Metadiscourse to Foster Student Collective Responsibility for Deepening Inquiry

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Abstract: This study examined two complementary designs of metadiscourse to foster collective responsibility for sustained, progressive inquiry in two comparable Grade 5/6 classrooms that investigated astronomy. Class A's metadiscourse focused on reviewing student questions to formulate deepening goals. Class B's focused on co-monitoring disciplinary key concepts in readings that suggested possible areas for deeper discourse. Analyses of classroom videos and online discourse suggest the positive impact of such metadiscourse on sustained knowledge building, along with specific conditions required.

Introduction

To prepare students for creative careers in a knowledge-based society, schools need to cultivate collaborative, inquiry-based practices by which knowledge-creating communities (e.g., R&D networks) expand our society's knowledge. Key to the productivity of these communities is a self-sustained, progressive trajectory of inquiry by which ideas are generated, refined, and further built upon by peers to formulate more advanced ideas and problems that continually inform further initiatives (Bereiter, 2002; Dunbar, 1995; Sawyer, 2007). Inquiry-based learning in schools needs to similarly foster such a self-sustained, progressive trajectory among students in order to develop their creative capacity (Hakkarainen & Sintonen, 2002). This sustained course of inquiry is not pre-defined by the teacher but co-developed by students through an interactional, unfolding process. Students need to take on high-level collective responsibility for continually advancing their community's knowledge (Scardamalia, 2002). Our recent studies shed light on conditions and designs to foster collective cognitive responsibility among young students (Zhang et al., 2007, 2009). Among other conditions, metadiscourse—collaborative, metacognitive conversations to review progress of understanding and formulate deeper goals and actions as a community—was identified as a critical means for students to enact collective cognitive responsibility. The present study intends to test designs to facilitate metadiscourse, focusing on co-monitoring of progressive questions and key concepts in knowledge building discourse.

Elaborating the vision of self-sustained inquiry, we (Zhang et al., 2007, 2009; Zhang, 2012) recently analyzed a set of design experiments conducted in elementary classrooms that implemented knowledge building pedagogy using Knowledge Forum, a collaborative online environment (Scardamalia & Bereiter, 2006). Instead of relying on teacher-specified steps, scripts, and resources of inquiry, students elaborated what they needed to know, set forth theories, searched for resources, and designed experiments to test and improve their ideas. Students in a whole class collaborated opportunistically to investigate a focal area (e.g. optics) and progressively identify important issues to be understood (e.g., how light travels, how people see colors, how lenses work). Small groups formed and reformed based on evolving needs. Knowledge Forum provided the online space in which student collective works were recorded, in views (workspaces) corresponding to the progressive goals identified. Ideas contributed became shared objects of continual online discourse accessible to all students. Essential to this emergent, opportunistic approach to inquiry, students engaged in metacognitive practices to reflect on what they had learned and what they needed to better understand on an ongoing basis. Leveraging such personal efforts, whole class metacognitive conversations—metadiscourse—were carried out to review progress, highlight important insights, and identify deeper issues and weak areas as the focus of further inquiry. To highlight important knowledge goals and structure their work accordingly, students discussed what views should be created in Knowledge Forum and how the views should be structured and linked, with contributions (i.e. notes) in each view organized into theme-based clusters (Zhang, 2012; Zhang & Messina, 2010).

Despite the importance of metadiscourse, this discourse pattern is rarely seen in classrooms even in inquiry-based settings (van Aalst, 2009). We as a field have little understanding about how metadiscourse works to sustain knowledge building and how it can be facilitated in classrooms. The present study aims to test and elaborate two complementary strategies to structure metadiscourse in knowledge building communities.

(a) Metadiscourse focusing on collaborative, progressive questioning. This strategy supports student collaborative efforts to monitor what is known and what is missing—gaps and problems of understanding—so as to identify knowledge goals based on their deepening wonderment (Zhang et al., 2007). Although inquiry is entering more and more classrooms, in practice students often address pre-specified problems or tasks; rarely do they spontaneously generate curiosity-driven questions (Chinn & Malhotra, 2002; Rop, 2003). Part of the problem is the difficulty elementary and middle school students are found to have in formulating questions that guide inquiry in productive directions (Krajcik et al., 1998). This problem is, of course, heightened by concerns with meeting curriculum standards and assessments. It is not essential that students' initial questions target core concepts or issues, however, provided there is a process through which questions are progressively deepened as student understanding is advanced. Such a process has been formulated by Bereiter and Scardamalia (1993) as "progressive problem solving" and by Hakkarainen and Sintonen (2002) as an "interrogative model of inquiry." This study engages students in metadiscourse to examine questions contributed by individual members so as to co-develop shared, promising research goals.

(b) Metadiscourse focusing on co-monitoring disciplinary key concepts used in knowledge building discourse. This strategy engages students to monitor what is out there in the larger world in order to better reflect on their own work and discourse in a domain area. Students deepen their inquiry into the "intellectual heart" of a discipline (Gardner, 1999) by making use of authoritative sources that bring core concepts of the domain into their focus. A recent study provided preliminary evidence showing that productive use of key concepts from reading materials stimulated new lines of inquiry (Zhang et al., 2007). This study further tests designs to support student collaborative metacognitive efforts to identify key concepts from reference materials, review their own discourse to identify progress made related to the key concepts, and speculate over what needs to be further investigated.

In short, this study aims to test the above two ways to structure metadiscourse in knowledge building communities. The purpose is not to find out which design is superior, but to examine and elaborate each in depth so we can refine and integrate them to foster student collective responsibility for sustained inquiry. Our research question asks: How did the metadiscourse using the two strategies take place in the classrooms to help students develop a progressive course of inquiry, as reflected in their knowledge building discourse?

Method

Classroom Contexts

This study was part of a larger initiative to develop pedagogical designs and visualization tools to foster a self-sustained, progressive trajectory of inquiry among elementary students using a design-based research methodology (Collins, Joseph, & Bielaczyc, 2004). It was conducted in two comparable Grade 5/6 classrooms at the Dr. Eric Jackman Institute of Child Study in Toronto, which has been implementing Knowledge Building pedagogy and Knowledge Forum (see Scardamalia & Bereiter, 2006 for details) for more than a decade. The two classes—each involving 22 students—investigated astronomy over approximately eight weeks, taught by two teachers who had equivalent experience (2-3 years) with using Knowledge Forum to support inquiry. The astronomic study integrated face-to-face activities (e.g. whole class conversations, small-group experiments, reading) and online discourse in Knowledge Forum that extended and enriched each other. A pretest revealed no significant difference between the two classes in student prior knowledge ($p > .10$).

Focal Designs

Each classroom tested a focal design of metadiscourse: collaborative progressive questioning in Class A and co-monitoring of key disciplinary concepts in knowledge building discourse in Class B. Each classroom could also use the strategy of the other, although not as explicitly.

About once every two weeks, students in Class A held a whole class, metacognitive meeting (20-30 minutes) to reflect on progress and identify problems of understanding as the focus of their further inquiry. In preparation for each meeting, students were given time to read the online entries of their peers to identify knowledge advances and problems. Using the discourse scaffold "I need to understand" as a sentence starter, students contributed new and deeper questions in Knowledge Forum. Questions identified were then listed on chart paper and reviewed in the whole class meetings. In such meetings, the teacher worked with her students to reflect on progress made and identify promising questions—questions that seemed important and might stimulate deep inquiry and understanding. These questions were highlighted to focus further inquiry and revisited in the subsequent metacognitive meetings to review progress.

Classroom B also held whole class metacognitive meetings, about once every two weeks, to reflect on progress and identify deeper goals of inquiry. In preparation for each meeting, students were given time to read Knowledge Forum entries of their peers and use curriculum guidelines and other materials to identify key concepts that seemed important but yet to be used in their inquiry. Using a discourse scaffold, "Key concept," as a sentence starter, students wrote notes to introduce new key concepts and propose issues to be explored. During their metacognitive meetings, students reviewed the key concepts identified, with their teacher recording the key concepts on a digital whiteboard. A concept map was thereby co-constructed to highlight the concepts and their connections. The concept map was used as a reflective planning tool to help students review progress, identify weak areas, and plan deeper inquiries. In the subsequent meetings, the concept map was revisited and updated in reflection of new concepts and deeper goals identified.

Data Analysis

Following design-based research (Collins et al., 2004), we integrated qualitative (e.g. videos, online discourse patterns) and quantitative analyses (e.g. counting domain words in discourse) to elaborate and evaluate the interventions. Primary data analysis was conducted after each metacognitive meeting and further discussed with the teachers to refine the classroom designs.

To understand how students deepened inquiry, we conducted inquiry thread analysis (Zhang et al., 2007) of their online knowledge building discourse in relation to the metacognitive conversations recorded in videos. Unlike physically linked threads of online discourse (e.g. build-on trees), an inquiry thread represents a line of inquiry composed of a series of conceptually related discourse entries—which may involve multiple build-on trees—that address a shared principal problem over an extended period of time. Visualizing online discourse using inquiry threads helps to understand how diverse themes of inquiry emerge, evolve, and deepen in a community space and trace idea improvement and student participation within and across the threads. Two coders read and re-read all the Knowledge Forum notes and identified 19 major themes (e.g. planets, moons, atmosphere) addressed by the two communities. Using these themes as the "tracers," the primary coder clustered the notes that addressed the same theme into one inquiry thread. The second coder then reviewed the notes in each thread and discussed with the primary coder about any disagreements. To gauge reliability, two coders independently coded 27 notes with an inter-rater consistency of 95%.

To examine deepening moves in each inquiry thread, we further conducted content analysis (Chi, 1997) of questions in student notes. Using a previously tested coding scheme (Zhang et al., 2007), each question was coded as (a) factual, to be answered with factual information (e.g. where, when, how many), or (b) explanatory, to be satisfactorily answered with an explanation (why, how, what-if). Although both types of questions are valuable, explanatory questions represent deeper epistemic efforts to elaborate on reasons and mechanisms behind scientific phenomena. Additionally, we conducted lexical analysis of student online discourse to trace the emergent use of domain-specific terms as an indicator of the depth and scope of their inquiry (Sun et al., 2010). A word list containing 59 terms was developed including 39 from the Ontario Curriculum and 20 additional terms used in student online discourse. A software tool, Simple Concordance Program (SCP), was used to trace the occurrences of these terms—including their grammatical variations—in the online discourse.

Following a narrative approach to video analysis (Derry et al., 2010), we further analyzed the metacognitive meetings recorded in videos to understand the complex processes by which students co-developed and deepened inquiry goals through metadiscourse. We first browsed the videos and transcriptions to develop an overall sense of the knowledge building processes, aided by the inquiry threads identified from the online discourse. We then identified "digestible" chunks in the videos—major episodes in which students proposed questions or key concepts, reviewed connections and progress, and formulated new and deeper goals. These chunks were contextualized and linked based on thematic and conceptual connections (e.g. questions and concepts deepening the same theme) to develop a storyline for each classroom, showing how the two focal designs worked out to foster progressive inquiry.

Results

Inquiry Thread Analysis

Students wrote a total of 121 discussion notes (3966 words) in Class A and 190 (5370 words) in Class B (excluding individual summary notes). Inquiry thread analysis identified a total of 19 themes addressed by the two classes in the online discourse. Discourse entries focusing on each theme constituted an inquiry thread that extended from the first to the last note contributed (see Figure 1). The inquiry thread map of each class visualizes the emergence of the various themes over time and contributions and contributors involved. The themes of inquiry were not pre-specified by the teachers, but emerged through student interactive discourse that brought important issues to their focus. Each class investigated multiple themes in parallel through extended and interconnected discourse input, with a large number of notes addressing multiple themes simultaneously, serving as interconnectors between different lines of work. Several core themes in astronomy (e.g. planets, moons, gravity) engaged the most intensive contributions in both classes. Class B covered more themes (n=18) then Class A (n=16). Through student use of key concepts to monitor and focus their discourse, issues related to nebulas, constellations, and orbit were brought to the focus of Class B. These themes were absent from the discourse in Class A. Consistently, Class B conducted more extended discourse on themes that are more distant from student personal experience, such as the origin of the universe, black holes, stars, and space technology. Class A carried out more intensive inquiry in more personally relevant areas, such as the Earth, planets, moons, gravity, and atmosphere. Interestingly, Class B did not explicitly discuss issues about the Earth at all.

To further examine deepening moves of discourse in the inquiry threads, we analyzed student questions as well as domain-specific terms (e.g. planet, moon, orbit) used in the discourse (Table 1). Consistent with the focal designs of the two classrooms, Class A had a much higher percentage of notes raising questions, including fact-seeking (e.g. Are some planets smaller than some moons?) and explanation-seeking questions (e.g. Why are

Jupiter's moons so big? How did planets get their moons?). Among the 59 domain-specific terms identified, Class B used more unique terms, and at a higher frequency, in the online discussion. Overall, the online discourse in Class A was more driven by students' interest, curiosity, ideas, and experiences that were presented using more personal and informal language, with more deepening moves (e.g. problematizing); while that in Class B addressed more astronomic topics using sophisticated scientific language, including topics relatively far away from student personal experience.

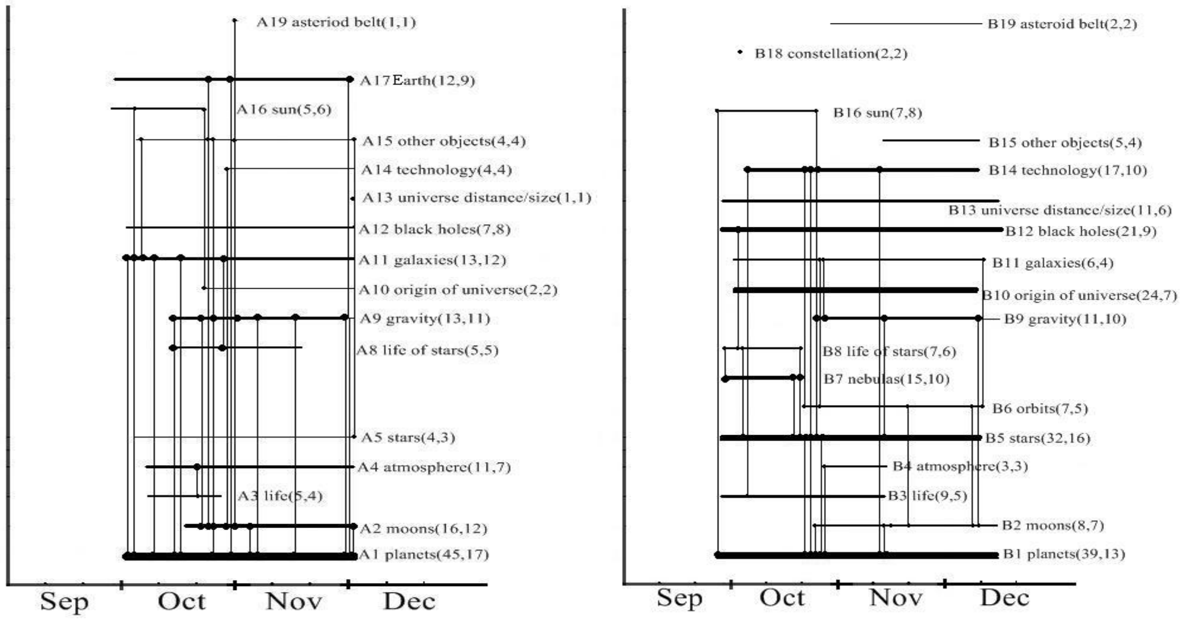

Figure 1. Inquiry threads of Class A (left) and B (right). The numbers following the title of each theme show the number of notes and authors involved, respectively. Vertical lines linking notes in different threads denote notes shared by the threads addressing multiple related themes.

Table 1: Questions and domain-specific terms incorporated in the online discourse.

Class	% of notes raising questions	% of notes raising fact-seeking questions	% of notes raising explanatory questions	Unique domain terms	Total occurrences of domain terms
A	41.32%	14.88%	26.45%	34 out of 59	425
B	23.16%	8.42%	14.74%	45 out of 59	603

Progressive questioning in Class A helped students to investigate deeper issues beyond their current understanding, leading to progressively deepening goals and focuses. Questions that were more interesting to students and of a greater intellectual value in the domain tended to engage more active and extended conversations, resulting in more sophisticated understanding that further illuminated deeper issues to be understood. For example, in the inquiry thread about moons (A2 in Figure 1), students first contributed information to address basic, factual questions such as what the moon is made of (rock, not cheese) and which planets have moons. Deeper questions were then asked: Why don't Mercury and Venus have moons? Why are Jupiter's moons so big? How did a planet get its moons? Such deeper, explanatory questions stimulated continual inquiries (e.g. reading, modeling, discussion) leading to advances of understanding, as shown in the following note: "I think that Mercury and Venus (the two closest planets to the Sun) don't have moons because whenever they get moons the Sun's gravitational pull pulls the moons away. Jupiter has so many moons because it has such a strong pull, that asteroids and comets get pulled in." The advances of understanding further helped students to problematize their knowledge at a deeper level. Even simple facts, such as how many moons a planet has, were examined for deeper inquiry:

Determined Moons by nw [2008, Oct 29]
I need to understand: how can you tell how many moons a planet has? My Theory I think that maybe astronomers use telescopes to see, but how can they see each side of all the different planets? I need to understand: How can people determine that? What facts can lead up to it?...

Through identifying and monitoring disciplinary key concepts, students in Class B engaged in active online knowledge building discourse, with the key concepts introduced serving to inform new and deeper focuses of inquiry. More extended online discourse were conducted about stars (B5), life of stars (B8), nebulae (B7), and the origin of the universe (B10)—all these threads were initiated through introducing key concepts from reference materials. For example, the inquiry thread on nebulae began with a student note: "Key concept is NEBULAS…Nebulas are the [remains] of stars they are created when stars explode. Nebulas also create new stars." The discourse was deepened when her peers identified deeper things to be further understood: "…do nebulas stay where they are or do they just disappear?" "why there['re] more stars than nebulas, because nebulas are dead stars…there['re] so many stars in the sky that there should be a nebula for each star that dies. " Theories were further developed to address these issues, such as the following:

This is why!!!!!!!!!!!!!!!!!!!!!!! by dc [2008, Oct 23]
Stars live for a few billion years but nebulas turn into stars in about a million so over time. [T]here will only more stars. But even though you would expect to see some nebulas but they are really hard to see, so you never see them in the city.

Metadiscourse Focusing on Collaborative, Progressive Questioning

We analyzed the metacognitive meetings recorded in videos in relation to the online inquiry threads. Students in Class A began the space study in late September by contributing initial ideas and information about the Sun and the planets and sharing questions in Knowledge Forum. The first metacognitive meeting was then held on October 3. Students gathered around a piece of chart paper that recorded a rich set of initial questions. The questions were read aloud, including: How long ago did Earth begin? How was the Sun formed? What are the dwarf planets, and why are they not normal planets? What is beyond Pluto? Is there anything beyond the Milky Way? Is there other life in space? Interactive discussions occurred focusing on some of the questions (e.g. planets and moons, galaxies). The remainder of the meeting was then focused on reviewing the questions and identifying good, promising ones as the community's focus. The teacher encouraged student reflection by asking: "Which question…that seems like… really 'meaty'…? So, that's a question that shows a lot of promise. We could probably do lots with that...A question we could generate lots of discussions. Lots of people can have input into it." Contrasting with the lively discussions to generate specific questions and ideas in the first part of the meeting, reflecting on the questions to identify promising ones was challenging for the students. To further scaffold such reflection, the teacher then worked with the students to examine a few examples:

Teacher A: "How big is the Sun?" Would that be a question that would generate lots of different conversation and people could input lots of different things?
Student 1: No.
Teacher A: No, and why not?
(Students murmur. Student 2's voice gains their attention)
Student 2: It's pretty… It's like a simple question …How does it heat people?... that would be a bigger, deeper question…Like, "How does the Sun heat the Earth?" or something.
Teacher A: Right. So… There are lots of questions about the Sun, that would be deeper, richer kinds of questions, that would generate lots of discussion, and those are the questions we're really looking for.

In the analysis of the example questions, the teacher provided metacognitive prompts such as: "Why do you think that's a solid, great question…?" "As you find out more and more about …, where can you go from there?" "Will this question take [us] in a productive path?" Although the first meeting did not end up with any explicit conclusion about which questions should be set as their common focus, questions related to several themes (e.g. the difference between the moons and planets, different types of galaxies) were highlighted to invite student input. Such themes became the major focuses of the online discourse in early October, with planets as the most intensive and long-lasting theme (see thread A1 in Figure 1).

Another metacognitive meeting was held two weeks later, on October 14. Students worked together to review progress made to address questions identified earlier, generate deeper and new questions, and identify promising and productive ones as their focus. First, a student shared her finding about what is beyond Pluto—a question identified in the first meeting: There are more galaxies, some of which scientists have not observed yet, so they just call them Dark Matter, or negative space. Questions were raised by her peers pertaining to what Dark Matter is and how it is identified. The teacher then reminded the students to record such questions in Knowledge Forum if these were promising and could help further their understanding. However, the topic of Dark Matter did not attract any contribution in the subsequent online discourse, probably because of the difficulty to advance understanding in this area. As the meeting proceeded, atmosphere was identified as a new theme based on information contributed online earlier: What is atmosphere made of? Are there atmospheres for other planets, other stars? Students further commented on the importance of this topic because atmosphere supports life. In contrast to the dismissal of Dark Matter as a possible discourse focus, rich and extended discourse was conducted focusing on atmosphere following this meeting (see thread A4 in Figure 1). Thus, in monitoring the "promisingness" (Bereiter & Scardamalia, 1993) of questions, the students were able to consider the importance of such questions as well as the challenges and difficulties involved.

Another metacognitive meeting was recorded on October 24. While understanding was deepened to address existing questions, students reformulated the problems in deeper and more productive ways. Deepening the question of what the atmosphere is made of, students asked how it is held in place and affects life on the Earth. Deepening questions about which planets have moons, students asked why only some planets have moons, how they got the moons and keep the moons in orbit. In the end of this meeting, three areas were explicitly identified calling for deeper work: moons, sun (in relation to planets), and atmosphere. Issues related to moons became a new major theme in the subsequent online discourse (see A2 in Figure 1) while discourse about atmosphere (A4) and planets (A1) continued to attract deeper input in relation to gravity (A9).

Overall, through generating and deepening questions and collaboratively reflecting on the value and importance of the questions for knowledge advancement, students in Class A were able to focus their efforts on core issues in the domain that are intellectually engaging and rich (e.g. planets, moons, atmosphere, gravity). However, several topics expected by the curriculum (e.g. constellations) were not explicitly addressed because of the lack of student questions in these directions.

Metadiscourse Focusing on Co-Monitoring of Key Concepts

Students in Class B also began their inquiry in late September by contributing initial thoughts and information. In the online discourse, they introduced key concepts to their community and suggested related issues to be understood. Whole class metacognitive meetings were held to review the key concepts, reflect on progress, and identify focal areas for further inquiry. These key concepts were recorded on a chart paper by the teacher to ground and focus the first metacognitive meeting on October 10, during which students reviewed the existing key concepts and related questions and ideas and identified major themes (e.g. galaxies, planets and life, orbit). As the class reviewed the concepts and ideas related to each theme, the teacher recorded the themes and related concepts on a digital whiteboard. For example, focusing on the theme of galaxies, concepts were identified including stars, Solar System, planets, and size (big), etc., with connections between related concepts highlighted (e.g. between the Solar System and planets). A concept map was thereby created and further expanded as students identified key concepts related to other themes. Figure 2 shows the full concept map co-created through this meeting. This map was used by students to discuss what areas had been explored and what needed to be better understood. It was later uploaded to their Knowledge Forum view as a background picture, which served to focus students collaborative discourse on key themes and additionally provide a source of domain-specific vocabulary to be used in their discourse.

Figure 2. Concept map generated through the first metacognitive meeting in Class B. Circled terms represent major themes identified. Numbers show the sequence by which the terms and links were added.

Another metacognitive meeting was held on October 21. With the concept map (Figure 2) displayed on the digital whiteboard, students reviewed progress made in areas indicated by the existing concepts and identified new key concepts that had not been explored much yet. In reflection of students' deepened understanding, a new concept, "satellites," was added to the map and connected to "orbit" as well as "moons." Issues related to orbit (B6 in Figure 1) and satellites (B14) became a focus in the online discourse and were addressed at a much deeper level than in Class A.

On October 30, students held their third metacognitive meeting. Several new concepts were added to the map to elaborate the theme of gravity. A new theme was added about space exploration. To facilitate reflective conversations to review progress and plan further exploration, the teacher asked: "What of the things up there are the things that you know a lot about and what do we want to know more of?" Atmosphere was identified as a topic that had been overlooked. It was added to the map and linked to "gravity." Altogether, eight topics were identified as the focus of their further inquiry, including atmosphere, Asteroid Belt, galaxies, black holes, jovian/terrestrial, the moon and tides, white dwarves, spaceships. Students then formed into temporary small groups to study these topics and contribute findings in Knowledge Forum, as reflected in the discourse in threads B4, B19, B11, B12, B1, B2, B5, and B14.

Overall, through co-monitoring key concepts used in readings and in their own knowledge building discourse, students monitored and shaped the conceptual landscape of their collective knowledge, identified weak areas, and focused their personal and collaborative efforts accordingly. Key concepts introduced were not simply something for the students to remember, but suggested main directions of search for new information and deeper thoughts. Responding to the key concepts introduced (e.g. constellations), students developed personal thoughts and asked questions, such as "can't you just see any cluster of stars and say that is a constellation?" Such deepening moves are critical for students to make productive use of key concepts to deepen inquiry. However, in several inquiry threads, such deepening moves were scarce and emerged late, making the online discourse factual and dry.

Discussion

Metadiscourse provides a social, epistemic structure for a knowledge building community to execute high-level collective responsibility for sustained knowledge advancement. The results shed light on two complementary strategies to structure metadiscourse, each with partial success and facing specific challenges.

Metadiscourse focusing on progressive questions represents an "inside out" process to deepen inquiry natively among students, with their personal wonderment and curiosity serving as the driving force. It was implemented in Class A productively, resulting in fruitful questions and ideas that deepened one another over time in the interactive, lively knowledge building discourse. With student questions setting directions for their inquiry, the online discourse engaged student thinking more deeply from the onset in each inquiry thread. The metacognitive meetings further provided the opportunity for students to collaboratively examine their personal questions and envision promising directions. Questions addressing core disciplinary issues were highlighted to the attention of all members, and initial questions were later reformulated and deepened, increasing their potential for knowledge advancement. As a result, the inquiry driven by student questions in Class A addressed almost all the expected curriculum themes, as reflected in their inquiry thread map, even though some of the specific terms noted in the curriculum guidelines were missed from the students' discourse.

The analyses suggest a few conditions of productive metadiscourse focusing on progressive questioning. First, students need to work as a community to co-reflect on the individually identified questions to examine their importance and potential for knowledge advancement. Second, the community needs to be allowed and supported to go through a continual, progressive process by which questions are revisited and refined drawing upon new understanding achieved. Working with the progressive process is a challenge for both the teacher and students. For example, one of the questions initiating the inquiry thread on the Earth presented a "wild" wonderment: What would happen if scientists turned the Earth inside out? This question attracted many responses but with little knowledge advancement for a long time; although a few educationally productive issues did eventually surface, such as the structure of the Earth and how gravity works in the center of the Earth. Helpful moves were made when students connected their "wild" discourse to concepts from readings, with fruitful disciplinary topics coming to their attention.

Metadiscourse focusing on co-monitoring of key concepts used by a community in reference to those in authoritative sources represents an "outside in" process for students to monitor what is out there in the larger world and selectively "adopt" ideas from the field to help focus and grow their own inquiry. Key concepts in a field serve as conceptual landmarks using which students can understand the landscape of the discipline so to better navigate in it. Bringing such key concepts into their own discourse to help review their ideas and initiatives helps to focus, connect, and deepen their discourse in productive directions. Class B conducted such metadiscourse at multiple points of the inquiry with positive impacts. Important topics and issues, including those that were relatively far away from student experience, were brought to student focus. Concepts introduced were used to develop ideas and identify gaps and problems, leading to deeper inquiry. The concept maps created through the metadiscourse served to make the community's knowledge visible, so important advances were shared and weak areas identified and further addressed. Rich cross-theme connections were built surrounding core concepts in the domain, such as orbit, which was not explicitly discussed in Class A.

Several conditions seem essential to productive metadiscourse aided by disciplinary key concepts. First, students need to engage in personal and collaborative reflection on the potential value of concepts, so key concepts and ideas can be differentiated from simple facts and information (e.g. the size of the sun). Second, a constructive epistemological stance needs to be fostered in the community so students do not see key concepts introduced as the answer but resources for deeper questioning and thinking. This stance is critical for the new concepts to take root in the community to grow into productive lines of inquiry. As the analyses suggest, when such constructive moves are missing, student discourse tends to be dry and focus on digesting the concepts and adding factual information.

In conclusion, each of the two designs of metadiscourse supports students to enact collective responsibility to sustain and deepen inquiry under favorable conditions. An integration of both will likely lead to more productive and balanced metadiscourse to foster deep and sustained inquiry. Our future research will test integrated designs of metadiscourse supported by the development of new visualization tools (e.g. inquiry threads) that make collective progress and problems visible to support ongoing reflection and co-planning.

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