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Corresponding author: J. van Aalst, Faculty of Education, the University of Hong Kong, **vanaalst@hku.hk**.

Implementing Knowledge Building: Analysis of a Face to face Discussion by Grade Four Students

Jan van Aalst, Simon Fraser University

Michael Cummings, British Columbia School District 43

Abstract

Researchers say that teachers may implement an educational innovation without adhering to the principles underpinning its design. However, such principles may not take typical classroom conditions into account adequately. The goal of this study was to explore tensions between implementing principles underpinning knowledge building and contextual factors that may compete for the teacher's attention. To this end, we discuss five excerpts from a class discussion on the motion of spinning tops held by a class of grade four students, coming at the end of a five-month implementation of knowledge building. Each excerpt is first followed by the teacher's perspective and then by the researcher's perspective. Our analysis highlights two tensions that constrain agency, arising from the need for the students' social development and their need to learn scientific concepts. We offer some suggestions for addressing these tensions.

Introduction

Most educational innovations seem to have a similar fate: They do not produce the sustainable and scalable impact on teaching that is expected of them. For example, despite much writing on constructivism in the last two decades, the vast majority of classrooms remain teacher-centered and didactic. The learning cultures emphasizing student agency, real-world problems, collaboration, and classroom discourse pioneered in the 1980s (e.g., Brown & Campione, 1990; Cognition and Technology Group at Vanderbilt [CTGV], 1992; Edelson, Pea, & Gomez, 1996; Papert, 1980; Bereiter & Scardamalia, 1993) still only exist in relatively small pockets of practice. Though many factors contribute to this, discussions of innovative work increasingly focus on the *context* in which a new educational design is implemented. Proponents of design-based research examine an implementation of a design in terms of how well the principles underpinning the design have been implemented (Brown & Campione, 1996; Collins Joseph, & Bielaczyc, 2004; Design-Based Research Collective, 2003). However, such principles may not take typical classroom conditions into account adequately.

We propose that context needs to play a more prominent role in analyzing the work of innovating in classrooms. Contextual factors such as students' needs for social development, individual differences, the mandated curriculum, and emphasis on standardized assessment compete with the innovation for the teacher's attention, and may constrain implementation of the principles underpinning an innovation. As Hargreaves, Earl, Moore, and Manning (2001) point out, educational change is impossible if the teacher is not able to enact it, so it is important to create the conditions that make change possible. Fullan (2003) asserts that context is the very thing one hopes to change through innovation.

This paper explores tensions between contextual factors and implementing the principles underpinning 'knowledge building' (Bereiter, 2002; Bereiter & Scardamalia, 1993) and suggests ways the tensions may be addressed. We choose knowledge building as an example of an educational innovation to explore because it is a model of inquiry that is based on a long research program on how people learn

(Bransford, Brown, & Cocking, 1999); emphasizes 21st century skills such as collaboration, learning how to learn, and knowledge construction (Bereiter, 2002); and requires changes in educational culture (e.g., more emphasis on student agency). We discuss five excerpts from a class discussion on the motion of spinning tops held by a class of grade four students to illustrate how tensions among the various considerations guiding classroom discourse frequently move the implementation of an innovation into the background. The lesson was part of a two-week instructional unit on *balance* that came at the end of a five-month implementation of knowledge building. Each excerpt is accompanied by an informal analysis by the teacher showing what he was attempting to accomplish and how he interpreted the students' and his own actions. Each excerpt is also discussed by the researcher from the point of view of the principles underpinning knowledge building model. In the discussion section we discuss the two main tensions we identified.

Models of inquiry

In the last decade there has been much interest in inquiry as a method for learning science concepts (Edelson, Gordin, & Pea, 1999; National Research Council [NRC], 1996). In this section we review two common models of inquiry, 'guided inquiry' and 'progressive inquiry', and then describe Bereiter and Scardamalia's knowledge building model as a special case of the second.

Content-focused inquiry

The most prevalent use of inquiry in science education focuses on learning scientific concepts (NRC, 1996, p. 31); the most common model for such inquiry is usually referred to as *guided inquiry*. Typically, students work in small groups to complete a series of investigations designed to lead them from their current understanding to scientific understanding of content (e.g., CTGV, 1992; Goldberg & Bendall, 1995; White & Fredericksen, 1998). The design of these sequences is informed by extensive research on the ideas students use in thinking about science topics, and often involves collaboration with scientists. There also are clearly defined classroom roles for teachers, such as monitoring that students write down predictions and introducing new concepts. Though most researchers do not claim these uses of inquiry are a fair representation of inquiry as practiced by scientists, nor that students are expected to *discover* scientific laws, students do learn some skills that are also practiced by scientists, such as making predictions, data collection and analysis, making inferences, and discussing findings. Cognitive and metacognitive benefits from these uses of inquiry measured by pre- and post-tests of content knowledge, as well as some evaluations of inquiry skills, have been well documented (Gunstone, Gray, & Searle, 1992; Hake, 1998; Linn & Hsi, 2000; Thornton & Sokoloff, 1990; White & Fredericksen, 1998).

Progressive inquiry

Content-focused inquiry has two difficulties. First, it is highly structured and therefore leaves relatively little room for student agency. Studies in cognitive strategy instruction in the 1980s and 1990s have revealed that students at varying achievement levels are capable of roles traditionally reserved for teachers, such as instructing, planning, monitoring and summarizing, provided that they receive adequate scaffolding (Bereiter & Scardamalia, 1987b; Palincsar & Brown, 1984; Scardamalia & Bereiter, 1991; White & Fredericksen, 1998). Although the research literature on higher order thinking supports the thesis that many elementary school students are capable of being agents of their own and their peers' learning, many teachers continue to doubt this possibility and find it difficult to give more control to students.

Second, content-focused inquiry treats inquiry as a linear and predictable process. Rather, scientific inquiry is *emergent*: It is usually not possible to specify at the outset what investigations and concepts will be needed to make progress toward understanding a scientific problem (see Latour, 1987).

A number of inquiry models have been developed that aim to address these difficulties to varying degrees (authentic science, Roth, 1995; collaboratory notebook, Edelson, Pea, & Gomez, 1996; communities of learners, Brown & Campione, 1990; dialogic inquiry, Wells, 2001; knowledge building, Bereiter & Scardamalia, 1993; project science, Polman, 2000). These models all emphasize self-directed problem definition, investigation, and evaluating knowledge advances through discourse; in some cases the discourse occurs in a community (e.g., communities of learners, authentic science) while in other cases it involves a smaller group of students and a mentor who has expertise in the area of the inquiry (e.g., project science). We refer to these inquiry models as *progressive inquiry* to emphasize that they proceed through cycles of investigation in which students seek progressively deeper understanding: One question leads to new questions in ways that are not predictable at the outset. In progressive inquiry, students are expected to examine their current understanding of real-world problems and revise it through cycles of studying, investigation, and discussion. It is expected that students' understanding of the science related to these problems will be significantly better than before their inquiry; nevertheless, in many cases there will remain misconceptions, inconsistencies, and questions. This somewhat "messy" outcome is in our view a fair representation of what happens during a limited period of research by scientists. However, as in scientific inquiry, it is essential that students become aware of the limitations of their explanations and of the need for further learning in the future to address them.

Knowledge building as an example of progressive inquiry

The term 'knowledge building' is now commonly used by researchers to describe models of progressive inquiry; we use it to refer to the model developed by Bereiter and Scardamalia (1993). Accordingly, in this article knowledge building refers to a model of how a community creates, scrutinizes, tests, and improves knowledge, and gradually incorporates it into its practices. The knowledge building model can be regarded as an example of progressive inquiry models – but it holds a unique position among them, as explained below.

First, knowledge building places much emphasis on *writing* as a process that can aid knowledge revision (Bereiter & Scardamalia, 1987a). To facilitate knowledge revision through writing, students contribute their ideas to a communal, computer-supported database, where they remain available for reflection, peer commenting, and revision. Originally called CSILE (computer supported intentional learning environments, Scardamalia, Bereiter, McLean, Swallow, & Woodruff, 1989), the current version of the software is called Knowledge Forum™ (www.knowledgeforum.com). Features that distinguish Knowledge Forum from other computer-supported discussion environments provide support for maintaining focus on the knowledge-revision possibility of writing and for working with ideas once they have been entered into the database, such as synthesis of ideas and the formulation of "rise above" ideas. Studies of knowledge building have focused on the database as the primary site of knowledge building, and have sometimes been criticized for neglecting the role of classroom discourse.

Second, ideas are regarded as *improvable objects* (Bereiter, 2002). This does not simply mean that students improve their own understanding but that they recognize that though currently accepted scientific knowledge is highly reliable, it has undergone a process of testing, scrutiny, debate, and revision, and that it may in the future again become necessary to modify it (van Aalst, 2006). King and Kitchener (1994) made this epistemological position the highest stage of their Reflective Judgment Model.

Third, knowledge building places strong emphasis on advancing the *collective knowledge of a community* (usually a class of students) rather than only on individual knowledge advances (Scardamalia, Bereiter, & Lamon, 1994). Students are expected to add to the frontier of knowledge in the community, as they see it. Of course, this does not mean that students are discovering things that are unknown to scientists or that they are engaged in ‘discovery learning’, which has been criticized extensively in the science education literature for distorting the nature of science (Hodson, 1996). Students are expected to learn science that is accessible to them, but apply this knowledge to a problem that is situated in the community. For example, a class may be interested in understanding how to design a good spinning top with materials available in the community. While no texts may be available that provide a solution, students do not need to *discover* the relevant science. However, they do need to understand the science to be able to defend their solutions. Whether or not students are working on a problem that has been solved before by someone beyond their community, the knowledge building process is the same from an epistemological and sociocognitive perspective (Bereiter, 2002).

Fourth, though *student agency* is at the heart of progressive inquiry, it is especially prominent in literature on knowledge building. According to Scardamalia and Bereiter (1991), teachers often do a great deal of cognitive and metacognitive work such as planning, summarizing, reviewing, and synthesizing, much of which can be done by students. Making students agents of their own learning would seem essential to promoting lifelong learning.

In sum, knowledge building provides a model of how knowledge is advanced in scientific communities from an epistemological and sociocognitive perspective. Of course, as practiced in schools it is only a model, and there are important differences from scientific communities. For example, White and Fredericksen (1998) liken students engaged in inquiry to novice scientists rather than seasoned scientists due to a much greater need for mentoring. Nevertheless, we suggest knowledge building can become an important model for teaching students about the emergent and discourse-based nature of scientific inquiry – important aspects of the nature of science – and for fostering self-directed learning.

There is a growing literature indicating positive effects of knowledge building in several domains: nature of science (Hakkarainen, Lipponen, & Järvelä, 2002), conceptual change and metacognition (Chan, Burtis, & Bereiter, 1997; Oshima, Scardamalia, & Bereiter, 1996), and literacy (Scardamalia, Bereiter, & Lamon, 1994). For a comprehensive introduction to knowledge building which discusses its theoretical foundations and relation to contemporary learning theories see Bereiter (2002).

Knowledge building principles

As explained earlier, analysis of implementations of educational innovations has focused on how well the principles underpinning the innovation have been implemented. In the case of knowledge building, Scardamalia (2002) has proposed a system of twelve interrelated sociocognitive principles that describe knowledge building. These are based on experience accumulated over 15 years in elementary schools in Canada and the United States (ranging from inner city to laboratory schools), as well as the developing literature on expertise and knowledge building. Together, they explain the key features of “best practice” examples of knowledge building that have been obtained from classrooms. The classrooms may be described as being typical of schools in metropolitan centres in terms of the range of achievement, the proportion of students designated English as a Second Language (ESL), and socioeconomic status. We describe a subset that is used later in our discussion (adapted from Scardamalia, 2002):

- *Epistemic agency*: Students set forth their ideas and identify gaps in understanding; they deal with problems of goals, motivation, evaluation, and long-range planning that are normally left to teachers.
- *Democratizing knowledge*: All students are legitimate contributors to the shared goals of the class; all are empowered to engage in knowledge building.
- *Constructive use of authoritative sources*: To know a discipline is to be in touch with the present state and growing edge of knowledge in the field. This requires respect and understanding of authoritative sources, combined with a critical stance toward them.

The study

The goal of the study was to explore moment-to-moment teacher action during a class discussion with a view to understanding how features of the context produce tensions between current educational practice and the innovation being implemented. As well, though some studies of classroom discourse related to other models of progressive inquiry exist (Roth, 1995; Wells, 2001), most prior studies of knowledge building have focused on the computer database. Therefore, we examined a class discussion that came at the end of a five-month implementation of knowledge building. The discussion excerpts are first discussed by the teacher and then the researcher. The juxtapositions of the two perspectives brings the two tensions into focus.

The setting

In this section we describe the teacher's instructional approach, the students, and the lesson. We refer to the teacher – the second author – as "Mr. C."

The teacher

At the time of this class discussion, Mr. C was in his fourth year of teaching elementary school. His teaching was influenced strongly by the notion of *hunkering* (Cummings, 1998). This is an embodied state in which the teacher works with the students at their eye level rather than looking down at them and dispensing knowledge; hunkering embraces the notion that part of teaching involves developing an affectionate and emotional bond between the teacher and student. Such rapport seems necessary in a classroom if students are to feel empowered to explore their thinking through dialogue, without fear of being belittled or unduly judged by peers or the teacher. According to Mr. C, the role of the teacher in a knowledge building classroom is one of raising the spirits, of motivating and of creating an atmosphere such that there is a willingness of students to participate in conversation; the teacher must be seen as an equitable facilitator of *students' ideas*. The teacher listens carefully, and learns along with the students when to interject ideas, when to encourage the shy to speak, while making sure that vocally confident students do not dominate the conversation. All children need to feel respected and know that all contributions are important and necessary for co-building the curriculum and a knowledge base. With such teachers, children are involved in exciting educational enterprises and make the greatest growth in language learning and conceptual development. Mr. C believes that teaching is a craft that encourages language development rather than a teacher-delivered curriculum. That is, student talk, writing, and purposefully listening to each other's sense-making must be a foremost curricular concern in the classroom. Prior to the lesson discussed in this paper, the teacher participated in a four-day conference on knowledge building as well as monthly after-school meetings to discuss classroom work. As part of another study (van Aalst & Hill, in press), Mr. C received frequent in-class assistance from a graduate research assistant earlier in the school year, but not at the time of the lesson discussed here.

The students

The students were 28 grade four students (approximately ten years old) in a school in metropolitan Vancouver; eleven students were girls (39%) and seventeen students were boys (61%). The children, their parents, or their grandparents came from Europe, the Middle East, India, South-East Asia, South America, and Australia. The proportion of students designated as ESL (English as a Second Language) was above the provincial average.

The lesson

Mr. C spent the first few months of the academic year developing a classroom culture that emphasized dialogue. Important to this work were frequent class discussions during which Mr. C sat on the floor with the students, consistent with his emphasis on hunkering. Early in the second term, he introduced the idea of knowledge building and introduced Knowledge Forum in a three-month unit on electricity. At the beginning of the unit, the students were asked to light a flash light bulb with a single 1.5-volt cell using only one wire; Mr. C used this experience to explore the idea of a closed circuit and began to develop language for talking about electricity with the students. Class discussions led to writing notes on Knowledge Forum, but the converse also occurred. The use of Knowledge Forum was designed to be central to the class's electricity inquiry. Following the electricity unit, the class did a shorter unit on First Nations issues, also using Knowledge Forum.

At the end of the school year the class completed a two-week investigation of spinning tops. As with the electricity and First Nations units, this unit was an attempt to implement the knowledge building perspective, but this time the students did *not* use Knowledge Forum. They spent several days playing with and analyzing the spinning properties of tops. For example, one investigation involved students working in pairs timing and graphing the spinning motion as they raised and lowered a flywheel (a paper plate) on an axle (a dowel) held in place by two rubber stoppers (see Figure 1). Another investigation involved timing how long each top spun as students added weights (nuts and bolts) to the flywheel.

[Insert figure 1 about here]

We focus our attention on a single lesson in this short unit for two reasons: It occurred near the end of the school year so the students were relatively experienced with class discussions, and Mr. C regarded this lesson as showing rich dialogue. At the start of the lesson, the class was gathered in a large classroom with an array of commercially manufactured spinning tops. Included in this collection were wooden, plastic, string operated pull-type tops, as well as gyroscopes. After approximately 30 minutes of play, the 28 students gathered in a large circle, as they had done many times before, to debrief their experiences and express their views and ideas about why the top continued to spin.

Analytic approach

The class discussion was video recorded and then transcribed by a research assistant; the transcription was checked by the teacher. We analyzed five excerpts of the transcript that illustrate tensions between the sociocognitive principles of knowledge building (Scardamalia, 2002), and other voices in the classroom discourse that are in competition with it. Our goal was not to provide causal explanations of educational phenomena that can be generalized to other settings or to point out gaps between the teacher's and the researcher's goals, but to develop a better understanding of the constraints produced by features of the context. We provide two levels of interpretation, as explained below.

- *Teacher perspective*: The teacher provides his interpretation of the dialogue based on his own goals, what is being said, and insights into the students' thinking and actions derived from working with them throughout the school year.
- *Researcher perspective*: This, written by the researcher, examines the dialogue – and sometimes the teacher perspective – from the point of view of knowledge building and the literature on science education. The three knowledge building principles described earlier (epistemic agency, democratizing knowledge, and constructive use of authoritative sources) are used as the primary lenses for analysis.

In the final section of the paper we attempt to resolve some of the issues raised.

Excerpt 1: Inviting dialogue and scientific inquiry

Mr. C: Why does the top need a flywheel at all? (After removing the centre axle of one of the tops, he makes several unsuccessful attempts to launch just this portion as a spinning top.)
Danny: It makes the top spin because when it's smaller it can't have more speed and when its bigger air spins it. Then it spins longer.
Mr. C: The air spins it...
Jimmy: I have something to say about that...
Mr. C: OK.
Jimmy: Yeah, because like, when you took the middle part out, maybe the air is getting and making it fall over. When it has that circle thing on, the air goes on past the circle.
Mr. C: Wow! That's an interesting thought isn't it?

Teacher Perspective: I pose Danny's idea back to the children in the form of a question. Although my response to Danny is important in giving *air* some authority, I don't feel that I overly influenced the discussion at this point. In truth, I don't think I fully understood Danny; I merely chose a word from what appeared to me to be a jumble of ideas to try to keep the conversation going. Jimmy, who answers next, has obviously been thinking about the concept of air because his immediate and full answer indicates a well-formed thesis and sophisticated thinking. However, language is failing him in his efforts to produce a clear articulation of his reasoning. Again, I do not immediately understand his reasoning fully, but I do realize that he has significantly advanced the conversation that Danny had initiated.

Researcher Perspective: I also find the students' ideas difficult to follow and do not understand why Mr. C is interested in the word "air," which plays no significant role in a scientific explanation. (I think about the moment of inertia.) I am impressed that Mr. C encourages the students to explore their idea of the role of air without intervening. However, I wonder about the emphasis of his last statement, "Wow! That's an interesting thought isn't it?" Why does he validate Jimmy's idea so strongly? According to the principle of epistemic agency, one would expect students to be capable of validating the community's ideas.

Excerpt 2: Respect for students' ideas

One reason why Mr. C validated Jimmy's idea so strongly was that he was drawn into the discussion. This is consistent with his commitment to hunkering, in which he works with students at their elbow level (Cummings, 1998) – as a co-learner. Here we have the first example of competition between implementing the knowledge building principles and the context, in this case between supporting epistemic agency and forming emotional bonds with the students and participating in a year-long journey in with they have been exploring a range of scientific phenomena. The next excerpt begins to reveal a tension between supporting epistemic agency and developing social aspects of the learning environment.

> Mr. C: (To a group of students off camera.) I don’t want you playing with tops OK? Just leave them for one moment. … Aaron, what do you think about what was just said by Jimmy?
> Aaron: I don’t really get...like with the air.
> Mr. C: Say it again Jimmy.
> Jimmy: Like when you took the middle off and when you spun it. It’s like air hitting like the… It’s just hitting the things and making it fall over. When you add the middle on the round thing on the air goes faster around the round thing and making it spin. Make it get balance.

Teacher Perspective: When I notice some students playing with their tops during our discussion time, I reprimand them because of a need to remain consistent with my role as a teacher. In keeping with my pedagogical belief that student talk and listening are crucial to learning, I try to hold students accountable, to remain mindful, curious and on the alert during discussions. For me, *student talk becomes the very curriculum itself*. Staying tuned in and participating in peer-talk will bootstrap and assist them towards building their own understanding. Getting Jimmy to repeat his explanation helps me understand his theory more fully and gives me time to strategize my own input. Having Jimmy speak rather than me deflects a teacher-centered approach and validates the information the students are offering as important in forwarding our communal understanding of how tops work.

Researcher Perspective: Mr. C’s actions here are designed to develop a culture that empowers student ideas. He requires that all students listen when a student is speaking, elicits a new voice (Aaron’s), and asks Jimmy to explain his idea again so it can become understood more widely within the class. Mr. C’s actions are part of a theme in the discourse that has developed throughout the school year, in which he reminds students of the learning culture they are trying to build – a learning culture in which “student talk becomes the very curriculum.” This excerpt is another example where multiple considerations are in competition. As in the previous excerpt, one may expect students to execute some of the actions executed by Mr. C on the basis of epistemic agency, but here epistemic agency is in the background and the social development of the students in the foreground. Clearly, a culture in which there is respect for students’ ideas is important for knowledge building and for the development of agency. In this discussion, near the end of the school year, Mr. C still feels he needs to work with the students to encourage a respectful learning environment. A crucial question thus seems to be how to balance the need between the development of sociocognitive competencies such as epistemic agency with the need to support social development.

Excerpt 3: A scientific name

In the next excerpt evidence continues to build of a tension between supporting epistemic agency and developing social aspects of the learning environment. At the same time, another fundamental tension becomes apparent between “letting students’ ideas be the curriculum” and learning the content of science. This tension is an example where systemic features of educational systems – particularly strong emphasis on learning the content of science in the *National Science Education Standards*, the prescribed curriculum and the presence and nature of external examinations, constrain Mr. C’s efforts to engage his students in knowledge building.

> Danny: I have something to add onto that. If it doesn’t go around it goes under because it is flat. If it is just like that because it is round and then it won’t have any place to …try to go under bottom and then it will stick around.
> Mr. C: So what keeps it up Danny?
> Danny: The… (He is pointing to the flywheel)

Mr. C: Let's call … Why don't we give this a name? We are going to call it a flywheel… We are going to call this an axle (teacher shows the axle). When you put the axle and the flywheel together, it seems to work better.
Danny: Flywheel makes it go… if it tips on this side it still has weight on this side. So it gets balance.
Mr. C: Ahhhhhhh!

Teacher Perspective: Danny is from Trinidad and has been with the class only three months. Academically, his performance in language arts is poor; he is barely able to write a simple primary level sentence. Evident not only from this particular quotation, he seems to have trouble putting forward abstract ideas and reasoning these through to a logical conclusion. Danny is not held in high esteem in the classroom, whereas Jimmy is. I use Danny's struggle as a way of supporting his classroom status by validating his troubled thesis. Danny's struggling contribution also gives me room to laminate some of our everyday ways of talking onto scientific terms. Lemke (1990) suggests that it is the teacher's responsibility to make connections between scientific themes and the way students already talk about a topic. To help move our conversation forward, I suggest using the official terms *flywheel* and *axle*. By using the children's everyday ideas and language and re-framing them into a scientific discourse context, I validate their knowledge and introduce them to new conceptual tools and the language to articulate them. I feel these definitions would have been less significant and would have had less impact on knowledge building had I introduced them at the beginning of the lesson, before a genuine need to identify them occurred.

Researcher Perspective: When Mr. C exclaims "Ahhhhhhh!" he validates Danny's contribution, as he did with Jimmy's contribution in excerpt 1. Again, from the sociocognitive perspective of epistemic agency a student could have provided the validation, but now Mr. C is concerned with improving Danny's social status in the classroom and provides it. When Danny points at the flywheel and struggles to express himself, Mr. C concludes that to advance the discussion the students need more precise terminology, and he introduces the terms *flywheel* and *axle*; this action is consistent with his understanding of language as a conceptual tool in Vygotsky's theory of child development. Mr. C's action is also consistent with the knowledge building model as he attempts to provide scaffolding toward more productive discourse by introducing new terminology. However, a major tension is now beginning to appear. Mr. C does not just introduce new terminology or help students see that new terminology is needed but introduces the "official" terminology of the curriculum. He evidently feels that he cannot afford to let the students' dialogue run for too long without intervening, and uses this opportunity to attempt to guide the discussion toward scientifically accepted ways of talking about the motion of tops. Again, there are multiple considerations influencing the discourse, particularly that of knowledge building and of science education as learning the content of science; the content of science is in the foreground. A crucial question for knowledge building as a method for science education is thus how to reconcile it with competing goals of learning science content and how to prevent it from being an example of discovery learning.

Excerpt 4: A "discrepant event"

As the discussion continues, Mr. C becomes more concerned about leading the students toward scientific understanding. He had observed that the gyroscope the students used has spokes rather than a solid flywheel, and thought this may help to produce a cognitive conflict for the students' thinking about the role of air in the motion of tops. The class discussion of his idea continues for approximately ten minutes, and we quote two short dialogue excerpts, following each with our interpretations.

Mr. C: I'm wondering when we were feeling the gyroscope...Now the gyroscope really, all it is really, isn't it, just a top in a cage … right?
Kees: The top inside it fell out when we were using it and then we try to spin it. And then just fell back down.
Mr. C: OK, so the top itself would spin without …
Jimmy: It has too much weight.
Mr. C: It has too much weight…
Kor: The bottom part is too light.

Teacher Perspective: I feel that Kees has derailed my idea of offering the gyroscope as a discrepant event. Kees unseats my invitation that the gyroscope is simply a top in a cage by imposing his own issue. I am panicking somewhat because my strategy of turning around the conversation and wanting children to question their own proposition seems to have gone awry. My impression is that at this stage, the classroom dialogue has disintegrated from *my* initiative, as several students negotiate a new thematic notion about why the gyroscope is not like a top.

Researcher Perspective: Earlier, Mr. C said that he took just a word (air) from what a student had said to keep the conversation going, unsure of what the student meant. Here I wonder if he could be over-interpreting Kees's initial statement that the top fell out of the case – perhaps it also was no more than a statement to start the discussion. The students do seem to accept that the object inside the box is a top, and they are discussing it in terms of the distribution of what they call "weight" (mass). However, they are not focusing on the distribution *within* the flywheel but on the mass of the support relative to the flywheel: "The bottom part is too light."

The discussion continues as follows.

Ger: …and the original one and it's like two main parts stuck together. But if you take out the axle and the sil …(inaudible), would it still spin?
Mr. C: Without the axle?

Jimmy: You mean like on its side?
Ger: Yeh
Mr. C: You mean…well, why don't you try it? Why don't you try it out?

Teacher Perspective: Instead of helping us out, Ger's comments seem to take us further astray. Rather than dismiss them, however, I suggest that he explore his thinking. The dialogue becomes indistinguishable because of all the competing voices. It seems that giving Ger the opportunity to experiment releases the constraints on the conversation. Arash joins Ger by first spinning the wooden disk again and then spinning a big heavy washer. As both students attempt to spin their respective discs other voices chime in and become quite argumentative. It seems that each voice has its own hypothesis for the unfolding action. Although the heated argument is a healthy sign of engagement, all along I am struggling and don't know how to bring the conversation back "on track" without directly taking over and thereby deviating from my ideals about student conversation.

Researcher Perspective: I like that Mr. C suggests that Ger test his idea experimentally; scientific discourse is more than *talk*. It is interesting that the level of activity rises when the students begin their experimental test. As Mr. C explains, "the dialogue becomes indistinguishable because of all the competing voices." It is becoming more difficult to maintain the principle of democratizing knowledge in this whole-class mode of discussion, as some ideas are not spoken.

After a few minutes, Mr. C summarizes the discussion up to that point, focusing on weight rather than air. Arash had introduced a comparison of the weight of a wooden disk and a metal ring, and now explains "Wood doesn't really do much. Like metal it's a stronger thing. So maybe it has like stronger sense of spinning and this is also thicker." (He demonstrates what he means.) The *stronger sense of spinning* suggests to me the beginning of a notion that increasing the mass increases a disk's capacity for storing motion (i.e., rotational inertia).

Excerpt 5: A small group discussion

The final excerpt is a small-group discussion that followed the whole-class discussion. Initially, it was the high energy and the students' commitment to ideas in this excerpt that led Mr. C to analyze the classroom dialogue during this lesson in detail. In his commentary on this excerpt he realizes that the students are capable of monitoring and guiding the discussion themselves, an important aspect of epistemic agency. This segment begins after approximately 45 minutes of engagement in play and whole-class discussion. Mr. C suggests that the class use a framework proposed by Kor that involves balance, weight, and air as a topic for discussion.

> Jimmy: (Repeats an earlier point.) It's really balanced. Because when you spin it all the air goes here and then goes through these holes making it perfectly balanced. Air goes through the holes and the air hit the ground and making it balance when it hit the ground.
> Tommy: When I ..when I.. it is sort of hollow and the air goes up
> Jimmy: It is sort of like supporting the thing?
> Kor: Yeah like the tornado thing
> Jimmy: Like the twister how the tornado kept staying in the air. It moves around there but it stay perfectly balanced
> Kor: I think the air comes down through the holes and then gets spin around underneath to come back up and in to..
> Jimmy: You know the twister.. you know the tornado.. I think that the tornado spins really good because when it starts spinning all though wind.. it goes around it. It keeps going and going inside of it. So it keeps spinning getting more speed and spinning faster. It is like the cycle.
> Tommy: It always go faster
> Jimmy: Yeah, then the wind helps it get bigger. When wind starts to go in tornado getting smaller and smaller and it goes away. Tornados made out of wind.
> Kor: and dust particles
> Jimmy: Yeah dust particles
> Kor: I think the top exactly been as a tornado. I think the shape has something to do with it. Because it sort of like tears the air away and the shape of the inside in the holes. So then it will keep on ripping they are apart and then they are keep on spinning.

Teacher Perspective: Kor's participation intensifies the knowledge construction of Jimmy and Tommy, who develop his earlier idea of a tornado with Jimmy's concepts of air and weight, and Tommy's notion of floating and buoyancy. Kor puts together all three ideas in an eloquent and very believable scenario about air moving down the hole of the flywheel bouncing off the ground and supporting and stabilizing the top's movements. Kor leaves and brings back one of the tops and points out the shape of the design pattern that we have been calling holes. He notices that the design or shape "tears away the air away" and rips the air apart. I can only think how Jimmy has taken over questioning – a role usually taken by me as the teacher. This metacognitive development again reminds me of the genuineness of the inquiry approach.

Researcher Perspective: Though Jimmy asks only one question in the quoted dialogue, he does have a role similar to the teacher's – he keeps the conversation going. He asks the initial question, and the subsequent speeches alternate between him and the other students in the group. The discussion is focused and appears to build consensus within the group that tornadoes are like tops. Overall, there seems to be greater opportunity for epistemic agency and democratization of knowledge to be expressed than in the whole-class discussion.

Discussion and conclusion

Efforts to innovate in classrooms often focus on the extent to which the principles underpinning an educational innovation have been implemented (Brown & Campione, 1996; Collins et al, 2004; Design-Based Research Collective, 2003); we have argued that more attention needs to be given to creating the conditions needed for implementing such principles. In this study we examined moment-to-moment teacher action in the context of a specific educational innovation – knowledge building. The study revealed how at different moments other considerations, features of the educational context over which the teacher had little control, had precedence over implementing the knowledge building principles. This section summarizes the findings and explores the main tensions we identified and ways they may be resolved.

Fostering Student agency

In this study the teacher aimed to facilitate classroom discourse that helped students formulate and develop their own ideas; we suggest that he was mostly successful. Although Mr. C acted frequently, his actions were usually motivated by: (a) his own interest in understanding the motion of tops; (b) his commitment to a pedagogical style in which he views developing an emotional bond with the students as vital, working with them at their elbows without getting in the way (Cummings, 1998); or (c) a social situation that required an intervention. He introduced two new terms (*flywheel* and *axle*), but did so only after a context had arisen in which new terms were needed. When he asked a question that referred to an idea, it was usually because he was trying to understand a student's idea. The discourse in this lesson also was very different from the IRF sequence, a dominant form of classroom discourse in which a teacher initiates with a question, the student responds, and the teacher provides feedback (Mehan, 1979). The students' generation and discussion of ideas observed in the fifth excerpt is clearly an example of the type of discourse Mr. C aimed to facilitate. He commented: "I can only think how Jimmy has taken over questioning – a role usually taken by me as the teacher. This metacognitive development again reminds me of the genuineness of the inquiry approach."

In contrast with these positive findings, the researcher commentaries on excerpts 1-4 pointed out some examples of teacher action that could in principle be executed by students: e.g., validating students' ideas (excerpts 1 and 3) and summarizing students ideas (excerpt 4). These commentaries make two points. First, they show how implementation of the knowledge building principles was at times preempted by the teacher's ongoing work to develop a social climate that could support students' discussions of their own ideas; this made it difficult to identify evidence for the knowledge building principles in the classroom discourse. Clearly, researchers need to take contextual factors that produce this tension into account when evaluating how well the principles underpinning an innovation have been implemented. Second, though the need for developing the social climate is immanent in classrooms, the more important point is that students could with time assume more responsibility for this. For example, students could learn to reflect on the extent to which different students have had an opportunity to speak and invite others to offer ideas. Such social skills are important not only for knowledge building as a school-based practice, but are needed for teamwork occurring in many occupations. We therefore regard the work of improving the social climate as an *essential part of* learning to build knowledge, and dialectically related to it; the epistemic and social features of knowledge building must develop together in a classroom.

Progressive inquiry versus learning scientific concepts

A second tension that constrained epistemic agency was between knowledge building (taken as an example of progressive inquiry) and the goal to learn scientific content. As the lesson progressed, Mr. C became more concerned about "leading students toward correct understanding," and introduced the words flywheel and axle, as well as the discrepant event. After he introduced the discrepant event, he resisted the temptation to "correct" the students' thinking, but he nevertheless struggled deeply with his role as a teacher.

This tension poses a greater challenge to implementing progressive inquiry on a large scale because it stems from strong emphasis in prescribed curricula and external assessments on learning scientific concepts. For example, in the *National Science Education Standards* it is stated that inquiry "…is the central strategy for teaching science" (NRC, 1996, p. 31), and a method for learning scientific concepts (p. 105); the content standards then specify the concepts students should know at different grade levels. Whereas this orientation toward learning concepts as the principal goal of learning activities is consistent with what we have called content-focused inquiry, it is less consistent with progressive inquiry. All the progressive inquiry models we have mentioned are models of scientific practice; they place more emphasis on learning to participate the social practices involved in scientific inquiry than content-focused inquiry (e.g., Polman, 2000; Roth, 1995). There currently is a division between those who view learning as the acquisition of mental content and those who view it as increased participation in social practices; as Sfard (1998) has argued, we need both views and we need balance between them.

Elsewhere, it has been argued that work is needed to better integrate contemporary learning theory, instructional practices, and assessment (Chan & van Aalst, 2004). Because assessment plays such an important role in curriculum implementation (NRC, 1996; Shepard, 2000), we propose that it needs to be the main line of attack. Besides reliable assessments of learned concepts, it is important to develop reliable assessments that can be used to characterize other outcomes learned from inquiry, such as ability to critically examine information and ability to formulate a hypothesis, design an experiment to test it, imagine data obtained in such an experiment, and analyze the imagined data to arrive at a conclusion (White & Fredericksen, 1998). Clearly, if progressive inquiry approaches like knowledge building are to become scalable as educational methods, assessments are needed that can be used to evaluate their educational benefits (Chan & van Aalst, 2004).

The importance of disciplinary knowledge in progressive inquiry

Though learning scientific concepts is not the principal goal in progressive inquiry, it may be useful to explore the role disciplinary knowledge plays. We have said that that students are expected to improve their understanding of the problems they investigate, but that they would need to be aware of limitations of their explanations. Indeed, *students need to be on a trajectory toward learning disciplinary knowledge*. This leads to an apparent contradiction between the goal to foster student agency and leading students toward disciplinary knowledge. How can the conflict be resolved? We offer some suggestions that may clarify this issue.

First, it is worth noting that students cannot build knowledge from a complete lack of knowledge about the problem of interest – they need to *immerse* themselves in the problem. Though exploring their own ideas is important (as students did in the lesson we discussed), they also need to study texts and other resources that are accessible to them, and available in the school community, and conduct empirical investigations; the teacher may also introduce ideas. However, whether an idea comes from the teacher, a text, or the students, it needs to be examined critically. This critical stance toward ideas is underscored in the knowledge building model by the principle of *constructive use of authoritative sources* (Scardamalia, 2002). Whether any idea becomes important in a knowledge-building discourse depends on whether students understand or believe it, think it will be useful for understanding the problem under investigation, or find it intriguing. Although there are constraints, there still is much room for student agency. For example, besides the teacher, students can propose empirical explorations, take initiative to locate and study resources, or suggest that a discussion is needed to examine what progress has been made. With sufficient metacognition, students could also observe that something does not quite fit, for example that none of the popular science books they consulted dwell on the role of air in explaining the motion of tops and that they would need to resolve this issue.

Second, a key goal of emphasizing progressive inquiry in school is to acculturate students into practices that are likely to lead to reliable knowledge. Students are not likely to learn effective inquiry methods on their own and need opportunities to learn them and reflect on them (O'Neill, 2001; Schauble, Glaser, Duschl, Schultze, & John, 1995). This means there are strong roles for the teacher in mentoring students in the use and creation of inquiry practices that are likely to lead to reliable knowledge. As many authors have noted, it is a distortion to depict young students as "little scientists" (White & Fredericksen, 1998). We propose that an important aspect of fostering agency is to put conceptual tools in students' hands that they can use to examine the effectiveness of the inquiry practices in use in the community. In this regard, some studies indicate that secondary school students can monitor their progress using knowledge building principles (Lee, Chan, & van Aalst, 2006). With time, they need to self-regulate the use of such tools and learn to create new ones.

Conclusion

In summary, we have explored teacher action in the context of an implementation of progressive inquiry in a grade four classroom, especially the question of fostering student agency. Though the analysis drew from only one lesson, it revealed two important tensions that constrained agency. We attempted to resolve these tensions as follows. First, we argued that it is necessary to consider the work of learning to build knowledge as involving the development of social, not just epistemic, practices. Second, we posited that in spite of the goal to foster student agency, it is necessary to constrain how an inquiry develops. However, this constraint does not follow from the need to aim for scientifically acceptable understanding of concepts, but from a need to equip students with increasingly powerful tools for inquiry – tools that make it likely that students can build reliable knowledge. In this, the major role of the teacher is to allow students to control those aspects of the learning process they can manage while mentoring them in the others so that they can eventually control these as well. Proponents of knowledge building argue that students in elementary schools are capable of managing much more than is commonly assumed (Bereiter & Scardamalia, 1991). We suggested that assessment is the major line of attack for establishing conditions that make progressive inquiry an educational possibility on a large scale.

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References

Bransford, J.D., Brown, A.L., & Cocking, R.R. (1999). *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academy Press.

Bereiter, C. (2002). *Education and mind in the knowledge age*. Mahwah, NJ: Erlbaum Associates.

Bereiter, C., & Scardamalia, M. (1987a). *The psychology of written composition*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Bereiter, C., & Scardamalia, M. (1987b). An attainable version of high literacy: Approaches to teaching higher-order skills in reading and writing. *Curriculum Inquiry*, *17*, 9-30.

Bereiter, C., & Scardamalia, M. (1993). *Surpassing ourselves: An inquiry into the nature and implications of expertise*. Chicago, Illinois: Open Court.

Brown, A.L., & Campione, J. C. (1990). Communities of learning and thinking, or a context by any other name. *Contributions to Human Development*, *21*, 108-126.

Brown, A.L., & Campione, J.C. (1996). Psychological theory and the design of innovative learning environments: On procedures, principles, and systems. In L. Schauble & R. Glaser (Eds.), *Innovations in leaning: New environments for education* (pp. 289-325). Mahwah, NJ: Lawrence Erlbaum.

Chan, C.K.K., Burtis, J., & Bereiter, C. (1997). Knowledge building as a mediator of conflict in conceptual change. *Cognition and Instruction*, *15*, 1-40.

Chan, C.K.K., & van Aalst, J. (2004). Learning, assessment, and collaboration in computer-supported environments. In J.-W. Strijbos, P. A. Kirschner, and R. Martens (eds.), *What we know about CSCL: And implementing it in higher education* (pp. 87-112). Dordrecht: Kluwer Academic Publishing.

Cognition and Technology Group at Vanderbilt [CTGV] (1992). The Jasper series: A generative approach to mathematical thinking. In K. Sheingold, L.G. Roberts, & S.M. Malcolm (Eds.), *This year in science series 1991: Technology for teaching and learning* (pp. 108-140). Washington, DC: American Association for the Advancement of the Sciences.

Collins, A., Joseph, D., & Bielaczyc, K. (2004). Design research: Theoretical and methodological issues. *Journal of the Learning Sciences, 13*, 15-42.

Cummings, M. (1998). *Learning in Elementary Science: "Hunkering" by the Light of Children*. Unpublished M.A. thesis, Simon Fraser University, Burnaby, Canada.

Design-Based Research Collective (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher, 32*, 5-8.

Edelson, D.C., Gordin, D.N., & Pea, R.D. (1999). Addressing the challenges of inquiry-based learning through technology and curriculum design. *The Journal of the Learning Sciences, 8* (3&4), 391-450.

Edelson, D.C., Pea, R.D., & Gomez, L.M. (1996). The collaboratory notebook: Support for collaborative inquiry. *Communications of the ACM, 39*, 32-33.

Fullan, M. (2003). *Change forces with a vengeance*. New York, NY: RoutledgeFalmer.

Goldberg, F., & Bendall, S. (1995). Making the invisible visible: A teaching/learning environment that builds on a new view of the physics learner. *American Journal of Physics*, *63*, 978-991.

Gunstone, R.F., Gray, C.M.R., & Searle, P. (1992). Some long-term effects of uninformed conceptual change. *Science Education*, *76* (2), 175-197.

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, *66*, 64-74.

Hakkarainen, K., Lipponen, L. & Järvelä, S. (2002). Epistemology of inquiry and computer-supported collaborative learning. In T. Koschmann, R. Hall, & N. Miyake (Eds.), *CSCL 2: Carrying forward the conversation* (pp. 11-41). Mahwah, NJ: Lawrence Erlbaum Associates.

Hargreaves, A., Earl, L., Moore, S., & Manning, S. (2001). The intellectual work of change. In *Learning to change: Teaching beyond subjects and standards* (pp. 115-135). New York: John Wiley and Sons.

Hodson, D. (1996). Laboratory work as scientific method: Three decades of confusion and distortion. *Journal of Curriculum Studies, 28*, 115-135.

King, P. M., & Kitchener, K. S. (1994). *Developing reflective judgment: Understanding and promoting intellectual growth and critical thinking in adolescents and adults*. San Francisco, CA: Jossey-Bass Publishers.

Latour, B. (1987). *Science in action: How to follow engineers and scientists through society*. Cambridge, MA: Harvard University Press.

Lee, E.Y.C., Chan, C.K.K., & van Aalst, J. (2006). Students assessing their own collaborative knowledge building. *International Journal of Computer-Supported Collaborative Learning, 1*, 57-87.

Lemke, J. L. (1990). *Talking science: Language, learning and values*. Norwood, NJ: Ablex Publishing.

Linn, M.C., & Hsi, S. (2000) *Computers, teachers, peers: Science learning partners.* Mahwah, NJ, Lawrence Erlbaum Associates.

Mehan, H. (1979). *Learning lessons*. Cambridge, MA: Harvard University Press.

National Research Council [NRC] (1996). *National science education standards*. Washington, DC: National Academic Press.

O'Neill, D.K. (2001). Knowing When You've Brought Them in: Scientific Genre Knowledge and Communities of Practice. *Journal of the Learning Sciences*, *10*, 223-264.

Oshima, J., Scardamalia, M, and Bereiter, C. (1996) Collaborative learning processes associated with high and low conceptual progress. *Instructional Science, 24*, 125-155.

Palincsar, A.S., & Brown, A.L. (1984). Reciprocal teaching of comprehension-fostering and comprehension-monitoring strategies. *Cognition and Instruction*, *1*, 117-175.

Papert, S. (1980). *Mindstorms: children, computers and powerful ideas*. New York: Basic Books.

Polman, J. (2000). *Designing project-based science: Connecting learners through guided inquiry*. New York, NY: Teachers Colleges Press.

Roth, W.-M. (1995). *Authentic science*: *Knowing and learning in open-inquiry science laboratories*. Dordrecht, the Netherlands: Kluwer Acdemic Publishers.

Scardamalia, M. (2002). Collective cognitive responsibility for the advancement of knowledge. In B. Smith (Ed.), *Liberal education in a knowledge society* (pp. 67-98). Chicago: Open Court.

Scardamalia, M., & Bereiter, C. (1991). Higher levels of agency for children in knowledge building: A challenge for the design of new knowledge media. *Journal of the Learning Sciences*, *1*, 38-68.

Scardamalia, M., Bereiter, C., & Lamon, M. (1994). The CSILE Project: Trying to bring the classroom into World 3. In K. McGilly (Ed.), *Classroom lessons: Integrating cognitive theory and classroom practice* (pp. 201-228). Cambridge, MA: MIT Press.

Scardamalia, M., Bereiter, C., McLean, R.S., Swallow, J., & Woodruff, E. (1989). Computer Supported Intentional Learning Environments. *Journal of Educational Computing Research*, *5*, 51-68.

Schauble, L., Glaser, R., Duschl, R.A., Schultze, S, & John, J. (1995). Students' understanding of the objectives and procedures of experimentation in the science classroom. *Journal of the Learning Sciences, 4*, 131-166.

Sfard, A. (1998). On two metaphors for learning and the dangers of choosing one. *Educational Researcher*, 27, 4-13.

Shepard, L. E. (2000). The role of assessment in a learning culture. *Educational Researcher, 29* (7), 1-14.

Thornton, R.K., & Sokoloff, D. (1990). Learning motion concepts using real-time microcomputer-based laboratory tools. *American Journal of Physics*, *58*, 858-867.

van Aalst, J. (2006). Rethinking the nature of online work in asynchronous learning networks. *British Journal of Educational Technology*, 37, 279-288.

van Aalst, J., & Hill, C.M. (in press). Activity theory as a framework for analyzing knowledge building. *Learning Environments Research*, *9*.

Wells, G. (2001). *Action, talk, and text: learning and teaching through inquiry*. New York, NY: Teachers College Press.

White, B.Y., & Fredericksen, J. (1998). Inquiry, modeling, and metacognition: Making science accessible to all students. *Cognition and Instruction*, *16*, 3-118.

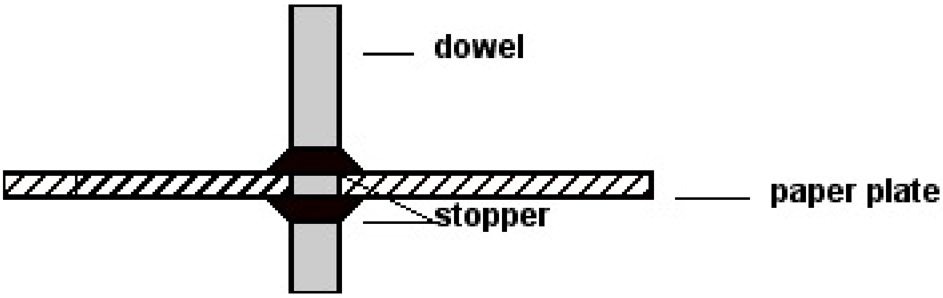

Figure 1. A top made from a paper plate, dowel, and two rubber stoppers