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Student-Generated Questions Fostering Sustainable and Productive Knowledge Building Discourse

Questions générées par les élèves Favoriser un discours sur le renforcement des connaissances durables et productifs

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Abstract

The role of questions in student learning is well recognized. However, the controversial issue of who should pose questions that direct inquiry continues: teachers or students? One perspective advocates that teachers generate questions as it assumes that students cannot generate high-quality questions. In contrast, Knowledge Building, a pedagogical approach that advocates transforming schools into knowledge-creation organizations, emphasizes student agency in generating authentic questions as they try to understand the world around them. This study examined the extent to which elementary students could generate questions and explore how student-generated questions help Knowledge Building discourse progress. Comparing question threads (i.e., a series of online notes started with questions) and non-question threads (i.e., a series of online notes not started with questions), we noticed that questions posted by students engaged them in sustainable and progressive discourses, which is central to Knowledge Building. Moreover, the content analysis of the data revealed that the threads starting with questions were more likely to end up with productive threads than the non-question threads.

Keywords: Knowledge building; Student-generated questions; Productive discourse; Sustainable discourse; Science education

Résumé

Le rôle de question pour l'apprentissage des étudiants est vraiment reconnu. Mais une question controversée est qui va poser les questions qui dirige l'enquête, les professeurs ou les étudiants? Une perspective souligne que les professeurs produisent les questions a cause que les étudiants ne sont pas capables de créer des questions de haute qualité. Une autre perspective souligne l'agence étudiante en posant les questions et suppose qu'un échec des questions généré par les étudiants peuvent avoir un résultat d'échec de la consolidation des connaissances. Cet étude examine le degré que les étudiants élémentaire sont capables de générer questions et explore comment les questions générées des étudiants aident la consolidation des connaissances du progrès de discours. Dans la comparaison d'un fil de questions (un série de notes en ligne qui ont commencé avec des questions) et un fil de non-questions (une série de notes en ligne non commencé par des questions), on a réalisé que les questions posé par les étudiants les ont engagés dans un discours progressive et durable. Cela est centrale dans la consolidation des connaissances. De plus, l'analyse du contenu des données a révélé que les fils qui ont commencé avec des questions était plus probable a finir avec des fils productive compare au fils de non-questions.

Mots clés: Développement des connaissances ; Questions posées par les étudiants ; Discours productif ; Discours durable ; Enseignement scientifique

Introduction

Researchers and educators have investigated the nature and types of questions and recognized the importance of students' questioning for learning and teaching (Chin & Osborne, 2008; Graesser & Olde, 2003). Questioning represents a thinking processing skill; it is "structurally embedded in the thinking operation of critical thinking, creative thinking, and problem solving" (Cuccio-Schirripa & Steiner, 2000, p. 210). There are different classifications of questions based on cognitive levels involved in responding to questions, i.e., input, processing, and output questions (Pizzini & Shepardson, 1991), the process of conceptual change, i.e., exploration, elaboration, and consolidation questions (Watts et al., 1997), and whether questions can lead to open investigations, i.e., investigable and non-investigable questions (Chin & Kayalvizhi, 2002).

Student-generated questions have the potential to direct students' learning and drive their knowledge construction, enhance their discourse quality, enable them to monitor and evaluate their learning progress, and sustain and even increase their interest and curiosity in learning topics. Furthermore, students' questions can help teachers diagnose students' understanding, stimulate further inquiry, provoke learning reflections, and evaluate students' high-order learning skills (Chin & Osborne, 2008).

These benefits of student-generated questions are essential to Knowledge Building, a pedagogical approach that advocates transforming schools into knowledge-creation organizations. Knowledge building usually starts with students' authentic questions while they are making sense of the world around them (Scardamalia, 2002). This knowledge-building approach supports them to take responsibility to sustain discourse and improve ideas by pursuing questions, theorizing, working with information, supporting discussions, and synthesizing diverse ideas (Chen et al., 2017; Scardamalia & Bereiter, 2006). Idea improvement is about continually asking whether a theory (i.e., student-generated explanations in Knowledge Building) could explain existing phenomena, identifying the weakness of theories, broadening explanations to encompass more new facts, achieving greater explanatory coherence, and deepening explanations of why theories work (Thagard, 2007). Discourse sustainability is important because a community that fails to sustain the discourse may only have knowledge sharing rather than knowledge construction or progressive inquiry discourse (van Aalst, 2009).

In the knowledge-building context, questions are usually classified as factual questions (e.g., who, what, where, and when questions) and explanatory questions (e.g., why or how something works questions) (Hakkarainen, 2003; Lai & Law, 2013; Resendes, 2014). Zhang et al. (2018) added the sub-category of idea-deepening questions to differentiate whether a question is asked to initiate or to sustain an inquiry. Scardamalia and Bereiter (1992) argued that compared to basic information questions (i.e., factual questions), wonderment questions that reflected students' curiosity and puzzlement had a greater potential for advancing students' conceptual understanding. Our explanatory study (Khanlari et al., 2017) with a dataset from one Grade 4 class suggested that student-generated questions tended to lead to longer inquiry threads and were more likely to lead to more productive threads in science learning. With a larger dataset and more participants, this study aimed to examine further the extent to which students in a knowledge-building community could generate factual and explanatory questions, and whether student-generated questions could engage fellow students in sustainable discourse and community knowledge advancement in science learning.

Literature Review

Student Generated Questions

As briefly discussed in the introduction, student-generated questions have several documented benefits that can be classified into the following aspects. First, student-generated questions can help students shift from passively acquiring knowledge to actively constructing their knowledge by negotiating a fit between prior knowledge and new information (Osborne & Wittrock, 1985). Also, questions can initiate hypothesizing, predicting, thought experimenting, and explaining processes and may also help students construct missing pieces in their knowledge structures or resolve their understanding conflicts (Chin & Brown, 2000). Second, questions foster the development of students' discourse and discussions. When students co-construct or co-create knowledge with their peers, questions are embedded in their discourse, and these questions help to scaffold ideas, encourage learners and peers to further think about and elaborate on their ideas, and negotiate meaning in their construction space (Chin & Osborne, 2008). Third, questions can help students self-regulate their understanding and learning, for instance, helping detect inconsistencies between their prior knowledge and new information (Black et al., 2002). Finally, questions can help students take control and ownership of their learning and may enhance their interest in learning and motivation (Chin & Osborne, 2008). For example, Chin and Kayalvizhi (2005) found that the Grade 6 students they studied described being "happy," "excited," or "proud" about posing their investigating questions.

Previous studies have researched how to support students in generating questions and how student-generated questions may influence students' learning performance and engagement positively. One study by Hsu and Wang (2018) found that an online puzzle-based game learning system and a student-generated question strategy enhanced students' algorithmic thinking skills and willingness to participate in the activity. As well, Yu (2009) created an online student question generation system to support students' learning activities by adopting various scaffolding techniques and mechanisms. She found that scaffolding (e.g., reflective social discourse, process prompt, process model) embedded in the system was perceived to provide high levels of support.

Similarly, other studies found that in the Knowledge Forum, scaffolding such as "I need to understand," "I wonder why," and "this theory cannot explain" can be used to support students in generating questions and building theories (Scardamalia, 2004; Zhu et al., 2018).

Concerning the nature and types of student-generated questions, a common distinction is factual questions and explanatory questions (Hakkarainen, 2003; Lai & Law, 2013; Resendes, 2014). Factual questions (i.e., who, what, where, and when) seek information and definitions, whereas explanatory questions (i.e., how and why) seek reasons and mechanisms. Explanatory questions are crucial for progressive inquiry because they cannot be satisfactorily answered without elaborating on an explanation (Hakkarainen, 2003). Further, explanatory questions can push inquiry forward in new and promising directions. Factual questions, in contrast, tend to produce fragmented pieces of knowledge, although these could potentially serve as evidence to justify theories (Resendes, 2014).

Knowledge Building and Knowledge Forum

Knowledge building is not about getting the correct answers as quickly as possible. Instead, it concerns improving ideas and advancing collective knowledge on problems and questions of value to the community. To achieve this goal, asking deep and rich questions that can spark and sustain a prolonged Knowledge Building inquiry is crucial (Resendes & Dobbie, 2017).

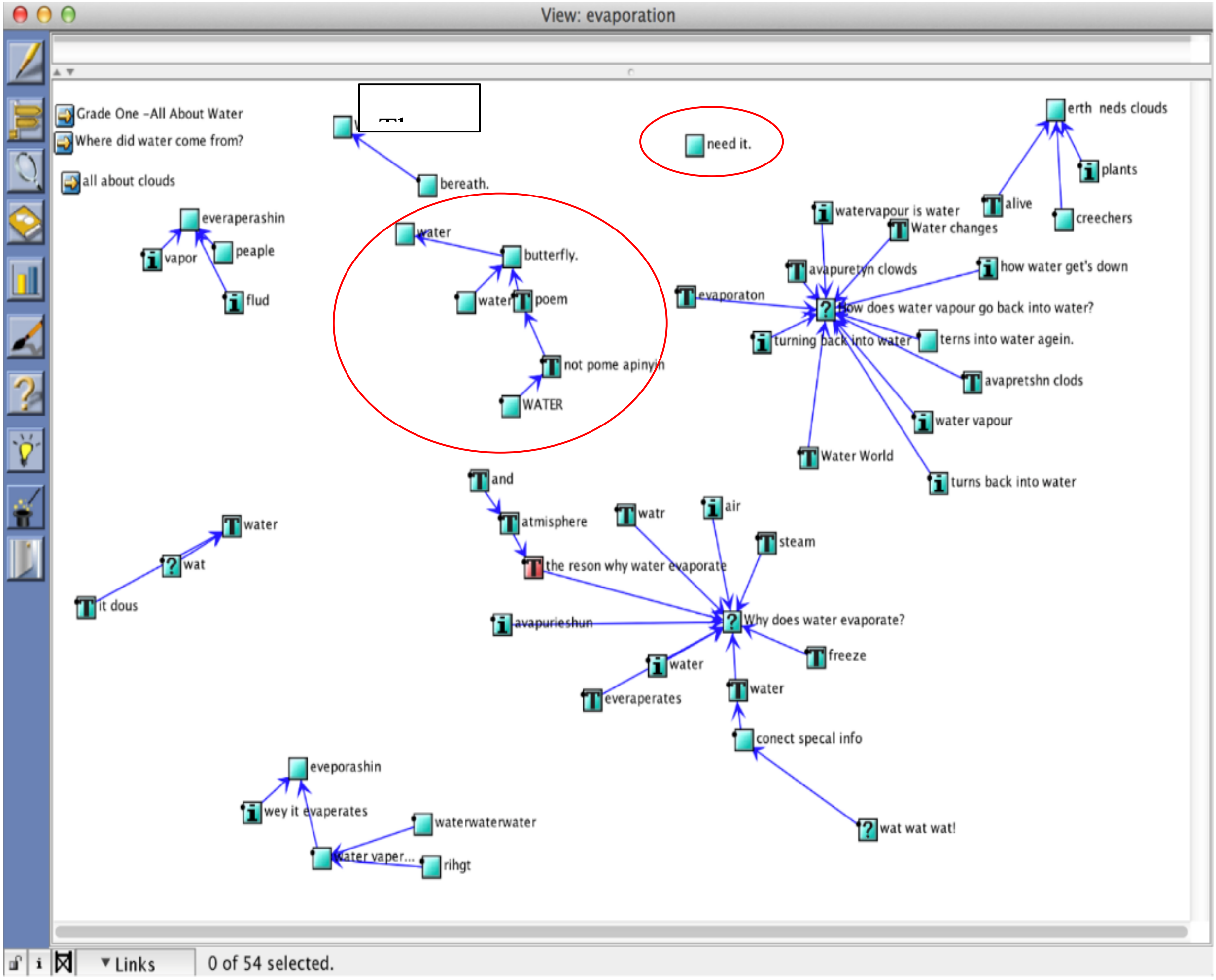
In Knowledge Building, students take responsibility for setting goals, engaging in long-range planning, using different ideas to spark and sustain ideas, monitoring idea coherence, and assessing their work (Scardamalia, 2002). These responsibilities align with the functions and advantages of student-generated questions. Knowledge building places students' ideas at the centre, and student-generated questions initiate and drive their collaborative inquiry. A key knowledge-building principle, engaging students in real ideas and authentic problems, means focusing on the ideas that students come up with and the questions they care about, not what others decide as engaging (Scardamalia, 2002). Rather than solving given problems, students learn to mine the world around them for interesting issues and challenges and discover opportunities for building theories and knowledge advancement. In pursuing real ideas and authentic problems, students engage in sustained creative work with ideas through Knowledge Building discourse (Scardamalia & Bereiter, 2006).

Knowledge building discourse can happen in physical classrooms. Students can share ideas and ask questions through face-to-face "Knowledge Building talk" (Reeve et al., 2008). In Knowledge Building talks, all class members, including the teacher, sit in a circle (ideally) so everyone is at the same level and can see and talk to everyone else.

Figure 1 shows the interface of Knowledge Forum (version 4), an online platform supporting students' collaborative knowledge creation discourse (Scardamalia, 2004). As one of the earliest computer-supported collaborative learning (CSCL) environments, Knowledge Forum shares the benefits of collaborative learning technologies such as supporting collaboration skills and knowledge creation, making social interactions a source of cognitive advancement, improving the equality of participation and depth of analysis, keeping track of students' collaborative work, and enabling time and space flexibility (Campbell & Stasser, 2006; Fjermestad, 2004; Resta & Laferrière, 2007). Furthermore, Knowledge Forum has several specific affordances. First, it provides scaffolds to support students' question development and theory building (Scardamalia & Bereiter, 1983), and these scaffolds can be used in any order and customized to meet students' emergent needs (Zhang et al., 2011). Another feature of Knowledge Forum is the rise-above function which allows users to connect, synthesize and archive different ideas, identify gaps, and plan for future inquiry directions in a public space open to all community members. Furthermore, various analytical tools can be used to assess students' activities, social networks, semantic networks, and discourse to improve the awareness of students and teachers concerning their Knowledge Building (Chen & Zhang, 2016; Zhu & Kim, 2017).

Figure 1

The Interface of Knowledge Forum v.4 Used by the Participants



Sustainable and Productive Knowledge Building Discourse

A thread-level analysis of Knowledge Building discourse helps researchers understand the development of ideas, whether ideas are improved, and the extent to which questioning contributes to collective knowledge advancement (Lai & Law, 2013). Previous research mainly identified threads in two ways. First, some researchers (Hewitt, 2005; Hewitt & Teplovs, 1999) adopted the natural relations between notes in the Knowledge Forum when discussing discussion threads and considered a thread as a series of physically connected notes linked by building on or referencing relationships (Figure 1). Another way of classifying threads is based on the semantic meaning of notes. For instance, Zhang et al. (2007) defined an inquiry thread as a sequence of notes that address the same principal issue or topic. In order to classify threads, researchers usually need to download and read all Knowledge Forum notes to identify the principal problems, and divide notes into different sub-inquiries, namely inquiry threads based on the main issue or topic they aim to address (Yang et al., 2016). The sustainability of discourse can be measured by the length of each thread (Khanlari et al., 2017).

In addition to the sustainability of the threads, it is important to investigate whether the discourse is advancing community knowledge (Bereiter et al., 1997). The essence of Knowledge Building is the production and continuous improvement of ideas to advance community knowledge (Scardamalia & Bereiter, 2003). Therefore, thematic analysis is usually conducted to examine which types of threads demonstrate idea improvement. For instance, the "ways of contributing" framework (Chuy et al., 2011) categorizes students' contributions into six main categories (i.e., questioning, theorizing, obtaining information, working with information, synthesizing and comparing, and supporting discussion) and 24 sub-categories (such as asking explanatory questions, proposing an explanation, improving an explanation, or synthesizing available ideas). Employing this framework, Chen et al. (2017) classified threads into productive and non-productive threads based on whether there is an "improving an explanation" code within a thread. Their rationale for doing so is if any note in a thread is coded as improving an explanation, this thread demonstrates students advancing their initial explanation in relation to their questions. Otherwise, the thread was considered non-productive because students did not improve their ideas or explanations in relation to questions.

A few studies suggest the relationships between student-generated questions and their idea improvement (i.e., the productiveness of threads) in Knowledge Building. For example, Scardamalia and Bereiter (1992) compared text-based questions (i.e., answers that can be found in the text) and knowledge-based questions (i.e., questions generated out of students' effort to make sense of the world and to extend their knowledge). They argued that among knowledge-based questions, the wonderment questions, which reflected students' curiosity and puzzlement and aimed at constructing explanations or resolving discrepancies, have a greater potential for advancing students' conceptual understanding. Along this line of research, some studies (Hakkarainen, 2003; Lai & Law, 2013) differentiated factual and explanatory questions. For instance, Hakkarainen (2003) found that Grade 5 and 6 students generated much more explanatory questions (89.7%) than factual questions (10.3%), and students' explanations were at a relatively high explanatory level. He concluded that students generated intuitive theories and searched for explanatory scientific information to answer their questions. Lai and Law (2013) explored the relationship between the level of questions and the epistemic complexity (i.e., fact versus explanation, unelaborated versus elaborated) of knowledge constructed by Grade 6 and Grade 10 students. They found for the Grade 10 students, there was a significant positive correlation between the average level of questions of a thread and students' average level of explanations, suggesting that a thread with higher-level questions was more likely to contain high-level knowledge.

The Current Study

The literature reviewed above suggests the importance of student-generated questions to their learning in general and Knowledge Building in specific and explores the relations between questioning and discourse. However, there is a need for more focused studies to examine the influence of questioning on the sustainability and productiveness of Knowledge Building discourse. The current study aimed to address these gaps. More specifically, the following research questions guide this study:

1. To what extent can students generate questions in Knowledge Building discourse?
2. What is the difference between factual, explanatory and non-questions (i.e., sentences that are not factual or explanatory questions) in affecting the sustainability of their Knowledge Building discourse?
3. How do explanatory, factual, and non-question threads affect the productiveness of Knowledge Building discourse?

Methods

Participants and Context

The participants of this study were 102 primary school students from Grades 1-5/6 in a private lab school located in a larger city in North America. In each class, there were 20-22 students with a similar number of girls and boys. The school had used the Knowledge Building pedagogical approach and Knowledge Forum technology for about three decades, with the approach usually being introduced to the students in junior kindergarten and the technology often being introduced in Grade 1. Therefore, the knowledge-building culture was well established in the school, and the students and teachers felt comfortable with the Knowledge Building pedagogical approach and technology.

At the time of this study, in a typical semester in each class, science learning was organized around an overarching topic, such as water in Grade 1, trees in Grade 2, and fungus in Grade 3 (see Table 1 for a complete list of topics). The Knowledge Building of each class started with Knowledge Building talks in which students and their respective teachers discussed what questions, ideas, and theories they cared about and wanted to inquire about more. In this process, students were likely to bring their authentic questions concerning the topic, which might have been triggered by their previous observations or materials prepared by the teachers. As a result, the teachers usually came up with several overarching questions that tended to cover students' interests and guided their following collaborative inquiry (although new questions would emerge as the Knowledge Building unfolded). Students were encouraged to record and synthesize content in the Knowledge Forum to make the ideas public and permanent for others to further build on. Students built explanations to respond to questions, evaluate the explanations, identify inconsistency between different theories and incoherence of theories, and rose above diverse theories to achieve new syntheses. This idea improvement process was usually supported by evidence from authoritative sources, field trips, experiments, and other investigative activities. In each class, the students and teachers usually engaged in offline Knowledge Building talks and online Knowledge Forum discourse, flexibility and seamlessly as they saw appropriate. The knowledge-building activities in each class lasted for about three months.

Data Collection and Analysis

The dataset used for this study consisted of 1101 online notes archived in the Knowledge Forum where students could post individual notes and build on existing notes in the discussion space. A build-on note, a contribution that links directly onto an existing note, is indicated by an arrow connecting the two notes on the screen (Figure 1).

This study adopted the natural and technical connection of notes when classifying notes into threads because students usually did not read all the notes to develop a comprehensive understanding when built on each other's notes in the Knowledge Forum. Our previous analysis (Zhu et al., 2017) suggested that students might ask semantically similar questions before, during, or after they read existing questions and responses in knowledge-building communities. To focus on how different kinds of questioning influence the sustainability of the Knowledge Forum discourse, we adopted the natural connection of notes and followed what students intuitively tend to do.

The ways of contributing framework were employed to analyze students' Knowledge Forum threads in each grade (Chuy et al., 2011). This framework was chosen because it offered a systematic inventory of ways of contributing that could shed light on how Knowledge Building discourse moves toward learning goals. As described above, this framework includes six main categories: questioning, theorizing, obtaining information, working with information, synthesizing and comparing, and supporting discussion. The questioning dimension includes three sub-categories: asking a factual question, asking a design question, and asking an explanatory question. However, in this study, we focused on factual and explanatory questions since there were fewer design questions.

We analyzed the sustainability and productiveness of threads according to the definitions of sustainability (i.e., length of a thread naturally connected in Knowledge Forum or an isolated note) and productiveness (i.e., if any note in a thread fell under the improving an explanation sub-category) as described in the literature review section. Table 1 shows the detailed descriptions of the dataset used. In sum, there were 342 threads contributed by the students in the five classes; there were a similar number of factual question threads (94) and non-question threads (89), while the number of explanatory question threads (159) was almost double.

Applying the ways of contributing scheme, two researchers coded all the notes and achieved an overall agreement rate of 95.52% across the five grades. To answer the first research question concerning the extent to which students could generate questions, we summarized the descriptive data of questions asked by each class in the Knowledge Forum. To respond to the second research question on the sustainability of threads led by different questions and non-questions, we conducted ANOVA analyses to examine if and how the length of the factual question, explanatory question, and non-question threads differ. Finally, to uncover the third question regarding the productiveness of questioning threads, we compared the frequency of productive threads led by different types of questions and non-questions. We further qualitatively analyzed three randomly selected productive threads led by an explanatory question, factual question, and non-question to showcase how different questions and non-questions guided the threads and influenced their productiveness.

Table 1

Description of the Dataset

Grades	Topics	Number of posts	Number of threads	Factual question threads	Explanatory question threads	Non-question threads
Grade 1	Water	298	81	12	55	14
Grade 2	Trees	117	41	2	23	16
Grade 3	Fungus	193	51	16	12	23
Grade 4	Rocks and minerals	262	93	33	37	23
Grade 5/6	Astronomy	231	76	31	32	13
Total		1101	342	94	159	89

Results

RQ1: Types of Student-Generated Questions

Table 2 shows that the students in each class could generate factual and explanatory questions. Grades 1, 2, and 4 asked more explanatory questions than factual ones, whereas Grades 3 and 5/6 students asked relatively more factual questions.

Table 2

The Descriptive Data of Questions in Each Class's Online Discourse

	Grade 1		Grade 2		Grade 3		Grade 4		Grade 5/6	
	M	SD	M	SD	M	SD	M	SD	M	SD
Factual question	0.90	1.21	0.09	0.29	0.86	2.05	1.67	1.35	3.00	2.19
Explanatory question	4.45	4.31	1.05	1.00	0.82	1.05	2.67	2.18	2.62	2.04

(means and standard deviation)

The distributions of thread length led by explanatory, factual, and non-questions of the five classes are shown in Figures 2, 3, and 4, respectively. Overall, there were more threads led by explanatory questions. The threads led by factual and explanatory questions were longer than those led by non-questions. Most threads led by non-questions ended within three notes, while some threads led by factual and explanatory questions went beyond ten notes.

Figure 2

The Length Distribution of Threads Led by Explanatory Questions in All Classes

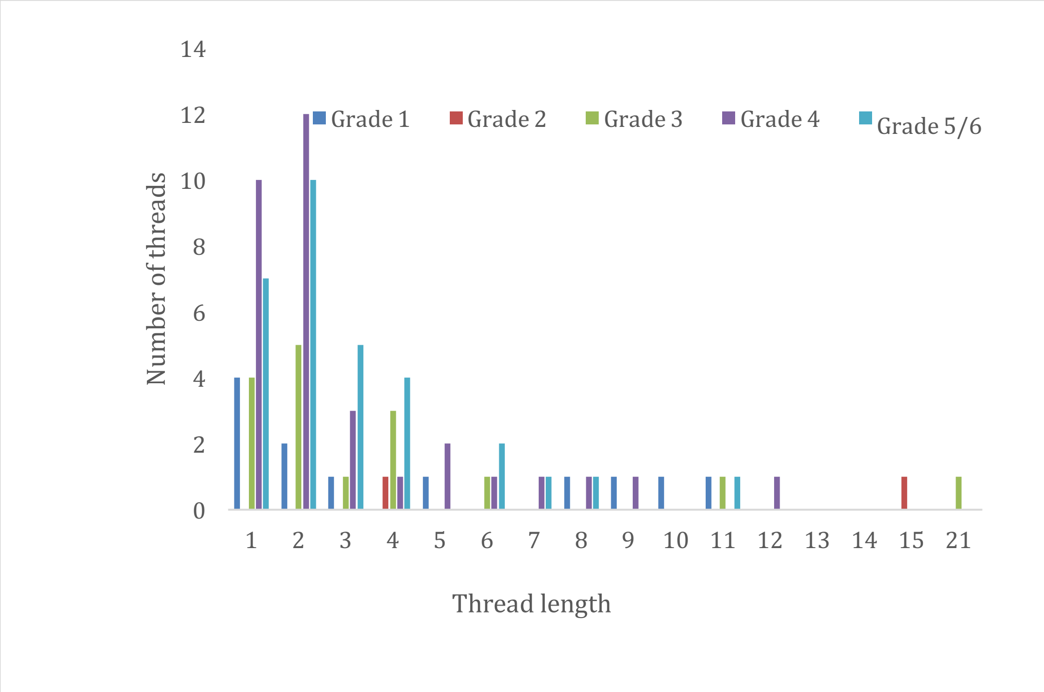


Figure 3

The Length Distribution of Threads Led by Factual Questions in All Classes

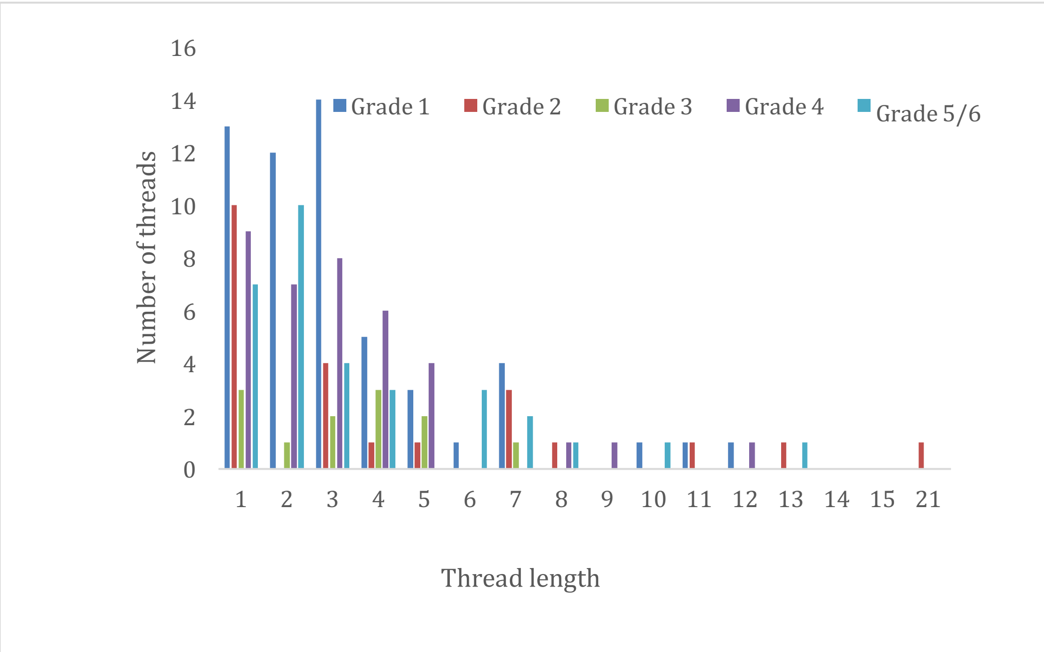
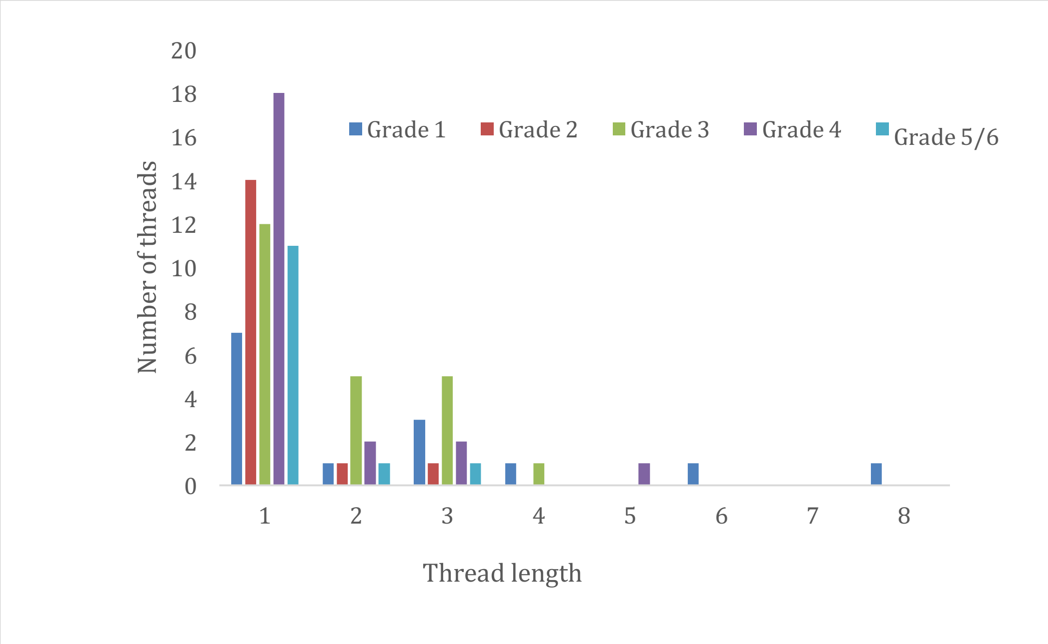


Figure 4

The Length Distribution of Threads Led by Non-Questions in All Classes



RQ2: Sustainability of Threads Led by Explanatory, Factual, and Non-Questions

Table 3 shows the descriptive data of the length of threads led by explanatory, factual, and non-questions and the ANOVA analysis results. The ANOVA analysis suggested that there was a significant difference between the length of explanatory, factual, and non-question threads (F (2, 339) =15.13, $p<.001$). To further reveal which types of threads had significantly different lengths, we conducted Tukey's post-hoc comparisons. The results suggested that explanatory question threads were significantly longer than non-question threads ($Mean_{difference}$=1.89, $p<.001$). Similarly, the factual question threads were significantly longer than the non-question threads ($Mean_{difference}$=1.93, $p<.001$). However, there was no significant difference between the length of explanatory and factual question threads ($Mean_{difference}$=.04, p=0.99). An explanatory question and a factual question led to the two longest threads, respectively, both including 21 notes. The results suggested that compared to non-questions, actual questions resulted in more sustainable discourse.

Table 3

A Comparison of the Length of Explanatory, Factual, and Non-Question Threads

Type of threads	Mean	SD	ANOVA results
Explanatory question threads	3.52	3.01	F(2, 339)= 15.13, p<.001
Factual question threads	3.56	3.45	
Non-question threads	1.63	1.22	

RQ3: The Productivity of Threads Led by Explanatory, Factual, and Non-Questions

The number of productive threads led by explanatory, factual, and non-questions is shown in Table 4. In this table, the numbers in parentheses show the total number of threads in each category. It should be clarified that some threads started with notes that included factual and explanatory questions; those threads were counted as factual- and explanatory-question threads.

Table 4

Number of Productive Threads Led by Explanatory, Factual, and Non-Questions

	Grade					
	1	2	3	4	5/6	Total
Productive threads led by explanatory questions (total explanatory-question threads)	10 (55)	5 (23)	4 (12)	5 (37)	5 (32)	29
Productive threads led by factual questions (total factual-question threads)	3 (12)	0 (2)	2 (16)	4 (33)	5 (31)	14
Productive threads led by non-questions (total non-question threads)	1 (14)	1 (16)	2 (23)	2 (23)	1 (13)	7
Total number of productive threads (total threads)	13 (81)	6 (41)	6 (51)	11 (93)	9 (76)	45

As shown in Table 4, in each grade, more productive threads were initiated by explanatory questions. Indeed, compared to factual questions and non-questions, explanatory questions led to more productive threads. Also, compared to non-questions, factual questions resulted in more productive threads. For instance, in Grade 1, ten productive threads were led by explanatory questions; three productive threads were initiated by factual questions, while non-questions initiated only one productive thread. In total, there were 45 productive threads, and 29 of them started with explanatory questions, 14 began with factual questions, while non-questions led 7.

Three productive threads led by an explanatory question, a factual and a non-question, and a non-productive thread are provided in a qualitative analysis below. These three threads were randomly selected as representative of productive explanatory-question threads, productive factual-question threads, and non-question threads. These examples demonstrate how qualitative analyses using the ways of contributing coding scheme complemented the quantitative analyses: quantitative analyses could only show the sustainability of the discussion, while qualitative analyses could reveal whether those sustainable threads are productive or not. All students' names are pseudonyms, and grammar issues were corrected. At the end of each note, we included our ways of contributing code. Following each example, there is a discussion of the case to show the nuances of how the initiating notes influenced the development of the thread.

Example of a Productive Explanatory Question Thread

Jim: How are rocks made? (*Explanatory Question*)

Jessie: My theory is that rocks are made by magma drying and being compacted. (*Improving a Theory*)

Amy: My theory is that sand is in the sea starts to form in a number of years, and finally, it [a rock] forms. (*Improving a Theory*)

Charles: Some rocks are made by sand hardened sand. (*Supporting a Theory*)

Rachael: My theory is that wherever the rock is found is probably where it is made. (*Proposing a Theory*)

Sophia: The rock that I brought in is made out of pure hardened sand. (*Supporting a Theory*)

Kevin: There was a whole lot of volcano, and the ash came and lava, so the lava cooled, and you have your rock. (*Supporting a Theory*)

John: Rocks are made by minerals coming together over many millions of years. (*Supporting a Theory*)

The above thread started with an explanatory question proposed by Jim. Then Jessie and Amy raised their theories from different perspectives, one stating that rocks were made of magma, and one focusing on the time for rocks to form. These two theories were coded as "Improving a Theory" since they extended two existing theories in the community, which were "I think rocks are formed by minerals and thousands of years" and "I think diamonds are made by minerals compacting." Charles supported Amy's theory by stating that rocks were made of hardened sand. Rachael proposed a theory about where rocks were made. Sophia, Kevin, and John all supported previous theories. As two notes in this thread were coded as "improving a theory" notes, this thread was considered a productive thread. The notes built onto the explanatory question, coded as "improving a theory," "proposing a theory," and "supporting a theory," were all responses to the question.

Example of a Productive Factual Question Thread

Tom: What is a rock? (*Factual Question*)

Rachael: A rock is something that got hardened over time. It could be a sandstone, a lava rock, and many different kinds of rocks. (*Improving a Theory*)

Sophia: I think that some rocks just are hard they don't have to be compacted. (*Seeking an Alternative Theory*)

Jessie: My theory is that a rock is just a bunch of minerals and atoms all stuck together. (*Supporting a Theory*)

In this thread, Tom asked what a rock was. Rachael synthesized different existing theories, responded to the question of what rocks were, and listed various forms of rocks. Therefore, Rachael's theory was coded as "Improving a Theory." Sophia proposed an alternative theory by stating that rocks "don't have to be compacted," and Jessie supported previous theories. All the notes built onto the factual question were theories in response to the original question. Rachael's synthesis of previous theories made this thread productive.

Example of a Productive Non-Question Thread

John: You know when the earth was just being created? There were volcanoes simultaneously erupting, creating tons of lava. But when the giant rains came (creating the oceans), the top of the lava flood cooled, trapping the magma inside. (*Improving a theory*)

John proposed an advanced theory explaining how the crust was created. This note was a stand-alone note on Knowledge Forum. Before that, the students had discussed volcanoes formation, lava eruption, the rotation of the earth, and plate movement. Then Amy proposed, "Maybe some of the earth's crust built up." John's theory could be considered an improvement of the existing theories on volcanoes and crust because it synthesized these ideas and moved their theory of how the crust was created to a higher level.

Example of an Unproductive Thread

Tom: Some scientists think that the thing that exploded was the remains of an old universe. What if that universe had a life? The old life from the old life particles C. (*Seeking an Alternative Theory*)

Jacob: I think that's true. BUT what does C mean? (*Giving an Opinion, Factual-Seeking Question*)

This thread is an example of a non-productive thread that does not show evidence of knowledge advancement because rather than responding to the question "What if that universe had life," Jacob gave his opinion to Tom's statement and asked a factual-seeking question. This thread did not extend after.

Discussion

The results of this study confirmed that students as young as Grade 1 could generate a reasonable number of questions, sustain Knowledge Building discourse, and improve their intuitive theories to achieve productive discourse. The results suggest that question threads (either factual or explanatory) are significantly more sustainable and productive than non-question threads. The results support the literature on the importance of student questioning in science learning in general (Chin & Brown, 2000; Chin & Kayalvizhi, 2005; Chin & Osborne, 2008).

We found that both factual and explanatory question threads are significantly more sustainable than non-question threads. The reason may be that compared to non-questions, questions are more likely to remind students to explore the subject further to achieve a better understanding or to encourage their peers to take collective responsibility to respond to the questions. As progressive inquiry proceeds, new and more specific questions may emerge from the interaction between intuitive explanations, idea-deepening or elaborating questions, and scientific information from different students (Hakkarainen, 2003). Questions help a community to identify their current understanding, articulate the knowledge gap for further work, and convey a sense of seeking responses (Chin & Osborne, 2008). Furthermore, student-generated questions reflect students' authentic curiosity and their epistemic agency of where their collective inquiry should go (Scardamalia, 2002).

The results did not show a significant difference between the sustainability of factual question threads and explanatory question threads. The reason may be relevant to the types of questions students asked as Knowledge Building unfolded. That is, different questions might help propel the Knowledge Building discourse at different times. Miyake and Norman (1979) argued that “to ask a question, one must know enough to know what is not known” (p. 357), suggesting the importance of domain-specific knowledge for students to ask good questions. To test this argument, Scardamalia and Bereiter (1992) compared the nature of student-generated questions concerning the topics “fossil fuels” (students suggested they had little prior knowledge) and “endangered species” (students were more familiar with). They found although the number of student-generated questions did not differ in the two conditions, the students tended to ask more basic questions, e.g., “What are fossil fuels?” for the less familiar topic “fossil fuels.” In contrast, they asked more wonderment questions, e.g., “How do scientists count a species so they know when it is endangered?” about the more familiar topic. In the current study, students asked more factual questions when they started their Knowledge Building on the science topics, and the questions helped sustain their inquiry; as the knowledge-building process unfolded as students became more familiar with the topics, they asked more explanatory questions. Further research should consider students’ familiarity levels with their inquiry topics and the temporal dimension to better understand and support students in asking certain types of questions.

Across the five classes, explanatory questions resulted in more productive threads than factual questions and non-questions, and factual questions led to more productive threads than non-questions. This result is compatible with the existing literature, which suggests that compared to fact-seeking questions, explanation-seeking questions contribute more to advancing knowledge (Hakkarainen 2003; Zhang et al. 2007). Explanatory questions give students more opportunities to theorize the relationships and mechanisms between variables (Zhang et al. 2007), provide alternative theories, synthesize different theories, and improve their theories. Therefore, explanatory questions have a higher chance of leading to productive threads. Factual questions are more likely to be responded to with facts, terms, experiences, phenomena, or simple statements rather than theories (van Aalst, 2009; Zhang et al., 2007). Factual questions not embedded in genuine inquiry may result in fragmented pieces of knowledge, while explanatory questions have more potential to guide progressive inquiry (Hakkarainen, 2003). Lai and Law’s (2013) study also suggested that threads with explanatory questions were more likely to lead to elaborated explanations.

The qualitative analysis of productive threads led by an explanatory question, a factual question, a non-question, and an unproductive thread suggested the importance of questioning and sustainable Knowledge Building discourse to productive threads. Hakkarainen’s (2003) study indicated that progressive inquiry relied upon student-generated questions and peer interactions that encouraged students to pursue questions further through dynamic information, theorizing, comparing, and synthesizing. Furthermore, students tend to reduce an unfamiliar phenomenon, which may be represented by questions and suggests their knowledge gaps, to a familiar one (Hakkarainen, 2003) by addressing the questions through sustainable and progressive Knowledge Building discourse. However, not all questions resulted in productive threads since some of them may not have been addressed by students. This result is consistent with Lai and Law’s (2013) study that concluded that one group of participants (i.e., Grade 10 students) were more capable of advancing their discourse through questioning, while the other group (i.e., Grade 6 students) were less capable of doing so. The authors mainly attributed such a difference to students’ ages and further hypothesized that school context, student backgrounds, teachers, pedagogical contexts, and implementation procedures might have contributed to such a difference. Future research should consider these factors when examining students' Knowledge Building discourse.

Limitations

This study contributes to the body of research by examining how questioning engages students in sustainable and productive discourse. However, this study has several limitations.

First, the unit of analysis in this study included threads of discussions constructed by students on the Knowledge Forum. However, students might discuss semantically similar questions in different threads on Knowledge Forum, especially when they did not acquire a good awareness of the questions being discussed in their community. Semantically similar questions may affect the analysis of sustainability and productiveness.

Second, aligned with other studies (Hewitt, 2005; Hewitt & Teplovs, 1999), we defined a thread as an isolated note or a series of connected notes. The rationale for considering an isolated note as a thread is that even a single note contains an idea. Within the context of Knowledge Building, each idea is valuable and important and may spark new ideas in the community. Excluding single notes may result in ignoring valuable contributions. However, such a definition might be unconventional because CSCL researchers usually define a thread as a series of two or more connected notes. For future work, it would be reasonable to replicate the study with a more conventional definition of a thread and explore how the results may differ from the results shown in this paper.

Third, this study focused on Knowledge Forum notes but did not provide the details of each class's activity design (e.g., duration of inquiries, students' other interests, or the priority of Knowledge Forum discourse to student goals). In addition to questioning, the sustainability and productiveness of Knowledge Building discourse may be influenced by factors such as class norms, teacher guidance, and student interactions. However, although these factors might influence the Knowledge Building discourse, within each classroom, the influence might apply to all threads unless threads led by different questions were treated differently in class, which was not the case. These factors should be considered in future studies. Future researchers could also conduct design experiments to facilitate students in advancing their community knowledge through questioning, such as by highlighting unaddressed questions, selecting promising questions, connecting semantically similar questions, and developing specific epistemic scaffolds.

Conclusion

This study analyzed the sustainability and productivity of Knowledge Building discourse led by student-generated factual questions, explanatory questions, and non-questions in five primary classes. The results suggested that factual and explanatory question threads were significantly more sustainable than non-question threads. Moreover, productive threads were more likely to be led by explanatory questions than factual ones, while less likely by non-questions.

In knowledge-building communities, questions provide students with an inquiry and conceptual space where they can build on the questions with diverse theories, provide information, contribute critical evaluation and alternative theories, synthesize different and even opposite theories, and eventually improve their theories. Therefore, student-generated questions are an asset for a community to start and continue their Knowledge Building journey. Teachers and students often do not have problems working with student-generated questions at the beginning, however, as Knowledge Building inquiry unfolds, emergent questions generated by the students may not capture the community's attention in a massive and messy conceptual space. How to continuously support teachers and students to work on promising questions is a direction worth further study.

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