Promisingness Judgments as Facilitators of Epistemic Growth and Conceptual Change

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Abstract: Promisingness evaluation plays an important role in knowledge-building discourse, helping the community identify promising ideas and make choices on directions to pursue. This study investigates promisingness judgments carried out by a sixth grade class in their study of a science unit, focusing on the impact of promisingness judgments on students' conceptual understanding and epistemic beliefs. After being engaged in a pedagogical intervention discussing the meaning of promisingness, students made promisingness judgments on their community ideas on a regular basis, using a Promising Ideas tool that is integrated into Knowledge Forum. Results indicated students' understanding of promisingness and capability of making promisingness judgments improved in this process. Analysis of student discourse found promisingness judgments had an impact on discourse patterns, such as contribution types, depth of questioning and justification of ideas. Students' conceptual understanding also improved, reflected by increases of scientific sophistication and epistemic complexity. Moreover, students' epistemic beliefs appeared to co-develop with promisingness knowledge and conceptual understanding. This study opens up rich possibilities of further investigations of promisingness judgments.

Perspectives

The Knowledge Building Approach to Foster Science Learning

Knowledge building as an educational approach was developed with a promise to address the contemporary emphasis on knowledge creation and innovation (Scardamalia & Bereiter, 2006). It treats education as a coherent component of a knowledge-creating society and engages learners in the full process of knowledge creation from an early age (Scardamalia & Bereiter, 2003). The knowledge-building approach, which has been extensively applied in science teaching, has two distinctive characteristics: (1) a "theory-building" approach for deep understanding, and (2) a community-oriented view of learning. The theory-building approach is partially grounded on a strand of conceptual change literature that embraces a “knowledge-as-theories” perspective. According to this perspective, science learning involves revisions of coherent structures grounded in persistent ontological and epistemological commitments (Özdemir & Clark, 2007). For example, Posner, Strike, Hewson, & Gertzog (1982) think conceptual change happens when a learner finds the existing conceptual schema inadequate in solving problems and seeks to replace the initial conception with a more scientific one. Similarly, Carey (1985) argues science learning is a process of “restructuring” a coherent theory framework that connects concepts (see also, Carey, Scholnick, & Nelson, 1999). This notion is also in line with research of “mental models,” which views conceptual change as a gradual shift from a learner’s initial models based on their everyday experience, to more scientific ones generated through reinterpreting their presuppositions and synthesizing them with the scientific theories (e.g., Vosniadou & Brewer, 1992). These theories of conceptual change urge educators to take students’ initial ideas seriously in science teaching. The “theory-building” approach represents one example of conceptual change teaching (Carey & Smith, 1993). It encourages students to produce an explanatory idea and further develop it for a better explanation. Students’ explanatory ideas are always treated as improvable and the goal is to improve them to have stronger “explanatory power” through elaborating, evaluating and refining (Bereiter, 2012). Knowledge building, defined as “continual improvement of ideas” (Scardamalia & Bereiter, 2003), embraces the theory-building approach and treats all student ideas with a development trajectory and subject to further improvement by means of discourse. When it is applied in science learning, students are genuinely engaged in progressive inquiry akin to mature scientific inquiry, seeking increasingly deep levels of explanation (Hakkarainen, 2003).

Besides the theory-building approach, knowledge building has a strong emphasis on knowledge advancement as a *community* enterprise rather than a task of each individual. In the field of science education and learning sciences there have been major shifts from focusing on development of individual minds towards emphasizing on both individual and social aspects of science learning (Vosniadou, 2008). The social construction of knowledge and discursive interactions in classrooms have been widely investigated in science learning research. For instance, research finds science learning can be promoted by engaging students in explaining and articulating their ideas to peers (Roschelle, 1992). Computer-Supported Collaborative Learning (CSCL) as a field of research and practice has produced numerous tools to support conceptual change by enabling, scaffolding, recording, and analyzing student collaboration (Miyake, 2008). For example, the Web-based Inquiry Science Environment (WISE)—a very successful science learning environment—provides functionalities to engage students to carry on scientific debates, review and revise each others’ ideas (Linn, Clark, & Slotta, 2003); rich empirical evidence shows benefits of such environments on students’ individual learning (Slotta & Linn, 2009). Knowledge building, while sharing many traits with such approaches of science education, rethinks school classrooms as knowledge-creating organizations in which the state of knowledge is more determined by the community rather than individuals (Scardamalia & Bereiter, 2006). Based on this understanding, the knowledge-building approach tries to elicit student ideas and treats them as "epistemic artifacts" that can be publicly shared and continuously improved by the community (Zhang, Scardamalia, Lamon, Messina, & Reeve, 2007). To improve their ideas, students take collective cognitive responsibility (Scardamalia, 2002)—which is normally assumed by teachers in other models—in building explanations, designing experiments, introducing resources, synthesizing, and making analogies (Chuy, Zhang, Resendes, Scardamalia, & Bereiter, 2011). The knowledge-building approach was found facilitating conceptual change (Chan, Burtis, & Bereiter, 1997) as well as the development of students' understanding of nature of science (Chuy et al., 2010).

Promisingness Judgments in Knowledge-Building Discourse

The theory-building approach adopted in knowledge building provides students the opportunity to go through long-stretches of work which is usually absent in other constructivist models. In this process, students are exposed to risks, uncertainty, and choice-making that abound in real-world problem-solving. Promisingness evaluation, which is a vital step of "design-mode" thinking in knowledge-building discourse (Bereiter, 2002; Bereiter & Scardamalia, 1993), helps students distinguish ideas and find the most fruitful direction for idea improvement. As expertise research indicates, this task is a natural component of all kinds of creative processes. In his studies of scientific reasoning in real-world laboratories, Dunbar (1995) highlights that scientists assess risks of research projects and are keen to work on research projects which could produce more promising or fruitful discoveries even though they might have a high probability of failure. In explaining creative process, Howard Gardner (1994) also emphasizes the importance of "promisingness" in helping people intuitively detect "discrepant elements" in their work and encouraging them to invest to deal with these elements. Although the "fruitfulness" (T. S. Kuhn, 1977) of the original idea will only become manifest later—until local coherence that explains these discrepancies is achieved—promisingness does play an important role in committing scientists to challenging lines of scientific inquiry that lead to these breakthroughs. This claim is widely supported by reported experience of creative individuals. For example, when discussing the development of the theory of *relativity*, Albert Einstein said, "*During all those years there was the feeling of direction, of going straight toward something concrete. It is, of course, very hard to express that feeling in words; but it was decidedly the case, and clearly to be distinguished from later considerations about the rational form of the solution* (M. Wertheimer & Wertheimer, 1959, p. 228)." Similarly, Michael S. Brown, Nobel laureate in medicine, said, "*I think, we almost felt at times that there was almost a hand guiding us. Because we would go from one step to the next, and somehow we would know which was the right way to go.*" Bereiter (2002) calls those vague, intuitive feelings of direction *knowledge of promisingness*, and goes further to stress that the ability of making promisingness judgments as something distinguishing creative experts from non-experts (see also, Bereiter & Scardamalia, 1993). Thus, the ability to identify promising ideas—ideas that with development might grow to something of consequence—is essential for creative work with ideas and ought to be attended in any form of education for knowledge creation.

As mentioned above, collective knowledge building calls for risk taking and judgments of promisingness in order to pursue novel solutions to problems. In knowledge-building classrooms, students' collective discourse usually starts from their real ideas—composed of naive conceptions in most cases—and gradually advances to more scientific understanding through continuous idea improvement. Substantial, long-stretches of work is normally needed to develop students' naive understanding into something coherent to address their collective knowledge goals. Prior studies found students capable of generating theories, posing explanation-seeking questions, designing experiments to collect data, introducing expert sources, and refining their ideas (e.g., Zhang et al., 2007). However, like anyone working in creative contexts, students in knowledge-building classrooms are also confronted with the significant challenge of identifying promising directions to avoid wasting time or becoming entrapped by unpromising ones (Bereiter & Scardamalia, 1993). Other models of learning, such as problem-based learning and inquiry learning, provide extensive scaffolding—from either teacher or technical tools—to support student learning in complex domains; these scaffolding strategies usually include structures for students to follow or models of performance for students to emulate (Hmelo-Silver, Duncan, & Chinn, 2007). In knowledge building, although students take greater cognitive responsibility than their counterparts under other instructional models, in many cases the teacher still need to take the "steering-wheel" and make decisions about which direction to follow for students (see Zhang, Scardamalia, Reeve, & Messina, 2009). Given the prominent role of promisingness in creative processes, it is intriguing to explore the possibility of explicitly turning more epistemic agency (Scardamalia, 2002) to students, by engaging them in making promisingness judgments in their knowledge building work.

Preliminary work on promisingness judgments has been done in the past few years. Two lines of efforts have been made to support young students' promisingness judgments. Firstly, because the concept of promisingness is naturally challenging for young students (Chen, Chuy, Resendes, Scardamalia, & Bereiter, 2011), pedagogical interventions were designed and tested in knowledge building classrooms to engage them in discussing this concept in meaningful scenarios. Research shows students as young as 8-year-old could grasp the essence of promisingness and apply it in their own knowledge building practice (Chen, Scardamalia, Resendes, Chuy, & Bereiter, 2012). Results indicated promisingness judgments could lead to greater knowledge advancement and closer collaboration. The second effort was devoted to design and develop technical tools to integrate promisingness judgments as an integral component of knowledge-building discourse. In particular, a Promising Ideas (PI) tool has been developed as an add-on of Knowledge Forum and continually refined through a series of design experiments (Chen, Chuy, Resendes, & Scardamalia, 2010; Chen, Scardamalia, Acosta, Resendes, & Kici, 2013; Chen et al., 2012). The current design of the tool allows students to highlight promising ideas in Knowledge Forum notes, tag ideas with specific knowledge goals, and conveniently export them to dedicated workspaces for further inquiry. The tool, coupled with innovative pedagogical designs, has been adopted broadly at various age levels and in several different contexts [e.g., @Boutin2013]. Further design research is needed to explore the impact of promisingness judgments on various aspects of knowledge building.

Epistemic Beliefs in Science Learning

Students' epistemological thinking is one of the aspects that appear to be connected with promisingness judgments. Research of epistemic beliefs, or beliefs about the nature of knowledge and knowing, can be traced back to Perry's (1970) influential work in 1960s and has come a long way to understand epistemic beliefs in multi-dimensions (Conley, Pintrich, Vekiri, & Harrison, 2004; Hofer & Pintrich, 1997; Sandoval, 2005; Schommer, 1990; Schommer-Aikins & Hutter, 2002) as well as to recognize the social aspect of epistemology (Kotzee, Eds., 2013). Early work on epistemic beliefs took a Piagetian stage-like developmental approach, tracing changes of epistemological thinking as a whole in a stage-like manner (e.g., Perry, 1970). Later studies challenged this view treating epistemic beliefs as unidimensional and started to distinguish a set of distinct beliefs that develop more or less independently of each other. For example, Schommer (1990) proposes a multi-dimensional model of epistemic beliefs composed of five dimensions, including the structure, certainty, source of knowledge, the control and speed of knowledge acquisition. Hofer & Pintrich (1997) do not agree with these dimensions and suggest four general epistemological dimensions including *certainty of knowledge*, *simplicity of knowledge*, *source of knowing*, and *justification for knowing.* Although disagreement on dimensions exists among different theories, it is generally agreed that students at all age levels are commonly infested with problematic conception about the nature of scientific knowledge and knowing (Carey & Smith, 1993; e.g., D. Kuhn, 1993; Ryan & Aikenhead, 1992; Sandoval, 2005); students' epistemic beliefs follow a developmental trajectory but could remain quite naïve even in college (Leach, Driver, Scott, & Wood-Robinson, 1996; Ryan & Aikenhead, 1992).

Student understanding of the nature of science knowledge has a direct link with student success in learning (Carey & Smith, 1993; Schommer, 1990). On one hand, students' beliefs about knowledge and knowing would affect their learning. For example, when encountering complex information, students believing in *quick learning* tend not to integrate knowledge deeply (Schommer, 1990). On the other hand, many researchers have attended to the importance of epistemic beliefs and have attempted to improve students' epistemological thinking in science teaching. Researchers argue that conceptual change involves not only changes in concepts, but also changes in students' views about the nature of science (Duit & Treagust, 2003). Chuy and colleagues (2010) find by emphasizing on theory development and sustained creative work with ideas, students could develop deeper understanding of the nature of theoretical progress, the connections between theories and facts, and the role of ideas in scientific inquiry. Chan & Lam (2010) examine the effect of reflective assessment and find as students examine their own and others' understanding their metaconceptual and epistemic awareness could grow.

Promisingness judgments are associated with epistemological thinking in many potential ways. Firstly, one premise of promisingness is that ideas are complex and tentative and knowledge builders can find promising directions to further advance them. Underlying promisingness lives the belief that knowledge is improvable, which is linked to the epistemological dimension of "certain knowledge" (Schommer-Aikins & Hutter, 2002). Second, promisingness judgments also require students to see knowledge as an evolving and changing subject that needs to be *justified* by observation and reasoning rather than residing in external authorities (Conley et al., 2004). Finally, while quality promisingness judgments require sophisticated epistemic beliefs, it also sounds promising to study whether by engaging students in making promisingness judgments their epistemological thinking could be improved. This study builds on prior studies on promisingness judgments in knowledge building, introducing epistemic beliefs as another important factor that is potentially related to promisingness. The present study aims to answer the following major questions: (1) To what extent could students' knowledge of promisingness be improved by pedagogical intervention and practice of promisingness judgments? (2) By practicing promisingness judgments, did students reveal any epistemic growth? (3) To what extent was students' scientific knowledge improved in the process of knowledge building?

Methods

Participants

Twenty six 6th grade students from one class in a Colombian K-12 school participated in this study. This school was a bilingual school; all science lessons in the class were taught in English and all student notes in Knowledge Forum were written in English. Students were from middle-upper class families in Bogotá. Before this study, the teacher and students had several years of experience with Knowledge Building and Knowledge Forum so they were comfortable with this pedagogy and technology.

The Promising Ideas Tool

Promisingness judgments in knowledge building are supported by a Promising Ideas (PI) tool in Knowledge Forum (KF). This tool was first implemented and integrated into KF in 2010 and its functionalities have then been continually revised in a series of design experiments (Chen et al., 2010; 2011; 2013; 2012). The PI tool used in this study included the following major functionalities:

(1) **Highlighting**: Students can highlight promising ideas (and other types of contributions) when reading any *note* in KF. The PI tool provides a customizable set of promisingness categories—called "highlighters"—which a student can choose from when highlighting ideas in a note. The promisingness categories customized for this study included *promising idea*, *unsolved problem*, *useful fact*, and *dead-end*. When finding a snippet fitting into any of those categories, a student can choose the related highlighter and highlight the piece of text in the note window. After the highlighting action is completed, a window will pop-up, asking students to intentionally choose or type-in a criterion for the highlighting and further justify the choice of any criterion (see Figure 1, left).

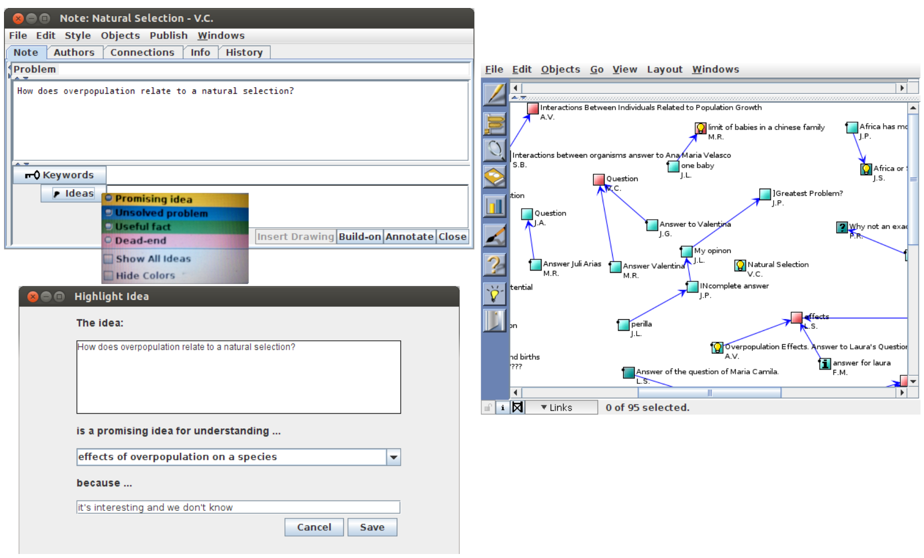

Figure 1: Highlight an idea with the Promising Ideas tool in Knowledge Forum. *Note: (1) upper-left–clicking on an "Ideas" button in the note window will activate a set of highlighters to be chosen from for promisingness tagging; (2) lower-left–this window pops-up when a highlight action is completed, and the student is prompted to provide a content-based criterion for this highlight and justify her choice.*

(2) **Reviewing**: Firstly, a note containing a highlight, whether it is a promising idea, an unsolved problem or a useful fact, will be embellished with a specific icon in the KF view interface (see Figure 1, right). In this case, a note containing a promising idea is embellished with a light bulb, a note with a unsolved problem gets a question mark, and a note with useful information has an "i" on top of its icon. These icon embellishments draw the community's attention to arguably more promising directions in their

community (depending on the quality of their promisingness judgments). Second, and more importantly, an idea aggregation window that lists all highlighted ideas in a view provides a handy way of reviewing highlights (see Figure 2, left). A few filtering and searching functionalities were implemented in the idea aggregation window to facilitate the reviewing process.

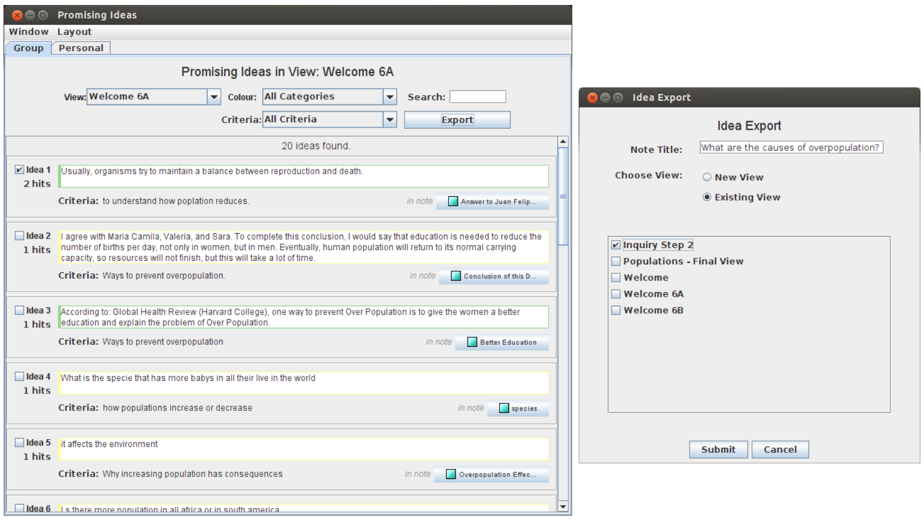

Figure 2: Review ideas in the idea aggregation window, and exporting selected ideas to another view.

(3) **Exporting**: Since the purpose of promisingness judgments is to define next steps of the inquiry, an exporting feature has been introduced since the last version (Chen et al., 2012). When reviewing the aggregated idea list, a student can choose several related ideas to be exported to another workspace for further inquiry (see Figure 2, right). Each time, selected ideas are exported to a single note as references, and the student can further revise this note to explain how these ideas are related and what the next step would be (see Figure 3).

Procedures

This study was conducted in one semester from January to March in 2013 for around 10 weeks (Colombian school calendar). The sixth grade class was studying a biology unit about "population growth." There were four lessons in each week, with each lesson lasting for 45 minutes. The knowledge-building

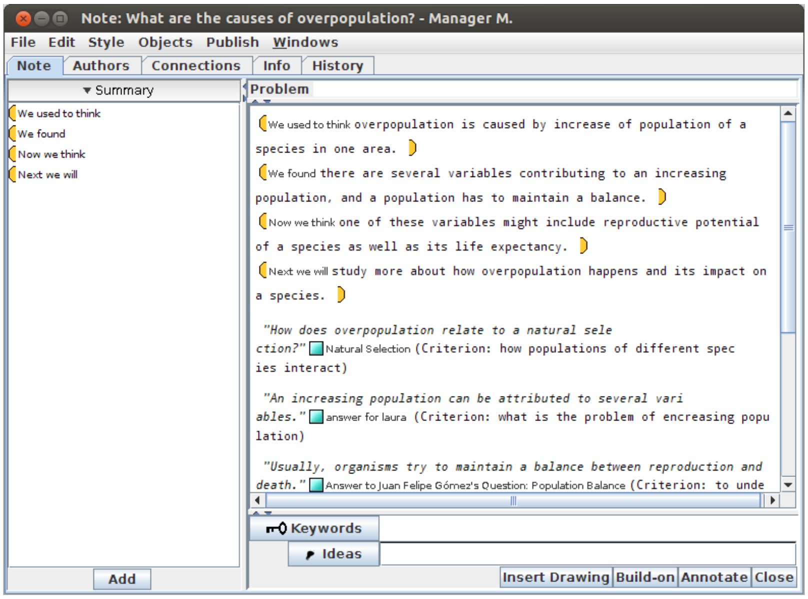

Figure 3: Summarize exported ideas in the exported new note using a set of "Summary" scaffolds.

approach was applied in the class; students discussed topics around population growth and wrote notes in Knowledge Forum.

The procedures of this study is described in Table 1. Detailed explanation of each activity is provided below:

Pre- and post-tests: Pre- and post-tests were designed to measure students' content knowledge, epistemic skills, and understanding of promisingness. Content knowledge was assessed with a conceptual test about "population dynamics"; the test included 3 multiple-choice items and 7 short-answer questions. Epistemic skills are measured with a questionnaire adapted from Conley et al. (2004), focusing on epistemic dimensions including *certainty of knowledge*, *source of knowledge*, *development of knowledge*, and *justification of knowing*. Students' understanding of promisingness was assessed with three items constructed by the authors (see Appendix). All items in the epistemic and promisingness tests were 5-point Likert-scale items. The tests were administered through an online survey, and all students responded together to the tests for one class session each time.

Knowledge building: In each phase, students participated in knowledge-building discourse, advancing their collective understanding by face-to-face discussion in classrooms, dialog in Knowledge Forum, use of authoritative sources, and various types of virtual experiments and games related to population growth.

Pedagogical intervention: Based on findings from the pre-test and previous studies (Chen et al., 2011,), the teacher and researchers identified students' areas of understanding of promisingness that need to be advanced. Pedagogical intervention was designed to tackle those areas, by asking students to discuss related issues and informing them with examples that confront their current beliefs relevant to promisingness. During this intervention, the teacher or the researcher did not directly teach students the "correct" definition of promisingness. Rather, students were engaged in discussing a series of important questions, including "what do you do next when an idea is posted in KF", "what does a promising idea or a promising question mean to you", "are our promising ideas all right or wrong", "what is a fact", "how is fact different from a promising idea", etc. After students achieve a favorable understanding of promisingness, a demo of the PI tool was conducted to get them familiar with the tool.

Table 1: *Procedures of the study.*

Phase	Time	Activities
Phase 1	Week 1-4	Pre-test
		Pedagogical Intervention
		KB + PJ
		PJ Intervention 1
Phase 2	Week 5-7	KB + PJ
		PJ Intervention 2
Phase 3	Week 8-10	KB + PJ
		PJ Intervention 3
		Post-test

Note: KB—knowledge building; PJ—promisingness judgments.

Promisingness judgments: After the pedagogical intervention, students were invited to identify promising ideas in their knowledge-building work and were encouraged to do so on a regular basis all through the semester. As introduced in the previous section, the tool guided them to evaluate each contribution and decide whether it fits into one of the four categories, namely "promising ideas", "unsolved problems", "useful facts", and "dead-ends".

Focal interventions (promisingness judgments reviews): At the end of each phase, reflection on students' promisingness judgments was carried out in a class session. During interventions in Phase 1 and 2, students worked in groups to review the list of ideas in the idea aggregation window. They collaboratively reviewed the community advances, identified frontiers of their knowledge, made connections among identified ideas, and exported related ideas pertinent to any topic they were interested in to a new view. In each group, students collaboratively wrote a synthesis note based on each set of ideas they exported. A set of meta-cognitive scaffolds, including “We used to think”, “We found”, “Now we think”, and “Next we will”, were used to guide their writing. At the end of each intervention, students brought their reflection back to the whole class for discussion. The new view containing these synthesis notes were treated as the starting point of the next phase knowledge building. In Phase 3, the intervention was conducted slightly differently. Given students have already experienced successes and failures in the course of promisingness judgments, they were asked to not only review their judgments made in Phase 2, but also to reflect on all decisions they had made and assess whether ideas they have identified to be promising turn out to be fruitful or not. Students discussed their thoughts as a whole group and each of them wrote a reflection note in KF. The class kept carrying on knowledge building after the reflective intervention; however, knowledge building in Phase 3 was limited because the end of the semester was approaching.

Data Analysis

Data collected in this study included students’ responses to the pre- and post-tests, students’ online discourse in Knowledge Forum, and video recordings of classroom discussion.

In the pre- and post-tests, students’ responses to the content knowledge test were scored. For the open-ended questions, two raters scored the results and the inter-rater agreement measured by Krippendorff’s alpha was .88. As for epistemic beliefs, each response was scored according to the 5-point Likert-scale in the survey (Conley et al., 2004). Students’ performance on each epistemic dimension was then scored by averaging scores of items under that dimension; the scores of reverse items were adjusted accordingly. An overall score of epistemic beliefs was computed by averaging scores of all four epistemic dimensions. Lastly, students’ responses to the promisingness items were scored with the same technique, and a score of promisingness understanding was represented by the mean score of three promisingness items.

In this study, students had worked in three Knowledge Forum views, mapping to three discourse phases. During the process, they wrote notes, read each other’s notes, build on each other, and highlight promising ideas in the communal space. An overview of notes and highlighted ideas in the views is provided in Table 2. Content analysis (Chi, 1997) was conducted on each note focusing on *ways of contribution*, *level of scientific sophistication*, and *epistemic complexity*. For notes under the *questioning* category in ways of contribution coding, *depth of questioning* was further analyzed. For notes under the *theorizing* category, ways of *justification* was also coded. A summary of coding schemes for content analysis of notes is presented in Table 3.

Table 2: *An Overview of Dataset*

Views	Notes	Ideas
Welcome 6A	89	20
Inquiry Step 2	64	17
Populations - Final View	51	1

Table 3: *Coding schemes for content analysis of KF notes.*

Coding Schemes	Categories and definitions
Ways of contribution	*Questioning*
(Chuy et al., 2011)	*Theorizing*
	Introducing or working with evidence
	Creating synthesis and analogies
	Supporting discussion
Scientific sophistication	*1–Pre-scientific*: Misconceptions based on naive
(Zhang et al., 2007)	conceptual framework (scheme).
(4-point scale)	*2–Hybrid*: Misconceptions show mixed
	misconception and scientific frameworks.
	3–Basically scientific: Ideas based on scientific
	framework, but not precisely scientific.
	4–Scientific: Explanations that are consistent
	with scientific knowledge.
Epistemic complexity	*1–Unelaborated facts*: Description of terms,
(Zhang et al., 2007)	phenomena, or experiences without elaboration.
(4-point scale)	*2–Elaborated facts*: Elaboration of terms,
	phenomena, or experiences.
	3–Unelaborated explanations: Reasons, relationships,
	or mechanisms mentioned without elaboration.
	4–Elaborated explanations: Reasons, relationships,
	or mechanisms elaborated.
Depth of questions	*Factual*—Questions to be answered with factual

(Zhang et al., 2007)	information (who, where, when, how many, etc.)
	Explanatory—Questions satisfactorily answered with an explanation (why, how, what if, etc.).
Justification	*Personal beliefs*— justified by personal beliefs
(Hmelo-Silver et al., 2008)	*Grounded beliefs*—a theory is proposed based on empirically or theoretically grounded evidence.

Table 4: *Coding schemes for content analysis of highlighted ideas.*

Coding Schemes	Categories and definitions
Promisingness	1–Already widely discussed
(3-point scale)	2–Worth exploring but not likely to lead to fruitful directions
	3–Leading to fruitful directions and possible breakthroughs
Judgment of Type	1–Not relevant at all
(3-point scale)	2–Relevant from a specific aspect
	3–Fits well naturally
Judgment of Criterion	1–Irrelevant or none criterion
(3-point scale)	2–Relevant direction, but too general
	3–Specific and relevant
Reasoning	1–No or unclear reasoning
(3-point scale)	2–Only mentioning relevant concepts
	3–Clear and through reasoning

Each idea was also analyzed for the quality of promisingness judgments. This quality rating focused on four different aspects of judgments: (1) *promisingness of an idea*—how promising an idea is in its knowledge building context from the perspective of an expert; (2) *judgment of idea type*—for each highlight, how well did a student make choices among four different promisingness categories, including "promising idea", "unsolved problem", "useful fact" and "dead-end"; (3) *promisingness criterion* (or promising for understanding what)—how well did a student identify the criterion each highlight was promising for; and (4) *reasoning*—how well did a student justify the promisingness criterion. We coded all her highlights in these four aspects. Table 4 presents details of coding schemes for this analysis.

Finally, videos of classroom discussion were transcribed and analyzed to track the change of students' conception of promisingness. Video analysis, combined with students' final reflection notes of their promisingness judgments, could provide further qualitative accounts of students' understanding of promisingness as well as their knowledge building work.

Results and Discussion

Evolution of Students' Knowledge of Promisingness

In this study, we first conducted a pedagogical intervention that elicited students' prior conceptions of promisingness and engaged students to discuss them among the class. Then students made promisingness judgments on their collective ideas on a regular basis and also had the chance to reflect on their judgments in three focal interventions. According to Bereiter (2002), the knowledge of promisingness accumulates from experiences of successes and failures of promisingness judgments in creative processes. One important research question we investigated was whether students' knowledge of promisingness had improved in this study.

In the pre- and post-tests, students' promisingness knowledge was assessed with three items. A paired-sample t-test indicated students' promisingness knowledge measured by these items has improved significantly during this study, $t(24) =$ -2.03, $p < .05$.

Classroom discussion was further analyzed to make sense of this change. In the pedagogical intervention session, students pondered on the question "what does a promising idea or a promising idea mean to you" and shared their thoughts to the whole class. Analysis of student discussion found their intuitive understanding of promisingness centered on "truthfulness." For example, two students said,

> *"A promising answer is something that convince you and is a good answer, and we proves that the answer is perfect.""*
>
> *"It is true. You have the observation that is true."*

This notion of promising ideas being true was also found in previous studies (Chen et al., 2011,); it could hamper the quality of promisingness judgments and needed to be treated. At the same time, it was interesting a few students held a relativist point of view towards ideas, although their view of promisingness still centered on truthfulness. For example, a few students said,

> *"It is impossible to locate the most promising answer because people have different points of view. So when someone think one answer is correct, but other people think it's wrong."*

> *"It depends on the person who write the answer because ... if the answer is answered by a scientist, the answer can be more accurate. As well, it depends on the information a person wants."*
>
> *"Other thing is like the point of view you have. If we are educated that way, we will think it's promising. But if we are not educated like that way, you will probably not agree."*

In the process of discussion, new thoughts of promisingness kept emerging. The relativist point of view challenged the original conception of being true, and some students stepped onto the notion of "possibility," which is an important element of promisingness (Chen et al., 2012). One girl said,

> *"We think promising idea is like a possible answer. It probably can be correct."*

A few students built on this idea and thought promising ideas were not necessarily true but closer to the "correct" idea. For example,

> *"I don't think it's absolutely correct because ... we don't think promising means absolutely correct but near correct."*
>
> *"A promising answer is one that is closer to the absolutely correct answer, since there is no absolutely correct answer."*

This change of understanding was fundamental because it gave rise to the notion that promising ideas are leading to scientific understanding. One boy began to think that the pursuit of promising ideas does not depend on expertise one has but on the amount of efforts one invests in.

> *"I disagree with ... I think that's not necessary an expert can make a promising answer. ... Because the promising question takes time, not like a question you're doing in a second."*

This notion touched the essence of promisingness, which is, as Gardner (1994) explains, the thing that encourages scientists to "cast around" for a long time to achieve local coherence. However, during the pedagogical intervention, this notion was only mentioned by this student, and most students still regarded promising ideas as ideas being correct, accurate or convincing.

After two focal interventions engaging students in promisingness judgments on their ideas, students were asked to reflect on their changes of understanding of promisingness. Analysis of recorded discussion indicated that the conception of being correct was widely replaced with more sophisticated views. For example, one girl explicitly discussed her change in this way,

> *"At the beginning I thought it was ... it was the correct answer, but now I think it's not, because there are many different points of view. ... So it's an idea that can be discussed to get to a ... I don't know ... a common opinion that can be the conclusion."*

Similarly, a few other student shared,

> *"I thought a promising idea is an idea that has a lot of answer. I thought like that. But a promising idea is something has a lot of 'searching'..."*
>
> *"I think what makes ideas promising is ... it produces interests of further investigation or discussion, to get to a conclusion."*
>
> *"A promising idea is not the answer, it is the idea that lead you to discussion. As we said before, they are not necessarily the correct answer, but those topics can lead you to discuss and be engaged, and learn a little bit about that topic."*

In these examples, it was evident students' explanation of their understanding of promisingness was a little bit constrained by their vocabulary, as they were struggling to find the proper words to describe promisingness. However, it was clear they had made a lot of progress comparing to their understanding in the pedagogical intervention.

Analysis of promisingness test results and student discussion found evident improvement of students' promisingness knowledge. We further analyzed quality of students' actual promisingness judgments in knowledge-building discourse to investigate their *in-vivo* understanding of promisingness. As described in the methods section, quality rating of promisingness judgments focused on four aspects including promisingness of selected "promising" ideas, judgments of idea type, criteria, and reasoning. Because only one idea was highlighted in Phase 3, we only compared the mean scores of each aspect between the first two phases. t-Tests indicated only the *reasoning* aspect was significantly different between Phase 1 and Phase 2, $t(31)$ = -3.52, $p < .01$, while differences in the other three dimensions were nonsignificant at the .05 significance level. Means and standard deviations of four dimensions in each phase are presented in Table 5. Further analysis of mean scores found students' performance on *judging idea types* already quite high in Phase 1 and left little space to improve in Phase 2. For the other two aspects, i.e. idea promisingness and judgment of criterion, great variance was found among students, implying substantial individual differences on those two dimensions. Overall, analysis of students' promisingness judgment quality indicated that even though their conception of promisingness has been improved in this study, their actually performance in most important aspect of promisingness judgments was not significantly improved. As Bereiter (2002) notes that knowledge of promisingness is acquired from rich experience; so perhaps students needed more experience to achieve significant improvement on their actually judgments.

Table 5: *Improvement of promisingness judgment performance.*

Phase		Promisingness	Categorization	Criterion	Reasoning
Phase 1	*M*	2.00	2.50	2.10	1.35
	SD	0.67	0.83	0.91	0.67
Phase 2	*M*	2.12	2.70	2.41	2.24
	SD	0.78	0.47	0.87	0.83

Impact of Promisingness Judgments on Discourse Patterns

Promisingness evaluation as a crucial component of design-mode thinking is expected to have a great impact on knowledge-building discourse. Effective promisingness judgments should help the class focus on promising ideas in the community and keep deepening the inquiry. Promisingness judgments could also promote higher-order thinking and metadiscourse in knowledge building, such as making synthesis and diagnosing knowledge progress. To investigate the impact of discourse patters, we focused on the changes of ways of contributing patterns, depth of questioning, and ways students justify their ideas in different phases.

Preliminary analysis of ways of contributing patterns focused on the distribution of contribution types in each phase. According to the results presented in Figure 4, students has maintained a high portion of theorizing contributions across three phases. Questioning contribution has declined, representing a trend of convergence in discourse. The number of synthesizing contributions started to appear in Phase 2 and Phase 3, mostly because in each intervention session students were exporting and synthesizing promising ideas to reset their discourse. Reflecting notes were only present in Phase 3, because students wrote their reflection on promisingness judgment at the end of this unit. To summarize, promisingness judgments had influenced contribution types in many different ways, such as encouraging synthesizing and and promoting convergence. However, to what extent had such impacts promote knowledge advancement is still to be further analyzed. For example, given questions are often regarded as important "boosters" of knowledge building, whether the decline of questions was a good thing is still to be analyzed. We plan to create Chronologically-Ordered Representations of Discourse and Tool-Related Activity (CORDTRA) diagrams (Hmelo-Silver, 2003; Hmelo-Silver, Chernobilsky, & Jordan, 2008) to further interpret the pattern of ways of contribution in discourse, focusing especially on the relations among different contribution types.

As for the depth of questioning, a *chi-square* test of independence found the

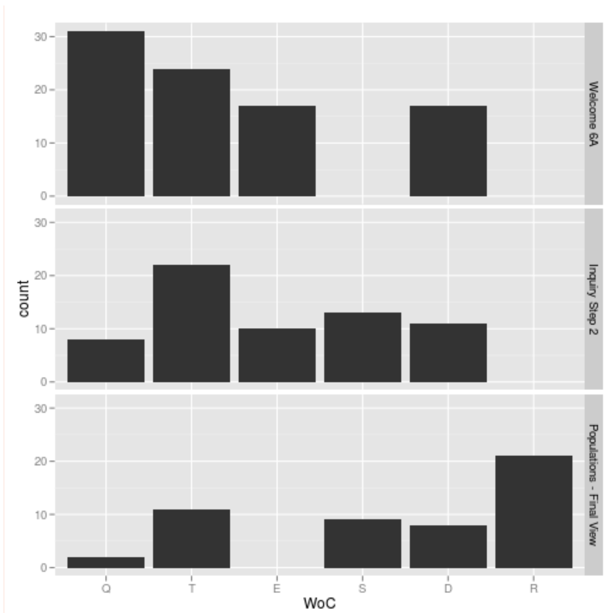

Figure 4: Changes of contributing types in three phases. *Note: Q–questioning; T–theorizing; E–evidence; S–synthesis and analogies; D–supporting discussion; R–reflecting.*

depth of questions marginally significantly different across three phases, $\chi^2(2) = 5.50$, $p = .06$. Further descriptive analysis found the number of *factual* questions declined from 16 (out of 31) in Phase 1 to 1 (out of 8) in Phase 2, and to none in Phase 3. Analysis of *justification of theories* did not confirm a significant improvement across three phases, $\chi^2(2) = 4.62$, $p = .10$. However, the count of theories grounded on evidence was found increasing from 4 (out of 24) in Phase 1 to 7 (out of 23) in Phase 2. Overall, results found an increasingly deep level of questioning and more sophisticated type of justification of ideas across phases. However, it is to be investigated whether these changes should be attributed to promisingness judgments or were just natural progression in knowledge-building discourse.

Conceptual Advancement in Population Dynamics

Conceptual quiz. A conceptual quiz was designed to tap into students' understanding of the biology unit "population dynamics" and administered in the pre- and post-tests. Items in this quiz were designed based on conceptual literature related to this topic. Each student's responses were graded. A paired samples *t*-test was conducted to assess the change of students' conceptual understanding during this study. Results indicated a significant improvement, $t(24) = -5.75$, $p < .001$. The average score was improved from $M = 5.44$ ($SD = 1.74$) to $M = 8.46$ ($SD = 3.16$).

Level of scientific sophistication. The level of scientific sophistication was coded for each note containing a *theorizing* contribution. We compared mean scores of scientific sophistication between Phase 1 and Phase 2 by two-sampled *t*-tests. Phase 3 was left out in this comparison because of its limited number of theorizing contributions. Results indicated scientific sophistication of notes had improved significantly from Phase 1 to 2, $t(44) = -2.02$, $p < .05$. Notes moved from a *hybrid* level of scientificness ($M = 2.12$, $SD = 0.85$) to a level closer to *pre-scientific* ($M = 2.65$, $SD = 0.93$).

Epistemic complexity. We further evaluated students' knowledge gains with respect to the level of epistemic complexity. Like analysis of scientific sophistication, all theorizing notes were coded using an epistemic complexity scheme adopted from Zhang et al. (2007). Unfortunately, two-sampled *t*-tests comparing epistemic complexity between Phase 1 and Phase 2 did not confirm a significant difference, $t(44) = -0.68$, *n.s.*. Most contributions stayed between levels of *elaborated facts* and *unelaborated explanations*, and there was a great variance among contributions in epistemic complexity. One possible explanation of this result is that epistemic complexity, comparing to scientific sophistication which is more directly related to content knowledge, is naturally harder to improve for younger students. The average epistemic complexity of Grade 4 students' portfolio notes reported in Zhang et al. (2007) was on the level of *elaborated facts*, and complexity of thinking by college students in problem-based learning studied by Hmelo-Silver et al. (2008) was still mostly *knowledge telling* or *elaborated telling*. Thus, the timespan of this study could be too short to change epistemic complexity in sixth grade students' knowledge building.

Changes in Students' Epistemic beliefs

One of the most important questions in this study was whether promisingness judgments could facilitate epistemic growth of students. In the pre- and post-tests, students were administered a questionnaire on epistemic beliefs adapted from Conley et al. (2004). This questionnaire measures epistemic beliefs from four independent dimensions, including *source of knowledge*, *certainty of knowledge*, *development of knowledge*, and *justification of knowing*. To test the consistency of this instrument with previous studies, confirmatory factor analysis (CFA) was conducted. Test of four-dimension hypothesis in CFA was sufficient, $\chi^2 = 307.6$, $p < .001$, with a goodness-of-fit score of 0.94. Detailed inspection on the loading matrix found four identified components were properly loaded on related questionnaire items as expected.

To investigate changes of epistemic beliefs happening with students, paired-sample t-testes were conducted on the sum score of epistemic beliefs as well as scores of four specific epistemic dimensions. Results indicated that students had significantly improved on their overall epistemic beliefs ($t(24) = -3.80$, $p < .001$), source of knowledge ($t(24) = -2.61$, $p < .05$), and justification of knowing ($t(24) = -2.96$, $p < .01$). The improvement on the other two epistemic dimensions—certainty of knowledge ($t(24) = -1.86$, $p = .08$) and development of knowledge ($t(24) = -1.72$, $p = .10$)—was nonsignificant. Means and standard devisions of all dimensions are presented in Table 6. Further inspection on mean scores found students' epistemic beliefs in the source and certainty dimensions were less developed compared to the other two dimensions. This phenomenon could be related to a school culture that emphasizes on testing. Since the certainty dimension had not significantly improved, we further investigated its change in this study. Because it is widely accepted gender is an important factor for epistemic beliefs (e.g., Perry, 1970), we further conducted a two-factor analysis of variance (ANOVA) of the certainty dimension on trial (Pre- vs. Post-tests) and gender (Female vs. Male). Results found gender as the only significant main factor ($F(1, 48) = 9.41$, $p < .01$), with girls having more sophisticated epistemic beliefs in certainty of knowledge. However, post-hoc comparisons among four groups indicated girls did not improve much on this dimension (from 3.52 to 3.54), while boys had caught up (from 3.00 to 3.44) during this study. This finding points to an intriguing direction for future studies.

To explore which factors might have contributed to the change of epistemic growth, correlation analysis was conducted among various measures, including epistemic beliefs, conceptual understanding, and a number of indices of KF activities. Results indicated overall epistemic growth was significantly correlated with change of promisingness conception ($r = .47$, $p < .05$) and conceptual understanding ($r = .46$, $p < .01$). Promisingness conception and conceptual understanding were also found significantly correlated ($r = .52$, $p < .01$). For each specific dimension, the *development of knowledge* dimension was found significantly correlated with promisingness conception ($r = .42$, $p < .05$) and marginally significantly correlated with conceptual growth ($r = .38$, $p = .06$); correlations between changes with other dimensions and promisingness conception and conceptual growth were nonsignificant.

Table 6: *Improvement of epistemic beliefs from pre- to post-tests*

Stage		*Source*	*Certainty*	*Development*	*Justification*	*Overall*
Pre-test	*M*	3.05	3.22	4.07	4.12	3.62
	SD	0.60	0.69	0.68	0.43	0.32
Post-test	*M*	3.44	3.47	4.29	4.40	3.90
	SD	0.85	0.75	0.34	0.38	0.41

The relation between epistemic growth and a number of KF indices were investigated too. Firstly, using the Analytic Toolkit (ATK, Burtis, 1998) we extracted several important individual measures of students, including number of notes created, number of notes linked, number of notes read, and number of revisions. Correlation analysis between these measures and epistemic growth dimensions only found the correlation between number of revisions and the development dimension was significant, $r = .56$, $p < .05$. This correlation is interesting and straightforward because the more a student believes an idea has a development trajectory, the more likely the student will revise their ideas in knowledge building.

Based on exported data and content analysis results, we further computed several other KF measures that reflected quality of students' contributions for analysis. These measures included: average scientific sophistication and epistemic complexity of notes, average word count of notes, average number of promising ideas identified in notes, average times one's notes were read by other students, and average times one's notes were referenced by other students. Correlation analysis found overall epistemic skills of students in post-test marginally significantly with average word count of notes, $r = .52$, $p = .07$. Average word count of notes were also found marginally significantly correlated the source and development dimensions, $r = .53$, $p = .06$ and $r = .55$, $p = .05$ respectively. These results implies the more sophisticated epistemic beliefs a student has, the longer notes she writes, or vice versa.

In summary, correlation analysis found epistemic beliefs co-developed with conceptual knowledge and understanding of promisingness. A number of knowledge building activities may have an impact on the development of some specific aspect of epistemic beliefs. However, it should be noted that these correlation analyses are quite preliminary, and no causal conclusion can be drawn at this point. More advanced analysis, such as path analysis, is needed to distinguish the relations among these variables.

Conclusions

Promisingness judgments are thought to be the heart of effective, creative actions, and improved by immersing in progressive problem solving (Bereiter & Scardamalia, 1993). In knowledge-building discourse, an important step is to assess promisingness of ideas presented in a community and choose the most promising direction to follow. This study engaged a class of sixth grade students in making promisingness judgments on their own ideas. Results indicated students' naive understanding of promisingness could be easily treated with a pedagogical intervention that simply invited them to discuss their thoughts about promisingness. Students' capability of making promisingness judgments, more specifically the ability to justify one's judgments with reasoning, appeared to improve across different phases. Further, promisingness judgments were found to have an impact on discourse patterns, such as distribution of contribution types, depth of questioning, and justification of theories. In the process, conceptual understanding also significantly improved, reflected by increase of scientific sophistication and epistemic complexity across phases. Last but not the least, students' epistemic beliefs appeared to co-develop with promisingness knowledge and conceptual understanding.

This preliminary study opens possibilities of further investigations on promisingness judgments in knowledge-building discourse, especially the effectiveness of promisingness judgments in facilitating students' epistemic skills. However, it should be noted this study has a few limitations. First of all, the lack of a control class undermines the comparisons made across different discourse phases in this study. Someone could argument that given the absence of a control group, it is unclear whether these improvement in conceptual knowledge and epistemic beliefs could be attributed to promisingness judgments. The second limitation of this study is the small sample size. This class only had twenty-six students, and around half of them were fairly active in using the Promising Ideas tool to make promisingness judgments. This limitation hampers same statistical analysis conducted in this study, especially correlation analyses which requires data from different sources and the valid number of cases further decreased in the data merging process. Future research with stricter design and larger sample sizes will be conducted to deepen this line of research around promisingness judgments. At the same time, we will also further advance technological design of the Promising Ideas tool and explore its integration with the next generation of Knowledge Forum.

Appendix: Items to measure promisingness understanding

1. Presented with two competing ideas, I may not be able to decide which one is true, but I could sense which one is better.
2. When I firstly come up with an idea to explain something, being correct is the most important thing.
3. Scientists often make mistakes, and they're good at learning from them.

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