A case study of emotion analysis for collective idea improvement

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Abstract: Although it is common to recognize the importance of emotional regulation in computer-supported collaborative learning, few studies have examined the development of emotional regulation in Knowledge-Building (KB) discourse. This paper reports on the students' emotions analyzed using automated detection while they engage in collective idea improvement. Data was taken from Students' KB Design Studio (2019), a two-day workshop attended by 37 students to tackle the real-world problem of sustainable food source. Using a multimodal approach, we analyzed a group of five students' face-to-face and online discourse; their emotions from video data; and their self-reported emotions at different points of the day. We found the group's face-to-face discussion comprised mainly of idea-sharing and brief suggestions for their prototype features such as fact-seeking questions and unelaborated explanations. However, the automated software detection suggested that two students who engaged more in idea sharing expressed more occurrences of happy emotions. Of these two students, the one who reported moments of frustration seemed to contribute more complex ideas about the prototype on Knowledge Forum. Our findings warrant the need for more MMLA research to explore how different student emotions can play a positive role to support knowledge building.

Introduction

Research on affective learning suggests that the social component of learning such as student discussions may uniquely influence students' emotional responses and subsequent engagement (Linnenbrink-Garcia, Rogat, & Koskey, 2011). For example, students can display affective reactions when they negotiate meaning in small group social interactions and subsequently influencing their choice to engage or disengage in the learning. Such affective reactions can also be richly present in collective idea improvement in Knowledge Building environments. For instance, a student who comes across an idea of interest may express curiosity while another student who has made a note contribution may express joy. Examining students' emotions in idea improvement offer an understanding of their cognitive activities and engagement as well as their emotional regulation as they work collectively towards knowledge advancement. Currently, literature focusing on students' emotions in relation to their learning in KB is thin (Zhu et al., 2019). This paper attempts to contribute to this understanding by reporting findings on students' emotion in relation to KB process from their face-to-face and online discourse in a unique out-of-school knowledge building environment.

Students' socio-cognitive dynamics in Knowledge Building

Knowledge building approach to learning positions students as agents of learning in an environment that focuses on collective idea growth. In a Knowledge Building environment, students work as a community, they constantly share, inquire and build on each other's ideas to bring about idea improvement and to advance community understanding and knowledge (Scardamalia, 2002). The last decade has seen much effort to understand and examine students' idea improvement in relation to depth of inquiry and understanding in terms of epistemic beliefs and knowledge (e.g. Chen, 2017; Lin & Chan, 2018; Zhang et al., 2010). For instance, Zhang and colleagues (2010) investigated elementary students' idea improvement based on the progression of depth of understanding and epistemic approach from students' questions and explanations in KF. They showed that students' engagement in idea improvement should generate more questions seeking for explanations of phenomena or inquiry as well as explanations elaborating reasons and relationships. Likewise, Lin and Chan (2018) showed that idea improvement can be understood by inquiry threads. They explored how elementary students deepened the inquiry and advanced knowledge as they contributed questions to sustain the inquiry discussion and explanations that supported deeper understanding of the issue at hand. More recently, there is increasing interest to explore the connection between student affective behaviors such as emotions or physiological responses with the learning processes of idea creation and improvement in group collaborations (e.g. Furuichi & Worsley, 2018; Zhu, et al., 2019).

According to studies on student emotions and academic performance, student emotions can positively or negatively influence achievements, motivation, attention and cognitive focus (e.g. Pekrun, 2000, 2017). For instance, it has been found that emotions such as enjoyment and pride can positively influence students' learning as compared to negative emotions such as boredom (Pekrun, 2000). However, negative emotions do not necessarily discourage learning and may even be an indicator of knowledge construction (e.g. D'Mello et al. 2014; Worsley & Blikstein, 2016). Thus, findings from existing research on emotional learning remained mixed. In addition, such studies have been mainly conducted on university students and little is known about primary and secondary students. Building on this understanding, we posit that students' emotion will affect their knowledge building work too. To our understanding, there has been only one recent study done on emotions in KB learning and work in this area is still largely underexplored in the KB classrooms. In the study, Zhu and colleagues examined grade 1 and 2 students' emotions from both online and face-to-face discourse in KB lessons. The researchers manually coded for emotions from classroom videos using speech emotion analysis and emotions from students' online discourse using sentiment analysis. They also coded for idea improvement (based on a set of idea improvement contribution types) from transcripts of classroom videos and online discourses using content analysis. The study found that emotions such as surprise, challenge, and neutrality can be beneficial as students who expressed these emotions tended to elaborate reasons, described relationship and mechanism surrounding ideas they explored. In addition, their work also highlighted that confusion can be an important predictor of affective states in students with high participation in collaborative discussion (Zhu et al., 2019). From this work, we can see that epistemic emotions which relate to knowledge and the generation of knowledge (Pekrun and Stephens, 2012) can emerge from knowledge building processes such as idea improvement. However, whether these emotions positively influence students' knowledge advancement warrants more research validation and investigation.

With advancements in multimodal learning analytics research, video analysis is increasingly adapted to detect students' emotions through their facial expression (e.g. Arroyo, et al., 2009; Bosch, et al., 2016; Truong et al., 2007). For instance, Arroyo and colleagues found that using sensors to detect students' affective states and facial detection software can predict more than 60% of the variance of students' emotional states, which fared better than predictions of emotions from other contextual variables from the instructor, when these sensors are absent. Likewise, Bosch et al., (2016) used FACET, a commercialized affect detection software to examine learning-centered affective states in a computer-enabled classroom. They reported that the webcams face-based detectors could provide automatic detection of boredom, confusion, delight, engagement, and frustration in natural learning environments. Thus, automated detection may be a feasible way forward to advance understanding of emotional learning in KB classrooms. In this study, we report a preliminary work to trial an automated detection system with 360 camera to explore students' emotions in relation to their engagement in idea improvement. By enhancing our understanding of the socio-emotional and socio-cognitive dynamics of student learning in KB, we aim to improve the quality of interactions for teachers and students in KB classroom as well as teachers' pedagogical knowledge of classroom discourse. For example, a teacher may tend to adopt guided inquiry in order to avoid student confusion, but may miss out what might be productive confusion that potentially lead students to delve deeper into the concept understanding. Furthermore, a more in-depth knowledge of socio-emotional and socio-cognitive developmental in children and adolescent can possibly shed new light on the design and implementation of knowledge building lessons.

Context

Data for this paper comes from the "Student Knowledge Building Design Studio (SKBDS)" which was a two-day (Twelve hours of engagement) workshop in which thirty-seven students from seven different schools came together to knowledge building on the real-world problem of sustainable living. Table 1 outlines the principle-based approach to designing the Design Studio. The workshop design planning was supported by KB principles such as Real ideas authentic problem, KB discourse, Idea improvement, Idea diversity, Rise above, Symmetrical advancement of knowledge. Briefly, students were introduced to sustainable farming and they conducted a series of KB discussion, experiments to investigate light and photosynthesis. Students then discussed and built the prototype for vertical farming. Students were engaged through various collaborative modes such as whole-class discussion, group work and discussions, KF discussions. The SKBDS was conducted in November 2019 and participated students had an opportunity to learn out of the boundary of a typical classroom setting and to give them opportunities to build knowledge in a vibrant and open community of learners. They had opportunities to interact with peers from other grade level and schools, as well as with teachers, researchers and scientists as they engage in idea improvement.

The unique design of SKBDS provided a specific context of KB learning for the purpose of this study. We recognized that not all occurrences showing epistemic emotions can be expected to have similar effects on learning. For example, a student may feel uncertainty during a lesson if his or her textbook was misplaced (before the lesson).

This affective behavior may be a distraction to the child and may or may not impact the child's learning process. To address such nuances and the complexity of emotions in learning, we have noted the importance of the contextualized instances of epistemic emotions with specific reference to learning or knowing activities. Furthermore, the same epistemic emotions detected may not produce the same impact on learning each time it is detected, as there may be both productive and negative epistemic emotions. Thus, the design studio promoted a KB learning environment to better allow us to explore such nuances and complex nature of epistemic emotions in relation to KB processes.

Table 1: Design Studio activities.

Design Principles	**Activities**	**Mode of engagement**	**Purpose of activity and alignment to KB principles**
Real ideas authentic problem: Supporting students to understand how a real scientific community work and think about real world problem. Supporting students to make connections to the problem that they have to tackle as a community. Symmetrical advancement of knowledge: Engaging students with experts in ways that allow students to understand their own contribution to the field. Shifting students from thinking that there is an expert-know-it-all view to a co-construction view of knowledge.	Students introduced to the big problem of sustainability cities and communities, leading to sustainable farming. Engagement with real Scientist: How do scientists respond to problems in the real world? How do scientists improve ideas?	Whole-Class Discussion Initial small group KB talk to generate ideas about sustainable living.	How do an innovator, scientist or designer think? Students to appreciate the idea improvement process embarked by innovators and scientists and that the path of problem solving is not linear.
KB discourse: Initiating students into a culture of discourse and collaboration at the start of the design studio, rather than following a regular classroom practice to focus on individual growth.	Whole-class: Discussion with expert scientists and researchers.	Whole-Class talk	Understanding the path of creative work with ideas. Students to identify with the real-world problem of sustainable living. How do we contribute? What does it take to improve ideas and make it work in the real world?
Idea improvement: Ensuring students have opportunities to continuously improve the quality, coherence and utility of ideas.	Design experiments: Series of hands-on experiments on properties of light.	Group work	Investigating the science and engineering aspects (e.g. photosynthesis; structural stability) necessary for the design of a vertical farming system. Students recorded their ideas, findings, questions and discussion on paper and KF.
Idea diversity: Helping students to understand how ideas expand – including contrasting ideas. Supporting students to go beyond a topic/the discipline to the present state and growing edge of knowledge in the field.	Students think about creation of a new farming system that covers the plants' nutritional needs, enable optimal growth of the plants and yet save space? Students collect useful information from articles provided to design a prototype system that can provide ensure high/ maximal rate of photosynthesis. Students produce detailed sketches and descriptions of their prototype and some of its unique features.	Group work	Constantly exploring diverse ideas and design of vertical farming prototype. Research: Students constructively use authoritative sources to inform their design. Students engage in KB discourse (small group, whole class, with experts, with researchers) to generate and put ideas together for prototype design.
Rise above: Promoting students' creative knowledge building by challenging them towards higher-level forms of problems. It means supporting students to learn to work with diversity, complexity, and messiness and moving to higher planes of understanding,	Translating ideas to concrete prototype: Students build their prototype and discuss on prototype improvement. Students present their work to the community. Group present ideas and prototype to one another.	Group work Whole-class discussion; connecting with community and expert scientists.	Improving on idea through prototype building, sharing and assessment. Engaging students in symmetrical knowledge advancement and Rise above.

		Scientists/teachers take on a discussant role instead of a judge role.	

Methodology and analysis

This case study explored multimodal data analysis and the use of multimodal learning analytics by incorporating software detection to examine students' affective engagement in relation to idea improvement. A mixed method research design was used incorporating multimodal learning analytics on facial expression analysis, idea improvement analysis, and student self-reports. These analyses serve to answer the following research questions: (1) To what extent can we characterize students' emotions in relation to idea improvement? (2) How accurate are the machine analysis in these emotion analysis? As shown in Table 2, we examined students' idea improvement from both their textual KF discussion and their verbal discourse from face-to-face discussion. Using video recordings of student discourse, we explored corresponding students' affective engagement by analysing emotions from their facial expression with an automated detection software. The emotion analysis was supported by self-reports generated through an emotional survey. Although we also collected students' physiological data from empatica, however, due to the large datasets involved, we focused this paper on the automated analysis of student emotions from a short 360 video footage from a group of students in relation to their idea improvement processes from their face-to-face discourse.

Table 2: Multimodal data collection.

Dimension	Modality	Data Sources	Data Analysis
Students' idea improvement	Textual	Student KF notes	Text analysis
	Verbal	Audio recording of students' face-to-face discussion	Content analysis
Students' affective engagement	Socio-emotional	Video recording of student facial expressions	Video analysis (manual and machine)
		Student self-report	Survey analysis
	Physiological	Empatica wearable	Physiological data using Empatica software (not included in this paper)

Figure 1 briefly illustrates our setup which involved the use of 360 camera and frontal camera to obtain close up capturing of facial expression of every student in the group as well as their actions and discussions. Lapel microphones were attached to individual students to obtain a clearer recording of their voices. The design studio involved a total of 6 student groups (5 to 6 students in a group seated around a common table). The 360 camera setup was trialed with 3 groups. All the students also completed an emotional-survey at different time interval of the Design Studio. The survey included the following ten items on a likert scale: (i) I am good at this; (ii) I feel challenged; (iii) I feel frustrated; (iv) I am learning; (v) I am feeling happy…sad; (vi) I am feeling irritated; (vii) I am feeling cooperative; (viii) I am interested; (ix) I am involved; (x) I am thinking. Students were paused at 8 intervals (points) on Day 1 and 6 intervals (points) on Day 2 and given few minutes to respond quickly to the emotion survey.

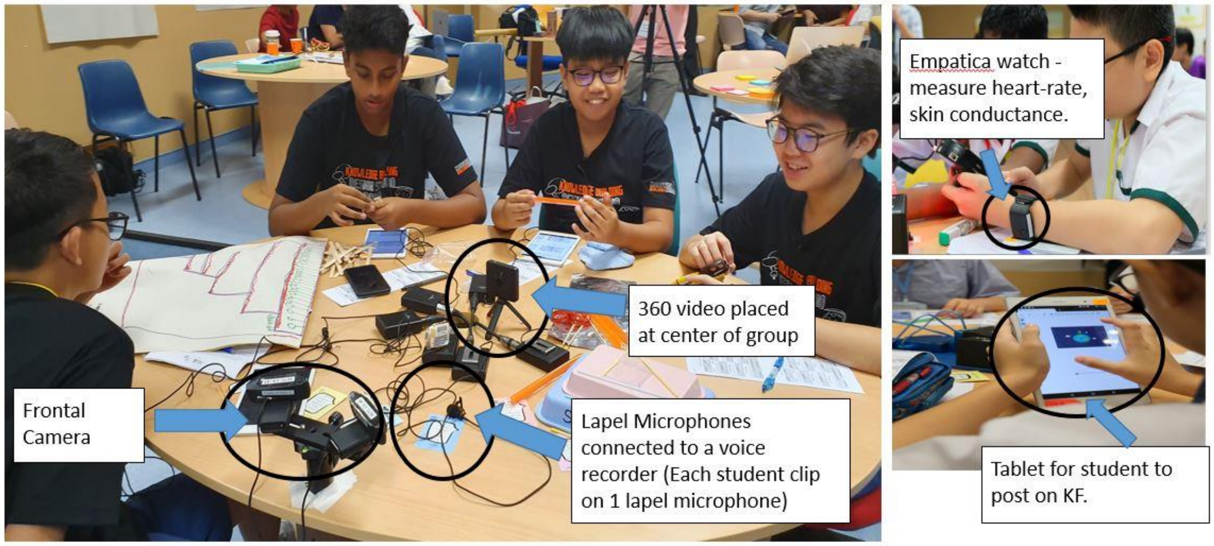


Figure 1. Setup of equipment to capture multimodal data.

Coding students' idea improvement

Based on theory building moves suggested by Zhang et al. (2018), we coded students' contributions in both face-to-face discussion and KF discussion for idea improvement. We analysed their ideas in terms of the quality of questions and explanations. In terms of questions, we coded fact-seeking question that only required basic factual responses or an explanation-seeking question that required elaboration on mechanisms and causal relationships. In terms of explanations, we coded simple (unelaborated) explanation such as giving a short opinion to an elaborated explanation that mentioned reasons and mechanisms with sound scientific understanding. Table 3 illustrates these codes and sample examples.

Table 3: Coding scheme for idea improvement

Contributions to idea improvement	Description	Sample coding (examples from KF and face-to-face discussion)
Asking a fact seeking question	Questions on the definition of terms or concepts, or seeking factual information	"you mean like two sides or what?"
Asking a explanation seeking question	Questions seeking open-ended responses with elaborative explanations	"so if it's inside the (building) how the solar panel receives light?"
Providing a simple explanation	Opinions without any elaboration or justification, indicating shared or different opinions or understanding, a restatement of the previous idea	"then make it waterproof" Saves more space than if there was a dedicated building
Providing a partially elaborated explanation	Expressing alternative ideas with partial explanations; requesting the previous author to elaborate; adding details to previous ideas. The explanations may include some misunderstanding.	"let's say the rooftop is like this right, then open, then there is some like latch that you can just hang over the=" We used solar energy as a main source of energy for our farm and wind energy as a secondary source of energy we decided to use this two energy as they are sustainable
Providing an elaborated explanation	Reasons, relationships or mechanisms elaborated. The explanations are scientific	Battery is used to store the excess energy produced from the solar panel and windmill so that minimal energy is wasted and the energy can be used during emergencies.

Machine analysis of students' emotions

We applied an automated detection software to analyse students' emotions from their videos. This research purpose software was developed by our collaborators from Panasonic Industrial Devices Singapore. Called the "Human Sensing Software", this software has been configured to measure 7 basic emotions labels including: Neutral, Fear, Disgust, Happy, Sad, Angry, Neutral. Figure 2 shows the detection of some of these expressions from student faces from video data. The software analysed movement of eyebrows, eyes, mouth, cheeks and face to match to the basic emotion labels. Based on a 30 frames per second (fps) analysis, the software outputs the average of the emotions detected per second for each face that appeared in the video. Detection accuracy with testing datasets (5545 images with 14 subjects) averaged at 81.45% with the highest (94%) for "happy" emotion and lowest (66%) for "sad" emotion. To ensure reliability of the software for this study, we conducted manual coding with the same framing as the machine to access the accuracy and usefulness of the machine analytics.

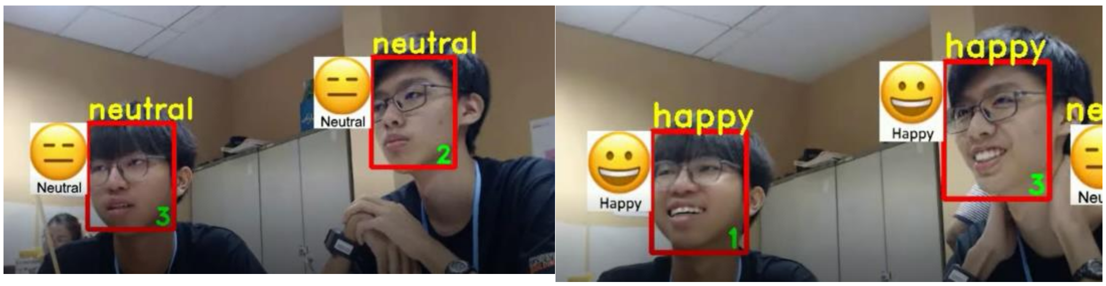


Figure 2. Sample of Happy emotion and Neutral emotion detected from machine.

Key findings

We present four key findings based on the detailed analyses of two students out of the five students in Group 6 (S6-1; S6-5) at the SKBDS.

Group discussion on Knowledge Forum more intense than face-to-face interaction

The group' idea improvement appeared more evident from their online discussion in a KF view "Group 6 Idea Journey". The group posted a total of 15 notes into the view. As illustrated below, students' posts in KF reflected a higher proportion of partially elaborated explanations and elaborated explanations (Figure 3) compared to their contributions in face-to-face discussion (Figure 4).

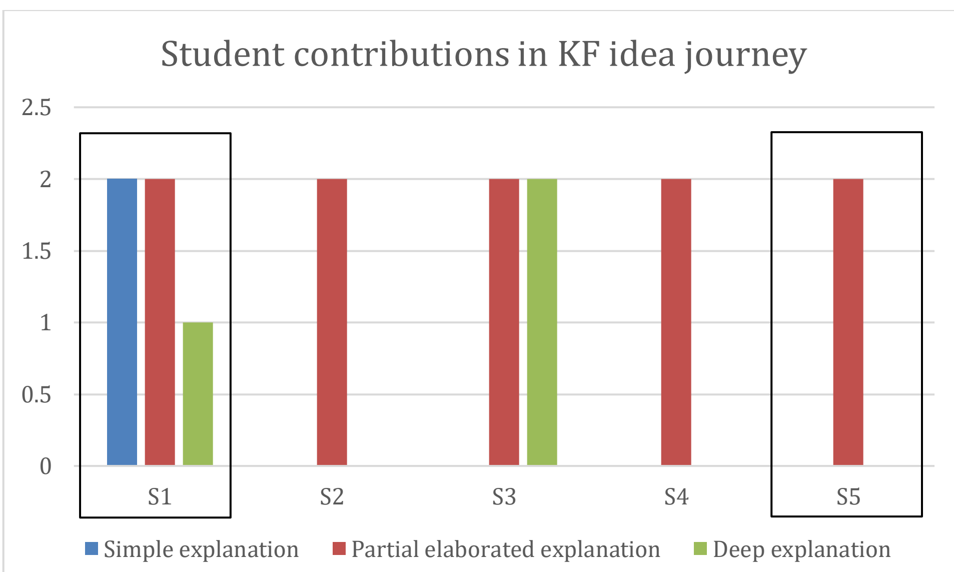


Figure 3. Contributions of ideas in Group 6 idea journey view

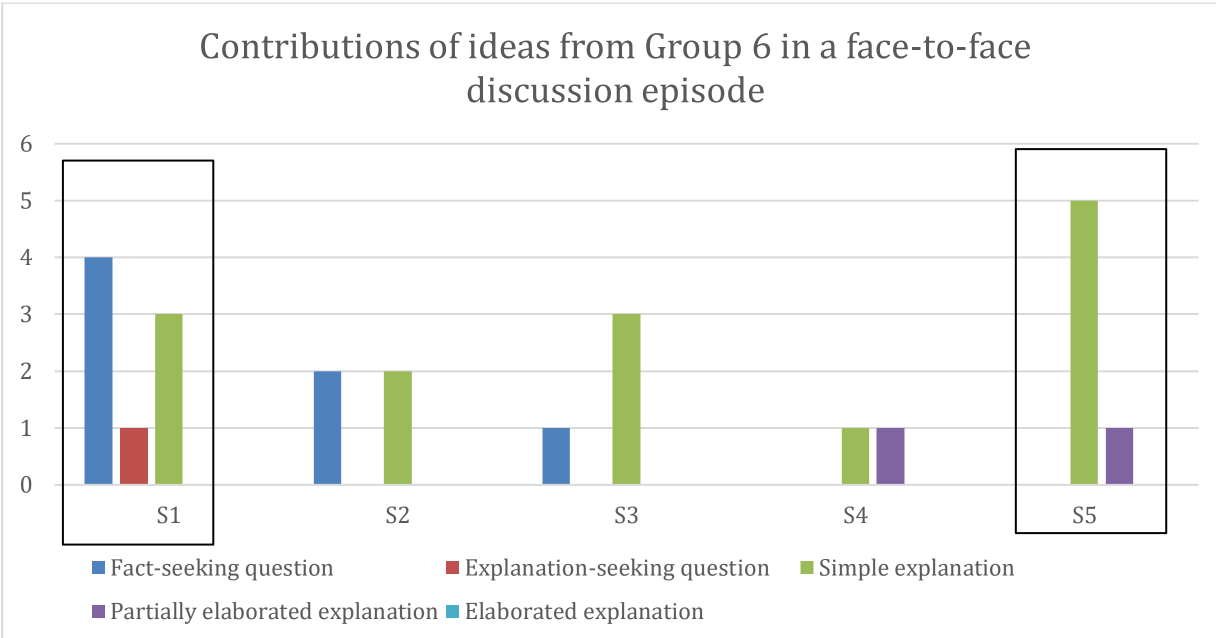


Figure 4. Contributions of ideas from Group 6 in a face-to-face discussion episode

Their notes showed additional information for understanding the prototype features such as battery and dome as well as some reasons or relationships for these ideas, as illustrated in Table 4. Compared to their contributions in the face-to-face discussion episode shown in Table 5, students' discussion in KF appears more intense. Notably, the analysis also suggested that the students, particularly student 1 (S1 or G6-1) who contributed 5 notes of the 15, contributed elaborated explanations on the prototype idea and asked question to engage in further idea improvement.

Table 4. Examples of students' elaborated explanations of their prototype design.

No	Title	Student	Content	Type of contribution
1	Water tank + funnel	S1	Independent source of water which is collected from the rain When there is insufficient water due to dry spells, water is obtained from pub tap which is connected Water is constantly recycled in this way	Partially elaborated explanation
2	Battery	S3	Battery is used to store the excess energy produced from the solar panel and windmill so that minimal energy is wasted and the energy can be used during emergencies.	Elaborated explanation
3	Our favourite part	S1	Our favourite part is the retractable dome. It is able to reflect light back to the plants and we really like the concept behind it. We like that we are combining both nature and technology to solve our problems in our own way. The shape also reflects light in random directions instead of straight back, distributing it evenly. To solve certain problems which may come, such as a possible disease infecting the plants, we suggest regular checkups by experts on the wellbeing of the plants.	Elaborated explanation
4	Dome	S3	The dome is at the top of the structure, which is retractable. It is opened during the day and closed at night to prevent light pollution and not let light within escape and go to waste.	Elaborated explanation

Table 5. Illustration of students' contributions in face-to-face discussion.

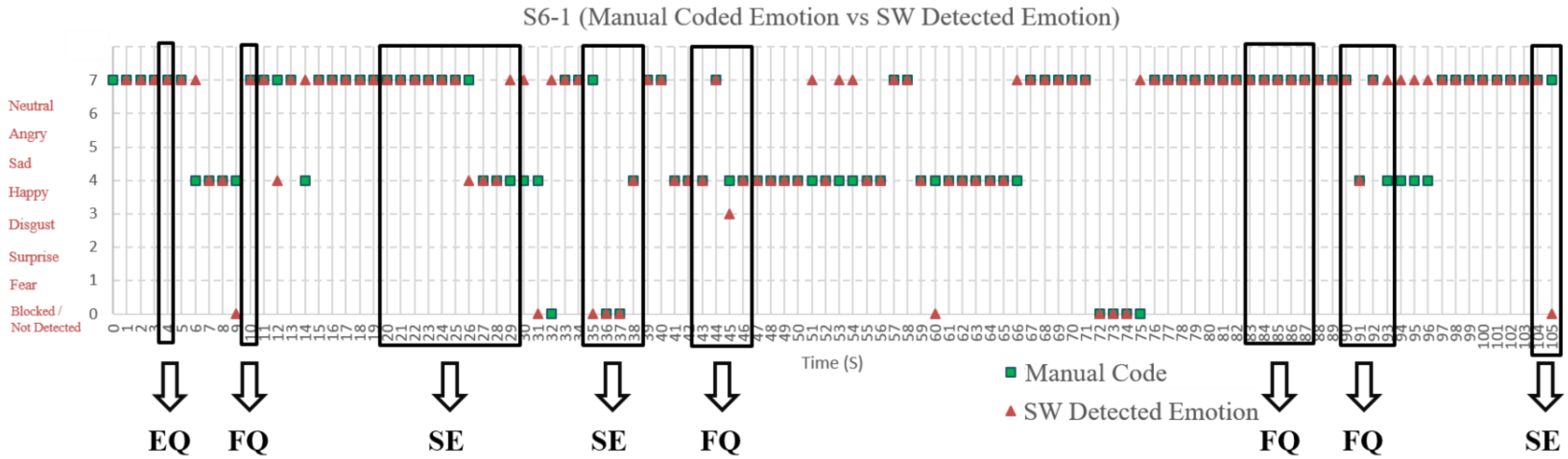
Time	Speaker	Content	Type of contribution
00:01:23	S1	solar panel can be waterproof or not?	Fact-seeking question
00:01:27	S5	yah easily waterproof	Simple explanation
00:01:30	S1	cause raining, (what if it rains)	Fact-seeking question
00:01:35	S3	then make it waterproof lah	Simple explanation
00:01:37	S4	I thought it's already waterproof	Simple explanation
00:01:39	S3	yah=	
00:01:39	S5	cause it is already water proof	Simple explanation
00:01:40	S3	it's already waterproof?	Fact-seeking question
00:01:42	T	cause if it's already waterproof the we can=	
00:01:44	S1	if it doesn't work then the windmill will take over	Simple explanation

Differences between students in contributions in face-to-face discussion (S6-1 more probing than S6-5)

When we studied a short two minutes segment of the group's face-to-face discussion on day 2, the discussion pattern inclined toward idea sharing as students mainly posed asking fact-seeking questions such as position of a solar panel and they contributed brief and unelaborated explanations such as whether solar panel was waterproof (Table 5). Notably, student 1 and student 5 (S5 or G6-5) appeared to contribute more to this discussion (Figure 3), one of students (S1) was consistent to the analysis on knowledge forum. Specifically, S1 asked questions in relation to positioning the solar panel and the function of a dome. While S5 provided suggestions such as placing the solar panel inside a dome and using sensor to activate the opening and closing of the dome. Student 3 and 4 were observed to be working on prototype building at times.

Similar expressions in both S6-1 and S6-5 from machine analysis of facial expression

Machine analysis of these two students (S1 and S5) showed that S1 displayed "happy" emotions in two occurrences of asking fact-seeking questions and providing simple explanations (see SW detected label in Figure 5a and 5b). Likewise, S5 displayed "happy" emotions in three occurrences of asking fact-seeking questions. However, neutral emotion does not mean that students were not engaged. Take S1 for instance, at the timestamp of 00:00:04, the machine detected neutral emotion when the student was asking an explanation-seeking question "so if it's inside the (building) how the solar panel receives light?" Similarly for S5, at the timestamp of 00:00:29 to 00:00:35, the machine also detected neutral emotion when student 5 was providing a partially elaborated explanation to explain the use of a daylight sensor. A researcher performed manual coding to check and validate these emotions detected from the machine (see manual label in Figure 5a and 5b). The results showed high correspondence in happy and neutral emotions but no validation for machine detection of sad, disgust and angry from the two students.



FQ – Fact-seeking question; EQ – Explanation-seeking question; SE – Simple explanation; PE – Partially elaborated explanation; Elaborated explanation

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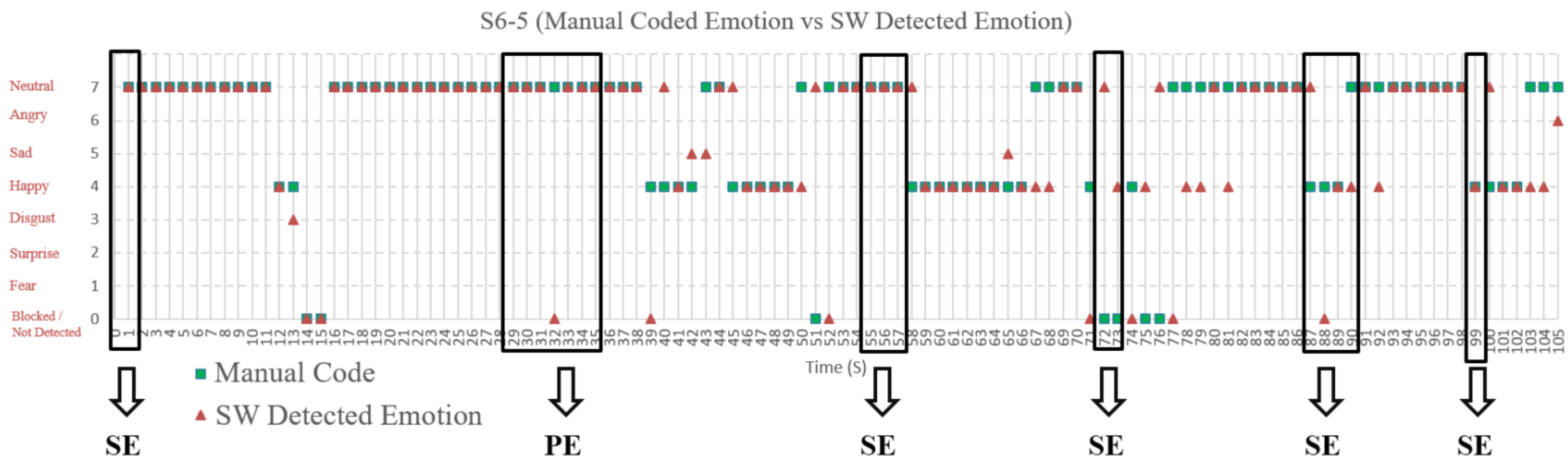

FQ – Fact-seeking question; EQ – Explanation-seeking question; SE – Simple explanation; PE – Partially elaborated explanation; Elaborated explanation

Figure 5a & 5b: Video analysis of students' emotions in illustrated episode (Top: Student 1; Bottom - Student 5)

Self-reporting emotion survey at 14 points throughout the two-days engagement

When triangulated with students' self-reports from the emotional survey on both days, we found a distinct difference in their rating on frustration on both days between the two students as shown in Figure 6. The findings from other items in self-report such as "feeling challenged", "feeling that I have learned", "feeling cooperative, "feeling irritated" and "feeling interested" were found to be almost comparable between the two students.

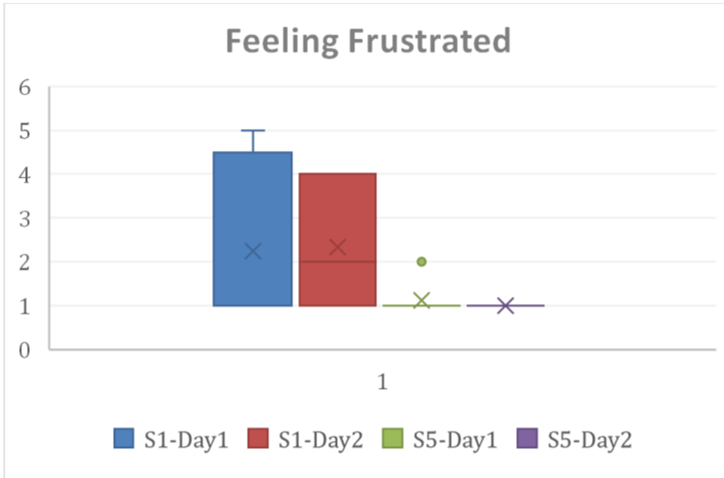

Figure 6. Difference in Frustration level between S1 and S5 from self reports.

Discussion and implications

MMLA represents a way forward to further understand students' emotional learning in KB. Although findings were based on a very short episode, the automated detection illuminated different student emotions as they engaged in idea sharing and construction. For instance, students who actively contributed questions and explanations to improve the group idea displayed higher occurrences of joy and neutrality, a finding that concurred with that reported by Zhu et al. (2019) on positive emotive indicators of students' idea improvement. However, more work is needed to understand these correlations, as we also found occurrences of joy and neutrality when students were not contributing to the idea improvement. Furthermore, ongoing work is also needed to understand other emotions. The software also detected emotions of sad, angry and disgust but manual cross-checking done by a researcher validated only neutral and happy. The accuracy between manual and machine coding is 60% to 70% which leaves much space for improvement before such emotion analysis can be made useful to teachers in their day-to-day practice. The difficulty in levelling up the accuracy of machine learning is increased significantly in an authentic knowledge building, collaborative learning situation where students are able to interact with other students and teachers and freely move around to build prototypes, to scribe ideas on papers and worked on their computers. The tracking functions in these cameras were unable to capture students' facial expression when they move around in a robust learning environment.

The nuances revealed from our analyses corroborate with earlier research on the productive interaction of emotions such as confusion or frustration with learning (Zhu et al., 2019), especially when these emotions that are usually deemed undesirable by teachers. In this study, we found that student S1 who reflected a significant level of frustration in his self-reporting survey was shown to have a higher participation rate on KF and face-to-face discussion. From his contributions, he appeared to be the most active (out of the five students) in advancing the group prototype idea. It is therefore essential to calibrate our machine analysis to increase its sensitivity to detect these "important" emotions that can challenge teachers' perception of students' engagement and interest in the topic. Lastly, our findings are not generalizable across groups and may not be representative of typical student participation in face-to-face discussion within the group. However, the short video data analysis provided a case for support to argue that idea improvement in KB requires emotional regulation. Ongoing work involves exploring relationships between student emotions with other types of discourse moves such as reasoning, reflecting or synthesizing ideas which may indicate students' collective idea building as well as data triangulation based on other data sources such as physiological data to validate different student emotions.

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