stays dry, hidden under leaves." So monarchs don't like rain.
G1_S9: It'll do damage to their wings.
T: Do you think, maybe?

Table 9 High participation students from grade 1 and their related speaking and written words

Students	No. of KBC speaking turns	No. of KBC words	No. of KF notes	No. of KF words	No. of all words	No. of productive threads/thread engaged
G1_S9	46	445	6	42	487	7/17
G1_S12	21	241	0	0	241	6/13
G1_S18	13	381	4	63	444	7/9
G1_S21	15	171	9	43	214	2/9

G1_S9: Yeah, because the rain is really hard on the wings. The wings are nice and flat, and rain can sometimes be really hard.
G1_S12: The rain can break the wings open!
G1_S11: The rain is harder than the wings. So if it is raining.
G1_S12: Poke a hole in their wings!
G1_S11: It could make a hole in their wing. Like they are scared of the water.
T: It might be too much for them.
G1_S18: And the, and the when they try to go up, because their wings are light and raindrops to us fell light, but when the butterfly flies, the air goes up and only goes down, the air goes down, so when they have rain, when they try to go up, the rain will stop them, and there will be holes, and when they try to go down, it won't work because the rain will already have a hole in it and then umm…
G1_S9: Then it will terminate them.
T: So it sounds like they really don't like to be in the rain.

Participation statistics for four students in grade 1 who participated at a medium level are shown in Table 10. They all spoke during classroom discussions and wrote on the online platform. Compared to the students who participated at a higher level, the students who participated at a medium level engaged in fewer threads and fewer productive threads. Among them, G1_S2 expressed "simple claim, appraisal, or paraphrase," "partial explanations or elaboration request," "explanations" and "fact-seeking questions" as well as curiosity and neutrality. G1_S2 did not speak much during classroom discussions but wrote a substantial number of online notes. G1_S10 expressed "simple claim, appraisal, or paraphrase," "partial explanations or elaboration request," "explanation-seeking questions" and "regulation" as well as joy, curiosity, confidence, and neutrality. G1_S17 displayed "simple claim, appraisal, or paraphrase," "partial explanations or elaboration request" and "explanations" as well as confidence and neutrality. G1_S20 displayed "simple claim, appraisal, or paraphrase," "partial explanations or elaboration request," and "new ideas" as well as joy, confidence, and neutrality. Compared to the students who participated the most, these students displayed fewer or no instances of "explanations," "new ideas," curiosity, or challenge. Encouraging these forms of input could help them to better advance community knowledge.

Table 10 Medium participation students from grade 1 and their related speaking and written words

Students	No. of KBC speaking turns	No. of KBC words	No. of KF notes	No. of KF words	No. of all words	No. of productive threads/thread engaged
G1_S2	1	1	8	75	76	0/1
G1_S10	6	85	6	41	126	3/3
G1_S17	8	60	2	14	74	2/3
G1_S20	4	71	3	13	84	1/2

An excerpt about the colors of butterflies in which G1_S10 and G1_S20 engaged was selected as an example of how students at their level participated in threads.

G1_S20: When they … I'm adding on to answering how they change. Maybe, when they make their chrysalis, their cocoon, they go in it, and then maybe in their cocoons, there are different colors, and they put the colors on themselves.
T: So the different colors are in there.
G1_S20: Yeah, like they make different colors. They make it different colors, somehow.
…
T: I wonder if that happens with all butterflies. So let's keep an eye on it and if you guys see that the chrysalises are starting to turn green, will you tell everybody so that we can all have a look?
…
G1_S10: Umm. Because it comes out fresh! Because they are new, that's why.
T: You say 'they' but I don't know what you are talking about.
G1_S10: Because like, when the caterpillars come out, they are wet. They are new. So maybe that's why.

As Table 11 shows, G1_S8, G1_S19, G1_S23, and G1_S16 either rarely spoke or did not speak at all during the classroom discussions. Several wrote a few notes online, but the content of these notes was simple, e.g. "bird," "water," "liquid," and "eating." For such students, inviting them to participate in face-to-face group discussions and providing them with prompts (e.g. "could you please explain more about what you mean") to encourage them to write online may help. The reasons why these students neither spoke in face-to-face discussions nor wrote much via the online platform needs to be studied. For example, it may have been that these students were too shy to talk, did not feel safe sharing half-baked ideas, could not type well, or did not know what good notes look like. Another strategy for supporting the participation of these students is enabling multimedia contributions so that they can contribute audio and video notes via Knowledge Forum.

Table 11 Low participation students from grade 1 and their related speaking and written words

Students	No. of KBC speaking turns	No. of KBC words	No. of KF notes	No. of KF words	No. of all words
G1_S8	0	0	1	5	5
G1_S16	0	0	8	12	12
G1_S19	0	0	1	10	10
G1_S23	1	4	2	7	11

5 Discussions

5.1 Students in the high-participation groups expressed significantly more positive emotions

As described in the results section, the students in the high-participation group tended to express more positive emotions such as joy, curiosity, and confidence as well as more neutrality than did the students in the low-participation group. These groups did not differ significantly in their expression of challenge or surprise. A possible explanation for these results is that when the students participated more frequently in face-to-face discussions and online knowledge construction, they tended to have more positive emotions or tended to have more opportunities to express positive emotions. Although the students were encouraged to participate in classroom discussions, due to the constraints of time and class size, the verbal and extroverted students are likely to speak more (Lossman and So 2010).

In both the high- and low-participation groups, "simple claim, appraisal, or paraphrase" and "partial explanations or elaboration request" accounted for most of the discourse. What should be noted is that in the high-participation group, a higher proportion of contributions were high and medium idea improvement types such as "explanations," "fact-seeking questions," "new ideas," and "regulation." The results suggest that compared to the students in the low-participation group, the high-participation students made more effort to advance community knowledge. It suggests that the quantity of students' participation is an indicator of the quality of their participation.

5.2 Negative and neutral emotions can be beneficial

Surprise, challenge, and neutrality can be beneficial. In the high-participation group, the students who expressed these emotions tended to ask "explanation-seeking questions," introduce new ideas and concepts, elaborate their reasons, and describe relationships and mechanisms related to butterflies and shapes. In the low-participation group, the students who expressed challenge contributed new ideas, explanations, and "regulation.," in line with previous studies (e.g., Csikszentmihalyi 1990; Worsley and Blikstein 2015) suggesting challenge plays an important role in the knowledge construction process. If an individual's knowledge and skills exceed the challenge, one first feels relaxed, then bored (Csikszentmihalyi 1990). If challenges exceed skills, however, one becomes first vigilant and then anxious. Thus "maintaining a level of challenge that is just manageable" is essential to maintaining flow, a state of deep absorption in an activity that is intrinsically enjoyable, as when artists or athletes are focused on their play or performance (Csikszentmihalyi 1990). A sense that one's capacity is appropriate for the challenge one is engaging in is a precondition for entering flow (Nakamura and Csikszentmihalyi 2014). Kort and Reilly (2002) propose a four-quadrant learning spiral model that describes how emotions evolve as time progresses. In quadrant I, students experience positive affect (e.g. awe, satisfaction, and curiosity) and constructive learning. At this point, the students can manage their challenges and have not experienced more puzzlement than they can handle. When contradictions between what they currently experience and previous understanding arise, they move on to quadrant II. Here, they may feel disappointed, puzzled, and confused but still construct knowledge. Worsley and Blikstein (2015) highlighted the importance of confusion as an indicator of knowledge construction. Specifically, their results suggested that being in or transitioning into a state of confusion was related to positive learning outcomes. Worsley and Blikstein (2015) also found that surprise served as a mediator of cognitive disequilibrium. The valence of these emotions and the relationship between these emotions such as how and when they trigger each other was not analyzed in the current study and represents an important area for future research.

The students in the high-participation group displayed significantly more curiosity. The importance of curiosity has been well-documented in the Knowledge Building literature (e.g., Khanlari et al. 2017; Scardamalia 2002). "Real ideas, authentic problems" is one of the 12 principles of Knowledge Building (Scardamalia 2002). Questions arise from students' efforts to understand the world. Problems that students are curious and care about are the starting point for Knowledge Building. When Knowledge Building fails, it is usually because of failing to deal with questions that students are curious about (Scardamalia and Bereiter 2006). Khanlari et al. (2017) indicated that student-generated questions engaged a community in sustainable and progressive discourse, which is central to collaborative knowledge building.

In this study, joy did not co-occur with idea improvement–a high cognitive effort move; rather, in the high-participation group, joy co-occurred with "simple claim, appraisal, or paraphrase" and "regulation," while in the low-participation group, joy co-occurred with "partial explanations or elaboration request," and "explanation-seeking questions." This is in line with Ellsworth and Smith (1988) who suggest that the feeling of joy requires little effort and arises in safe and familiar contexts (Izard 1977). Joy may also arise as a result of events construed as accomplishments or progress towards one's goals (Izard 1977; Lazarus 1991). Compared to negative emotions, such as anxiety and confusion, joy has been seldom investigated (Rantala and Määttä 2012) and merits further study.

5.3 Personalized support

The qualitative analysis revealed that the expressions of the students who participated most were characterized by curiosity and challenge as well as by "explanations" and "new ideas." These students also displayed diverse emotions and types of idea improvement. It is important to encourage these students to help others to engage in knowledge building communities. The students who participated at a medium level displayed most of the emotions and types of idea improvement, although fewer instances of curiosity and challenge as well as "explanations" and "new ideas." Showing students who participate at a medium level what productive threads look like and what kinds of emotions and types of idea improvement such threads elicit might help them to reflect on their own contributions. Previous studies have shown that young students can reflect on their contributions to knowledge building communities and adjust their behaviors (e.g., Resendes et al. 2015; Yang et al. 2016). In addition, the studies that indicate confusion may play a different role in learning outcomes under different conditions also suggest the importance of regulating students' learning. To support student participation, the reasons why some of the students did not participate much in the classroom or online discussions need to be investigated. Individual personalities and ability levels may influence their participation and emotions. For instance, Lallé et al. (2016) investigated how individual differences influenced participants' affective reactions to intelligent pedagogical agents in an agent-based learning environment. The results showed that individual achievement goals and personality traits influence the affective reactions to the pedagogical agents.

5.4 Limitations and future directions

The research reported represents an exploratory investigation, using methods and student populations seldom represented in studies of emotion and cognition. The sample size (N = 45) is small and data analysis is focused on speech and written discourse arising from classroom settings. Thus many of the forms on instrumentation and biometrics used to study emotions and cognition were not appropriate. Videos of Knowledge Building Circles suggested the influence of personality on individual expression of emotions, but personality variables were not explored. Nonetheless, it was evident that some students demonstrated excitement when they talked, or only talked when they felt good. Other students conveyed neutrality when contributing "explanations" or "new ideas" to the community. As the literature makes clear, emotional expression differs among age groups, genders, and learning environments, and people may disguise their facial expressions (Ray and Chakrabarti 2016). Subjective feelings are more reliable than other observable behavior when assessing the condition that an individual is in (Csikszentmihalyi 1990), but subjective ratings were not available in the present study. For these various reasons, the results of this study should be interpreted with caution; their main contribution is to open new areas of inquiry.

Future studies will require larger sample sizes and collection of more diverse data—e.g. facial expressions and self-reported surveys on subjective feelings—to provide better representations of students' emotions. Also, approaches using behavioral and psychological mechanisms to uncover socio-cognitive-emotional dynamics will be needed to complement current procedures. Future work will incorporate interventions to support students' idea improvement and well-being, with analysis of changes in emotions and idea improvement to provide more solid evidence of influences on the relationship between them. With a larger dataset, we will try to build machine learning models to automatically detect students' emotions and idea improvement types based on their face-to-face classroom discussions and online written notes. The detection results could help students and teachers immediately reflect on their knowledge building process. Personalized support can also be provided to students by teachers or online platforms.

6 Conclusions

In this exploratory study, we used prosodic features to manually code individual emotions in video-recorded classroom discussions and used sentiment analysis to identify individual emotions in online written discourse. The emotion analysis suggests that students who participated more in a classroom and online discussions expressed neutrality, joy, curiosity, and confidence significantly more often than did the students who participated less. However, the students in the two groups did not show significant differences regarding challenge and surprise. We use an idea improvement coding scheme to code the transcripts of classroom recordings and online notes to investigate the extent to which students in the high-participation and low-participation groups contributed to the advancement of community knowledge. Both groups expressed high proportions of "simple claim, appraisal, or paraphrase" and "partial explanations or elaboration request." The students in the high-participation group were more likely to elaborate their reasons, to describe relationships and mechanisms of ideas surrounding the topics they explored, and to introduce ideas and concepts that did not exist in their communities.

We then conducted a principal component analysis to investigate the extent to which individual emotions co-occurred with idea improvement in the high- and low-participation groups. The results showed that among the high-participation group, challenge, surprise and neutrality were likely to co-occur with advanced idea improvement types such as "explanations" and "new ideas", confidence correlated with a medium-level of idea improvement types (e.g., partial explanations or elaboration request), while joy happened with "simple claim, appraisal, or paraphrase" and "regulation" which require relatively low cognitive efforts. The patterns were different for the low-participation group. For instance, when the students expressed joy and neutrality, they contributed "partial explanations or elaboration requests" and "explanation-seeking questions," which were considered as medium level idea improvement types in this study. The qualitative analysis of selected students from the grade 1 class indicated that students with different participation levels showed different emotions and idea improvement types. "Explanations" and "new ideas" and curiosity and challenge distinguished different participation levels. Also, we recommended personalized support for students at different participation levels.

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References

Abdi, H., Williams, L.J.: Wires. Comput. Stat. **2**(4), 433–459 (2010)

Arguedas, M., Daradoumis, T., Xhafa, F.: Analyzing how emotion awareness influences students' motivation, engagement, self-regulation and learning outcome. Educ. Technol. Soc. **19**(2), 87–103 (2016)

Baker, R.S., D'Mello, S.K., Rodrigo, M.M.T., Graesser, A.C.: Better to be frustrated than bored: The incidence, persistence, and impact of learners' cognitive–affective states during interactions with three different computer-based learning environments. Int. J. Hum-Comput. St. **68**(4), 223–241 (2010)

Baker, M., Järvelä, S., Andriessen, J. (eds.): Affective learning together: social and emotional dimensions of collaborative learning. Routledge, New York (2013)

Bereiter, C.: Education and Mind in the Knowledge Age. Lawrence Erlbaum Associates, Mahwah (2002)

Bielaczyc, K., Kapur, M., Collins, A.: Cultivating a community of learners in K–12 classrooms. In: Hmelo-Silver, C., Chinn, C., Chan, C., O'Donnell, A. (eds.) The International Handbook of Collaborative Learning, pp. 233–249. Routledge, New York (2013)

Blikstein, P., Worsley, M.: multimodal learning analytics and education data mining: using computational technologies to measure complex learning tasks. J. Learn. Anal. **3**(2), 220–238 (2016)

Broadbent, S., Gallotti, M.: Collective intelligence, how does it emerge (2015). https://www.nesta.org.uk/sites/default/files/collective_intelligence.pdf. Accessed 29 Mar 2017

Brown, A., Campione, J.C.: Psychological theory and the design of innovative learning environments: on procedures, principles, and systems. In: Schauble, L., Glaser, R. (eds.) Innovations in Learning: New Environments for Education, pp. 289–325. Lawrence Erlbaum Associates, Hillsdale (1996)

Cahour, B.: Characteristics, emergence and circulation in interactional learning. In: Järvelä, S. (ed.) Affective Learning Together, pp. 52–70. Routledge, New York (2013)

Chen, B., Resendes, M., Chai, C.S., Hong, H.Y.: Two tales of time: uncovering the significance of sequential patterns among contribution types in knowledge-building discourse. Interact. Learn. Environ. **25**(2), 162–175 (2017)

Creswell, J.W., Clark, V.L.P.: Designing and Conducting Mixed Methods Research. Sage publications, Boston (2017)

Csikszentmihalyi, M.: Flow: The Psychology of Optimal Performance. Cambridge University Press, New York (1990)

Csikszentmihalyi, M., Hunter, J.: Happiness in everyday life: the uses of experience sampling. J. Happiness Stud. **4**(2), 185–199 (2003)

D'Mello, S., Lehman, B., Pekrun, R., Graesser, A.: Confusion can be beneficial for learning. Learn. Instr. **29**, 153–170 (2014)

Ellsworth, P.C., Smith, C.A.: Shades of joy: patterns of appraisal differentiating pleasant emotions. Cognit. Emot. **2**, 301–331 (1988)

Glaser, B.G., Strauss, A.L.: Discovery of Grounded Theory: Strategies for Qualitative Research. Routledge, New York (2017)

Grafsgaard, J. F., Wiggins, J. B., Boyer, K. E., Wiebe, E. N., Lester, J. C.: Automatically recognizing facial indicators of frustration: a learning-centric analysis. In: Proceedings of 2013 Humaine Association Conference on Affective Computing and Intelligent Interaction, pp. 159–165 (2013)

Grafsgaard, J., Wiggins, J., Boyer, K. E., Wiebe, E., Lester, J.: Predicting learning and affect from multimodal data streams in task-oriented tutorial dialogue. In: Proceedings of Educational Data Mining, pp. 122–129 (2014)

Grawemeyer, B., Mavrikis, M., Holmes, W., Gutiérrez-Santos, S., Wiedmann, M., Rummel, N.: Affective learning: improving engagement and enhancing learning with affect-aware feedback. User Model. User Adapt. Interact. **27**(1), 119–158 (2017)

Goetz, J.L., Keltner, D., Simon-Thomas, E.: Compassion: an evolutionary analysis and empirical review. Psychol. Bull. **136**(3), 351–374 (2010)

Hmelo-Silver, C.E., Barrows, H.S.: Facilitating collaborative knowledge building. Cognit. Instruct. **26**(1), 48–94 (2008)

Izard, C.E.: Human Emotions. Plenum Press, New York (1977)

Lazarus, R.S.: Emotion and Adaptation. Oxford University Press, New York (1991)

Keltner, D., Cordaro, D.T.: Understanding multimodal emotional expressions. In: Russell, J.A., Fernández-Dols, J.-M. (eds.) The Science of Facial Expression, pp. 57–75. Oxford University Press, Oxford (2017)

Khanlari, A., Resendes, M., Zhu, G., Scardamalia, M.: Productive Knowledge Building Discourse Through Student-Generated Questions. In: Proceedings of the 12th International Conference on Computer Supported Collaborative Learning (CSCL2017), pp. 585–588 (2017)

Kirschner, P.A., Erkens, G.: Toward a framework for CSCL research. Educ. Psychol. **48**(1), 1–8 (2013)

Koolagudi, S.G., Rao, K.S.: Emotion recognition from speech: a review. Int. J. Speech. Technol. **15**(2), 99–117 (2012)

Kort, B., Reilly, R.: An affective module for an intelligent tutoring system. In: Proceedings of the 6th International Conference on Intelligent Tutoring Systems (ITS2002), pp. 955–962 (2002)

Lallé, S., Mudrick, N. V., Taub, M., Grafsgaard, J. F., Conati, C., Azevedo, R.: Impact of individual differences on affective reactions to pedagogical agents scaffolding. In: Proceedings of the International Conference on Intelligent Virtual Agents, pp. 269–282

Lampert, M.: Teaching Problems and the Problems of Teaching. Yale University Press, New Haven (2001)

Loia, V., Senatore, S.: A fuzzy-oriented sentic analysis to capture the human emotion in web-based content. Knowl. Based Syst. **58**, 75–85 (2014)

Lossman, H., So, H.J.: Toward pervasive knowledge building discourse: analyzing online and offline discourses of primary science learning in Singapore. Asia Pac. Educ. Rev. **11**(2), 121–129 (2010)

Lutz, C.A., Abu-Lughod, L.E.: Language and the Politics of Emotion. Cambridge University Press, New York (1990)

Mega, C., Ronconi, L., De Beni, R.: What makes a good student? How emotions, self-regulated learning, and motivation contribute to academic achievement. J. Educ. Psychol. **106**(1), 121 (2014)

Nakamura, J., Csikszentmihalyi, M.: The concept of flow. In: Csikszentmihalyi, M. (ed.) Flow and the Foundations of Positive Psychology, pp. 239–263. Springer, Netherlands (2014)

Pardos, Z. A., Baker, R. S., San Pedro, M. O., Gowda, S. M., Gowda, S. M.: Affective states and state tests: Investigating how affect throughout the school year predicts end of year learning outcomes. In: Proceedings of the Third International Conference on Learning Analytics and Knowledge (LAK2013), pp. 117–124 (2013)

Pekrun, R.: A social cognitive, control–value theory of achievement motions. In: Heckhausen, J. (ed.) Motivational Psychology of Human Development, pp. 143–163. Elsevier, Oxford (2000)

Pekrun, R., Lichtenfeld, S., Marsh, H.W., Murayama, K., Goetz, T.: Achievement emotions and academic performance: longitudinal models of reciprocal effects. Child Dev. **88**(5), 1653–1670 (2017)

Philip, D. N.: Networks and the spread of ideas in knowledge building environments, Doctoral dissertation, University of Toronto (2009)

Polo, C., Lund, K., Plantin, C., Niccolai, G.P.: Group emotions: the social and cognitive functions of emotions in argumentation. Int. J. Comput. Support. Collab. Learn. **11**(2), 123–156 (2016)

Putwain, D.W., Becker, S., Symes, W., Pekrun, R.: Reciprocal relations between students' academic enjoyment, boredom, and achievement over time. Learn. Instruct. **54**, 73–81 (2018)

Popper, K.R.: Objective Knowledge: An Evolutionary Approach. Clarendon Press, Oxford (1972)

Ranganathan, H., Chakraborty, S., Panchanathan, S.: Multimodal emotion recognition using deep learning architectures. In: Proceedings of Applications of Computer Vision (WACV2016), pp. 1–9 (2016)

Ray, A., Chakrabarti, A.: Design and implementation of technology enabled affective learning using fusion of bio-physical and facial expression. Educ. Technol. Soc. **19**(4), 112–125 (2016)

Rantala, T., Määttä, K.: Ten theses of the joy of learning at primary schools. Early Child Dev. Care **182**(1), 87–105 (2012)

Reeve, R., Messina, R., Scardamalia, M.: Wisdom in elementary school. In: Ferrari, M., Potworowski, G. (eds.) Teaching for Wisdom: Cross-cultural Perspectives on Fostering Wisdom, pp. 79–92. Springer, New York (2008)

Resendes, M., Scardamalia, M., Bereiter, C., Chen, B., Halewood, C.: Group-level formative feedback and metadiscourse. Int. J. Comput. Support. Collab. Learn. **10**(3), 309–336 (2015)

Sakr, M., Jewitt, C., Price, S.: Mobile experiences of historical place: a multimodal analysis of emotional engagement. J. Learn. Sci. **25**(1), 51–92 (2016)

Scardamalia, M., Bereiter, C.: Computer support for knowledge-building communities. J. Learn. Sci. **3**(3), 265–283 (1994)

Scardamalia, M.: Collective cognitive responsibility for the advancement of knowledge. In: Jones, B. (ed.) Liberal Education in a Knowledge Society, pp. 67–98. Open Court, Chicago (2002)

Scardamalia, M.: CSILE/Knowledge Forum®. In: Kovalchick, A., Dawson, K. (eds.) Education and Technology: An Encyclopedia, pp. 183–192. ABC-CLIO, Santa Barbara, CA (2004)

Scardamalia, M., Bereiter, C.: Knowledge building: theory, pedagogy, and technology. In: Sawyer, K. (ed.) Cambridge Handbook of the Learning Sciences, pp. 97–118. Cambridge University Press, New York (2006)

Scardamalia, M., Bereiter, C.: Knowledge building and knowledge creation: theory, pedagogy, and technology. In: Sawyer, K. (ed.) Cambridge Handbook of the Learning Sciences, 2nd edn, pp. 397–417. Cambridge University Press, New York (2014)

Schutz, P.A., Hong, J.Y., Cross, D.I., Osbon, J.N.: Reflections on investigating emotion in educational activity settings. Educ. Psychol. Rev. **18**(4), 343–360 (2006)

Sinha, S., Rogat, T.K., Adams-Wiggins, K.R., Hmelo-Silver, C.E.: Collaborative group engagement in a computer-supported inquiry learning environment. Int. J. Comput. Support. Collab. Learn. **10**(3), 273–307 (2015)

Thagard, P.: Coherence, truth and the development of scientific knowledge. Philos. Sci. **74**, 28–47 (2007)

Worsley, M., Blikstein, P.: Using learning analytics to study cognitive disequilibrium in a complex learning environment. In: Proceedings of the Fifth International Conference on Learning Analytics and Knowledge (LAK2015), pp. 426–427 (2015)

Yang, Y., van Aalst, J., Chan, C.K., Tian, W.: Reflective assessment in knowledge building by students with low academic achievement. Int. J. Comput. Support. Collab. Learn. **11**(3), 281–311 (2016)

Zhang, J., Scardamalia, M., Lamon, M., Messina, R., Reeve, R.: Socio-cognitive dynamics of knowledge building in the work of 9- and 10-year-olds. Educ. Technol. Res. Dev. **55**(2), 117–145 (2007)

Zhang, J., Scardamalia, M., Reeve, R., Messina, R.: Designs for collective cognitive responsibility in knowledge-building communities. J. Learn. Sci. **18**(1), 7–44 (2009)

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