Design Collaborative Formative Assessment for Sustained Knowledge Building Using Idea Thread Mapper

Jingping Chen, University at Albany and University of Electronic Science and Technology of China,
chgping@gmail.com
Jianwei Zhang, University at Albany, jzhang1@albany.edu

Abstract: This design-based study investigated collaborative formative assessment for knowledge building in two comparable Grade 6 science classrooms. Students assessed their collective knowledge progress using the Idea Thread Mapper (ITM)—a timeline-based collective discourse mapping tool—and planned for further efforts to address deeper issues. Analysis of students' online discourse and individual portfolio notes suggests the positive impact of the assessment on the community's knowledge building discourse as reflected in students' idea-deepening and idea-elaborating questions, refined explanations, and build-on connections; and on student scientific understandings as documented in their individual portfolio notes.

Introduction

Designing new assessments in line with evolving conceptions of how people learn is a central challenge in the learning sciences (Pellegrino, 2014). Research on collaborative learning and knowledge building has demonstrated new learning designs and classroom practices to develop deep knowledge and high-order competencies, including knowledge-creating capabilities (Scardamalia & Bereiter, 2006; Stahl, 2006). The pedagogy of collaborative knowledge building requires new learning assessments to measure both individual and collective knowledge advances and feedback on students' inquiry and collaboration as the process unfolds. The purpose of this study is to design and examine formative, collaborative assessment in the context of knowledge building communities. In a knowledge building community, members continually advance the state-of-the-art understanding of core issues in a focal area(s) through interactive idea input. They build collective knowledge as a social product of their community beyond individual notions and concepts (Scardamalia & Bereiter, 2006). The community's collective knowledge is represented through the conceptual artifacts developed and shared by the community members as they engage in idea-transforming discourse. Using collaborative online platforms such as Knowledge Forum, students contribute and build on one another's ideas over time to address deepening issues and develop increasingly sophisticated understandings. Deeper challenges are identified as progress is made, leading to sustained cycles of inquiry and progressive discourse (Hakkarainen, 2003; Zhang et al., 2007). Existing assessments primarily focus on individual learning processes and outcomes, and capture very little of the sustained, collaborative knowledge building processes that continually deepen and evolve. Therefore, designing new assessment for sustained, collaborative knowledge building becomes a critical challenge (Scardamalia et al, 2010; van Aalst & Chan, 2007).

The current study explores the design of assessment for sustained knowledge building in light of a set of key principles deprived from the literature. These include:

(a) Student-directed assessment with high-level collective responsibility: Sustained knowledge building requires students to take on collective responsibility for high-level decisions, including setting goals, long range planning, and progress tracking (Scardamalia, 2002). Assessment for knowledge building hence needs to be student-directed (van Aalst & Chan, 2007). Student make collective decisions about what should be investigated and assessed, based on what evidence, and what further actions should be carried out based on the results of the assessment. They are active agents for the internal assessments of their own work instead of passive test-takers in the external assessments (Scardamalia & Bereiter, 2006).

(b) Collaborative assessment of collective knowledge in relation to individual learning: Assessment for knowledge building needs to capture both collective and personal knowledge advancement (Scardamalia et al, 2010; van Aalst & Chan, 2007). A community's progress and practices in collective knowledge advancements are evident through its trajectories and patterns of knowledge building discourse (e.g. deepening ideas and questions) and knowledge artifacts generated. Students' individual knowledge advancements are reflected in their contributions to the community's discourse as well as their personal artifacts generated to support their own learning and reflection.

(c) Formative and transformative assessment to inform sustained idea improvement: Beyond existing assessments that characterize student' performance and progress in past learning (Mislevy & Haertel, 2006), assessment for knowledge building needs to provide ongoing feedback to support sustained idea improvement and collective engagement (Scardamalia & Bereiter, 2006) and scaffold future learning and inquiry (Schwartz & Arena, 2013; Shepard, 2000). The collection and use of assessment information becomes an integral part of the ongoing learning process (Pellegrino, 2014).

(d) Technology-supported assessment using analytic tools: Assessment for knowledge building based on ongoing discourse and student artifacts requires technology support to analyze rich data and provide easily interpretable results and visualizations. Various analytic tools have been developed to capture cognitive and social dynamics of collaborative learning and knowledge building using sematic, lexical, and social network analysis (Scardamalia et al., 2010; Zhang et al., 2009). However, these new assessment and analysis tools mostly remain as research tools; they are often too complicated for students to use and interpret (Zhang & Chen, 2012).

Research by van Aalst, Chan and colleagues (Lee, Chan, & van Aalst, 2006; van Aalst & Chan, 2007) showed the positive impact of student-directed, formative assessment on collaborative knowledge building. In their research students created e-portfolios to identify productive examples of knowledge building contributions and discourse episodes. However, with the lack of effective means to making collective knowledge progress visible in current online discourse environments (Zhang, 2009), it is cognitively challenging for students to monitor and assess collective knowledge progress based on distributed discourse in long-term inquiry. Guided by the above-mentioned principles, this research tests a design of collaborative formative assessment for knowledge building supported by a timeline-based collective discourse mapping tool: the Idea Thread Mapper (ITM) (Chen, Zhang, & Lee, 2013). ITM interoperates with Knowledge Forum (Scardamalia & Bereiter, 2006) and potentially other collaborative learning platforms. In these online environments, student ideas are presented in distributed postings (e.g. notes) and responses (build-ons) in extended online discourse. To help students monitor what is going on in the discourse and interpret the collective focuses and progress, ITM incorporates conceptual threads of inquiry--"idea threads" (Zhang et al., 2007)--as a larger, emergent unit of ideas in online discourse. ITM allows students to create idea threads through selecting certain discourse contributions (notes) for various focal objects of inquiry. Each idea thread is composed of a sequence of discourse entries (possibly several build-on trees) contributed by a subset of the members of a community to address a shared problem or conceptual topic. The collective knowledge of the community in a whole inquiry-based initiative is further represented as clusters of idea threads that address interrelated problems. With the authors and build-on connections identified, the idea threads are displayed on a timeline as an "idea thread map" (left side of Figure 1). The progress in each idea thread is further made transparent by students through co-authoring a "Journey of Thinking" synthesis that includes three sections: *We want to understand, We used to think…and we now understand…, We need to do more* (right side of Figure 1). Idea threads and thread-based syntheses are co-editable by members of the community, with each version recorded for later review. New analytics tools in ITM support auto-clustering of notes based on thread topics and analysis of discourse contribution types (e.g. questioning, explaining) in each idea thread to support student reflection.

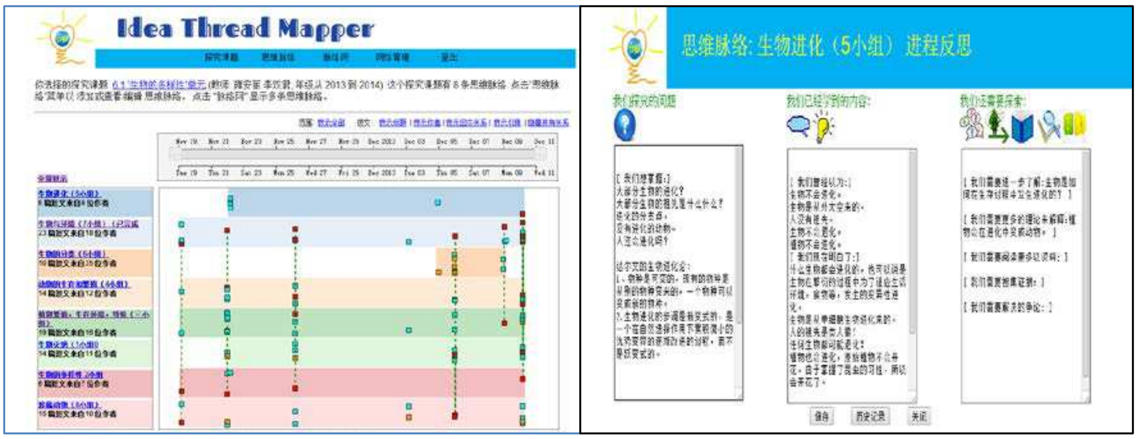

Figure 1. A map of idea threads (left) and a "Journey of Thinking" synthesis (right) created by one of the Grade 6 classrooms in this research studying biodiversity. Each colored stripe represents an idea thread extending from the first till the last note contributed addressing a shared focal problem. Each square represents a note. A dotted vertical line shows notes shared between different threads discussing interrelated issues. The "Journey of Thinking" page (right) shows students' co-authored reflection on what we need to understand, "big ideas" learned, and what we need to do in the next step.

Existing research suggests that ITM can support collective meta-discourse and reflection among students: to review ongoing discourse contributions to formulate shared focuses and goals of inquiry, monitor how ideas have been advanced in unfolding lines of inquiry, synthesize insights, idea connections and deeper actions to be taken by community members (Zhang et al., 2015). The current research further extends the ITM-aided discourse review into a systematic design of collaborative assessment to leverage sustained knowledge building. In light of the related literature (Scardamalia et al., 2010; van Aalst & Chan, 2007; Zhang et al., 2009), the collaborative assessment design focuses on three essential aspects of knowledge building: collective knowledge, evidenced through sustained and progressive discourse contributions to advancing various lines of work in the community; social dynamics of collaboration, evidenced through the active participation, idea connection, and distributed engagement of the members; and student individual understanding, revealed through their personal reflection on what they have learned. Students reflectively assess each aspect of knowledge building focusing on three questions underpinning formative assessment (Pellegrino, 2014; William & Thompson, 2007): (a) to define where we need to go; (b) to reflect on where we are now; and (c) to reflect on how we will go there by making productive moves.

To be specific, in this study students used ITM to review their discourse to identify collective themes and goals of knowledge building on the basis of the diverse range of questions and interests represented in their discourse and work. They also synthesized the "big ideas" learned and gaps using ITM's Journey of Thinking feature. To assess their social dynamics, they reviewed their participation in each idea thread and build-on connections as reflected in the social network graphs. As an extension of the collaborative assessment, each student further self-assessed his/her individual knowledge development through writing portfolio notes that summarize what has been learned from the whole community's work. By examining the idea thread maps, social network graphs, and portfolio notes, students identified strengths and advances of their work as well as weak areas and potential connections to be addressed in future inquiry. Based on discussions of these findings, they constructed plans to deepen their collective inquiry, refine collaboration, and increase personal contribution.

This design-based research was conducted to test and refine the above assessment design in two elementary classrooms. The process of the assessment, including the role of the teacher, was analyzed using video analysis and reported in Chen (2015). The current paper focuses on the role of the assessment in sustaining knowledge building. Our research question asks: In what ways does the collaborative, formative assessment support collaborative deepening moves in the community's online discourse and advancement of student personal understanding?

Method

Classroom contexts

This study was conducted in two comparable Grade 6 classrooms at Zongbei Elementary School in Chengdu, China. The two classrooms had been implementing knowledge building pedagogy using Knowledge Forum (Scardamalia & Bereiter, 2006) for two years. Students in each classroom (39 students in class A, and 42 in B) studied two science units—energy and biodiversity—over a four-month period. The two classrooms were taught by the same science teacher in cooperation with an ICT (Information and Communications Technologies) teacher who supported the online discussions.

Research design

This design-based study (Collins, Joseph, & Bielaczyc, 2004) adopted a two-phase, time-lag design. In phase/Unit 1 focusing on energy, only class A conducted ITM-aided collaborative assessment; in phase/Unit 2 focusing on biodiversity, the assessment was refined and extended to both classrooms. The impact of collaborative assessment in the knowledge building practice was examined by comparing Class A to B in phase 1 and comparing Class B' performance between the two phases.

The inquiry in each unit lasted for eight weeks. Each week they had four 40-minute lessons, typically two focusing on face-to-face activities and two for online discussions. The assessment was first implemented in Week 4. The community engaged in the following activities to assess its collective knowledge advancement:

(a) Setting focus: The community members reviewed their ongoing discussions to identify what they need to understand, represented as shared, high-interest themes of inquiry. The students first generated a "theme list" in their notebooks, and then proposed their themes to the community. Through a whole class discussion the community reviewed the themes and their connections, and co-created a list of shared themes of inquiry, as the assessment focus.

(b) Collecting evidence: Based on the shared focal themes of inquiry, the students formed into groups each of which used ITM to identify important Knowledge Forum notes for each focal theme of inquiry, as an idea thread. The idea threads were further co-refined through group discussions to remove the unrelated notes, add more notes, highlight key notes. Through reviewing the notes in each idea thread, each group co-authored a "Journey of Thinking" synthesis to highlight the important ideas and questions.

(c) Generating feedback: With the map of idea threads projected on a screen, the community collaboratively interpreted the processes and progress of collective knowledge advancement, using intensive discourse contributions, connections, highlighted notes, and "Journey of Thinking" syntheses in the different idea threads as indicators of collective advancements. Through the collective review, students identified important insights gained as well as gaps and challenges to be addressed in each line of inquiry and connections to be built across the inquiry themes.

(d) Planning: Based on the feedback, the community then made two types of plans to deepen their knowledge building work: in groups they made plans for deeper inquiry in their focal idea threads, and as a whole class they generated plans and suggestions for their whole inquiry initiative to guide the work of all members.

Extending the reflection on collective knowledge, the community reflected on their ways of collaboration with the social network analysis tool that shows who had read and who had built onto whose notes. Through interpreting the social network graphs, they reflected on possible ways to improve their participation and social connections. Informed by the collaborative assessment, each student further wrote a portfolio note to reflect on what he/she had learned about the various inquiry themes of the community and how they would better contribute to the collective knowledge work and improve their own learning.

Guided by the collaborative and individual plans, students conducted further inquiry for two more weeks. Near the end of the unit, the students conducted another round of assessment to update their idea threads (e.g. adding new Knowledge Forum notes), revisit the idea thread maps, and update their individual portfolio notes. The assessment design was refined based on its implementation and data analysis in Unit 1. The major changes were to create a more connected and smooth flow of the assessment activities, help students understand the purposes of the activities through discussions, and integrated the assessment information (e.g. social network graphs and ITM maps).

Data sources and analyses

The data sources included online discourse, personal portfolio notes, social network data of the online discussions, and the graphical and textual representations on ITM including idea threads, idea thread maps, and Journey of Thinking syntheses.

Content analysis (Chi, 1997) was conducted to gauge the quality of the knowledge building discourse before and after the assessment. Knowledge building discourse is characterized by progressive moves to identify deepening problems and develop increasingly sophisticated explanations (Hakkarainen, 2003; Scardamalia & Bereiter, 2006; van Aalst, 2009). Based on our prior studies (Zhang et al., 2007; 2009), our coding scheme first identified initial notes that posted questions, and classified the questions as basic fact-seeking questions (e.g. what) vs. deeper explanation-seeking questions (why and how); idea-initiating wonderments vs. idea-deepening questions and idea-clarifying questions. We then coded student build-on notes to examine students' interactive input based on theorizing and explaining (T), using evidence (E), referencing sources (R), connecting and integrating (C), and designing and applying (D). Theorizing/explaining included five sub-categories: intuitive explanations (T1i), alternative explanations (T1a), refined explanations (T1r), clarifying explanations (T1c), and suggestions (T1s) (see the coding scheme at http://tccl.rit.albany.edu/papers/Coding-scheme.pdf). The density of the build-on interaction (i.e. who had built on whose notes) was further analyzed using social network analysis.

Students' individual portfolio notes were coded by two independent coders through content analysis focusing on the scope of knowledge, depth of understanding, and connectedness of ideas. To examine the scope of student personal understanding, each portfolio note was coded based on the list of the themes covered by the community's online discussions. Student ideas related to each theme were coded for depth of understanding using two well tested four-point scales (Zhang et al., 2007; 2009): scientific sophistication (1=pre-scientific, 2=hybrid, 3=basically scientific, to 4= scientific) and epistemic complexity (1=unelaborated facts, 2=elaborated facts, 3=unelaborated explanations, and 4=elaborated explanations). Student ideas related to each theme were further coded based on connected/coherent vs. unconnected/scattered. A satisfactory inter-rater reliability was achieved: Cohen's Kappa = .84 for the coding of themes, .83 for scientificness, .82 for complexity, and .89 for idea connectedness.

Results

Content analyses of the knowledge building discourse

To investigate the role of the collaborative formative assessment in sustaining collaborative knowledge building, our analyses examined the changes in the knowledge building discourse before and after the assessment between the two classrooms based on questions raised and build-on moves to generate and improve ideas.

Questioning moves in the online discourse

Table 1 reports the distribution of the different types of questions in the online discourse of the classroom A and B before and after the assessment activities. In Unit 1 for the energy study, only class A implemented the assessment design. In Unit 2 for the biodiversity study, both classrooms implemented a refined version of the assessment design.

Table 1: The frequencies and percentages of different types of questions raised in the discourse of the two communities before and after the assessment in the two units of study.

		Fact-seeking	Explanation-seeking	Idea-initiating	Idea-deepening	Idea-clarifying
Class A Unit 1 (ITM assessment)	Before	30	4	5	3	3
		66.67%	8.89%	11.11%	6.67%	6.67%
	After	2	5	3	10	3
		8%	20%	12%	40%	12%
Class B Unit 1 (no ITM assessment)	Before class A's assessment	32	2	3	7	15
		52.46%	3.28%	4.92%	11.48%	24.59%
	After class A's assessment	5	3	0	2	7
		26.32%	15.79%	0%	10.53%	36.84%
Class A Unit 2 (refined ITM assessment)	Before	25	14	3	7	6
		45.45%	25.45%	5.45%	12.73%	10.91%
	After	3	8	3	9	3
		10.34%	27.59%	10.34%	31.03%	10.34%
Class B Unit 2 (refined ITM assessment)	Before	28	6	9	2	3
		58.33%	12.5%	18.75%	4.17%	6.25%
	After	5	6	5	8	8
		15.63%	18.73%	15.63%	25%	25%*

Note. The percentages of some contribution types add up to over 100% because each note may be coded for multiple categories.

In Unit 1 before the assessment, fact-seeking questions (e.g. what, how many) dominated the discourse in both classrooms (66.67% for A and 52.46% for B), with very few higher-level questions such as explanation-seeking questions. A Chi-Square test shows no significant difference between the two classes ($p > .05$). After class A's assessment, class A generated more explanation-seeking (20%) and idea-deepening questions (40%) to explain reasons, relationships, specific mechanisms while class B generated more idea-clarifying questions (36.84%) and fact-seeking questions (26.32%) to search for and clarify information (χ^2 (12) = 132.76, $p < .05$).

In the Unit 2, raising factual questions was the dominant pattern of discourse in both classes before the assessment (45.45% for A and 58.33% for B). After the assessment, both classroom had a drop in factual questions and an increase in explanation-seeking and idea-deepening questions that are essential to sustained, progressive discourse for knowledge building.

Patterns of build-on notes

The network density of who had built on whose notes increased over time for each classroom in each unit of study. In Unit 1, a greater increase in the density was observed in class A (15.38%) after its assessment than in classroom B (10.19%) that did not use the ITM-aided assessment. In Unit 2 when both classrooms conducted a refined version of the ITM-aided assessment, both classes had a higher increase in the density (Class A: 17.29%; Class B: 18.54%).

Figure 1 shows the patterns of the build-on notes to generate and improve ideas in the online discourse before and after the assessment in the two classrooms. In Unit 1, before the assessment of class A, a majority of students' build-on notes in both classes contributed intuitive explanations based on personal experience (58.11%

for A and 41.58% for B) and referred to sources of information from readings (24.32% for A and 29.21% for B). After the assessment, class A contributed less intuitive explanations (decreased from 58.11% to 36%) and more refined/sophisticated explanations (increased from 5.41% to 20%). In contrast, class B brought in even more intuitive explanations (increased from 41.58% to 62%) with few notes contributing refined explanations (4.95%).

In Unit 2, before the assessment a majority of students' build-on notes in both classes were also intuitive explanations (55.46% for class A and 46% for class B), followed by referencing sources of information (26.05% for class A and 34% for class B). After the assessment students in both classes contributed less intuitive explanations (38.98% for class A and 35.71% for class B) and referencing sources (16.95% for A and 22.32% for B). The percentage of refined/sophisticated explanations increased for both class A (from 8.4% to 12.71%) and B (from 2.67% to 16.07%). The changes after the ITM-aided assessment in Unit 2 in both classrooms are consistent with the changes observed in Unit 1 for class A after its implementation of the assessment.

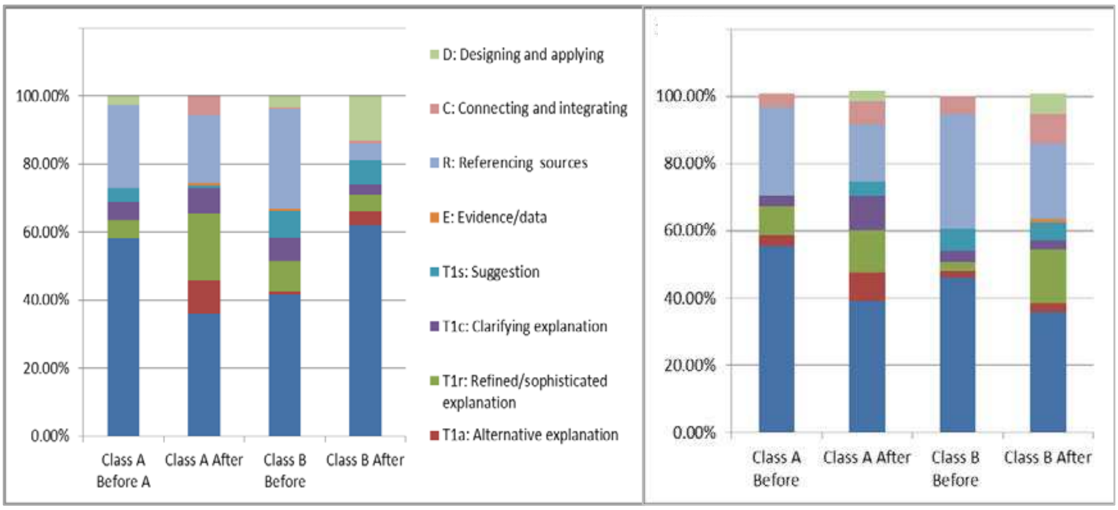

Figure 2. Patterns of the build-on notes before and after the assessment in the two classes in the two units: energy (left) and biodiversity (right).

Content analysis of individual portfolio notes

Table 2 reports the content analysis of student individual portfolio notes based on the themes of inquiry covered, depth of understanding about each theme as gauged based on the sum of two ratings, scientificness (1-4) and epistemic complexity (1-4), and percentage of inquiry themes with connected and coherent ideas.

Table 2: Evaluation of Personal Knowledge Advances Summarized in Student Portfolio Notes

	Class A			Class B		
	Themes covered M (SD)	Depth of understanding M (SD)	Connectedness of ideas M (SD)	Themes covered M (SD)	Depth of understanding M (SD)	Connectedness of ideas M (SD)
Unit 1: Energy	4.83 (1.84)	5.4 (1.89)	9.34% (18.22%)	4.26(2.11)	4.74 (1.76)	13.24 % (22.53%)
Unit 2: Biodiversity	5.11(1.57)	6.6 (1.44)	28.31% (26.70%)	5.41(1.97)	5.26 (1.7)	25.80% (27.99%)

Focusing on each of the three indicators, a two-way repeated measure ANOVA was conducted to compare the quality of the portfolio notes from the two classrooms in the two units of study. A significant between-class difference was found in depth of understanding ($F(1, 34) = 11.44$, $p < .05$) with class A outperforming B. The between-unit difference is significant in each of the three indicators, for the number of inquiry themes covered ($F(1,34) = 7.3$, $p < .05$), for the depth of understanding ($F(1, 34) = 23.49$, $p < .05$), and for connectedness of ideas $F(1, 34) = 18.67$, $p < .05$. The refinement of the collaborative assessment in Unit 2 led to improved results.

Discussion

This study tested a collaborative, formative assessment for knowledge building, which focuses on three major constructs: collective knowledge advancement, social dynamics, and individual understanding. Students played an active and collaborative role in each step of the formative assessment supported by their teacher: to identify shared focuses and deepening goals of inquiry as their discourse evolved; to collect and interpret evidence of idea contributions, advancement, and collaboration; and to generate feedback and guidance about how to address their deeper needs and gaps of knowledge through further inquiry. The ITM tool served to represent their collective focuses of inquiry, make the collective progress in various lines of inquiry transparent for collective review, and support student efforts to reflect on their Journey of Thinking in terms of where they were going, where they were now, and what deeper efforts were needed. As the results indicated, this collaborative, formative assessment played an important, positive role to improve students' collective, progressive discourse as well as individual understandings. Specifically, engaging in the collaborative formative assessment using ITM helped students to engage in deeper knowledge building discourse through generating more explanation-seeking and idea-deepening questions. The ITM-aided assessment on idea progress in each line of inquiry, including summarizing focal problems, "big ideas" learned and deeper issues, served to catalyze student intentional efforts of progressive questioning. In response to the deepening questions and ideas from their peers, students' build-on notes contributed more refined and sophisticated explanations after the formative assessment.

The positive association between the assessment and the enhanced discourse quality should largely be attributed to the purposeful design of the collaborative formative assessment: to enhance student monitoring of collective knowledge and generate ongoing feedback to guide sustained idea improvement (Zhang et al., 2009, Zhang et al., 2013). Through the assessment aided by ITM's visualization and analytic tools, students made more informed reflection on which lines of ideas needed to be improved through what deeper actions and contributions. Small groups then planned on how to further advance each idea thread, and the class, as a whole, discussed collective efforts to improve the whole inquiry. Supported by the collaborative reflection, individual students made informed decisions about how to connect their individual interest, strength and resources with the community's needs.

The results also revealed a positive role played by the ITM-aided collaborative assessment to enhance students' personal knowledge gains as they advanced their collective knowledge. Class A with the collaborative formative assessment in Unit 1 demonstrated deeper understandings in student portfolio notes than class B. Significant improvements were observed from Unit 1 to 2. In Unit 2 that implemented a refined design of the assessment, students' portfolio notes addressed a broader range of inquiry themes that were explained using more scientific, complex, and connected ideas. The assessment helped students to have a reflective awareness of the important inquiry themes and idea advancements across their community's knowledge space, understand discourse contributions and connections in a temporal context, and connect ideas to generate coherent understandings. These results suggest that the refinement of the assessment in Unit 2 to support a more coherent flow of the assessment activities and integrated view of the assessment information helped to increase the effectiveness of the assessment. Of course, this two-phase research design cannot rule out the possible impact of the content topics (e.g. energy vs. biodiversity) on the complexity of student portfolio texts, although both topics are open-ended and relevant to student interest.

In conclusion, this research tested a collaborative formative assessment for knowledge building communities, with ITM mapping out the community's online discourse as unfolding conceptual trajectories of inquiry. In line with existing research on student-directed, technology-supported assessment for knowledge building (van Aalst, J., & Chan, 2007), this study found a positive role of the assessment in enhancing the progressive discourse of the community with deepening questions and refined explanations while supporting individual efforts to generate deeper and connected understandings. A condition to increase the effectiveness of such assessment is to integrate the assessment process coherently with the knowledge building process without causing much additional work among students. We are conducting research to refine the design of this assessment to integrate the activities and assessment information with an easy flow, supported by automated analyses in ITM that can assist students to cluster discourse contributions based on inquiry topics and review discourse contributions based on different types. Further research also needs to test this assessment design in other classroom contexts and content areas to elaborate the design and examine its impacts.

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