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Knowledge building: Rationale, examples, design, and assessment

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Introduction

This article is based on a keynote address I gave at the symposium Knowledge Building: The journey begins, held in Wanaka, November 19, 2012, and sponsored by the Centre for Distance Education and Learning Technologies of the University of Otago and OtagoNet. The article explores knowledge building by examining its big ideas, examples of attempts at knowledge building in secondary schools, linkages to curriculum, and assessment.

What is knowledge building?

Knowledge building is an educational model based on research on how experts learn and developed by Marlene Scardamalia, Carl Bereiter and colleagues (www.ikit.org/). In brief, knowledge building can be understood as a community's effort to advance its collective knowledge; it involves collaborative work on the community's ideas, a process that occurs, in part, in a web-based knowledge-building environment called Knowledge Forum. In this section, I briefly describe three contrasts—"big ideas"—that are useful for understanding the nature of knowledge building.

Experts and experienced non-experts

Research on how experts differ from people new to their field—novices—has shown that experts have vast knowledge about their areas of expertise. For example, chess experts remember thousands of chessboard configurations they have seen before, and use this knowledge to decide on a move. If we consider only the amount of knowledge they possess, children clearly are not like experts.

Bereiter and Scardamalia (1993) approached the problem of expertise from a different angle. They did not compare experts with novices but with people who, despite having had similar training and experience, have not become experts. They called these people *experienced non-experts*. The research showed that experts do three things that experienced non-experts do not:

- Experts know the limits of knowledge in their field
- Experts engage in "progressive problem solving". When they understand a problem at one level, they invest effort into studying the problem at deeper levels or in additional situations. Experienced non-experts tend to reduce problems to ones they can already deal with.
- Experts have a goal to advance the state of knowledge in the field.

The question then becomes whether children can learn and use these strategies of experts. The answer is a qualified yes. Some young children, even those in kindergarten, can, provided that the learning environment has the right features (Bereiter & Scardamalia, 1993; Scardamalia & Bereiter, 2006). Much of the task for this article is to elaborate how the learning environment needs to be designed.

Learning and knowledge building

A second useful distinction is between learning and knowledge building (Scardamalia & Bereiter, 2006). "Learning" refers to the process by which people acquire the intellectual heritage of their community. For example, children learn to write—just as generations before them have done. They also learn such things as the law of supply and demand and may learn to appreciate poetry. In all these examples the object of learning, what is being learned, is not changed. The law of supply and demand is still the same after students learn it.

Knowledge building is the educational variant of knowledge creation: the process by which new knowledge is created in science, engineering, medicine, and other fields of human endeavour. Knowledge creation is, as Scardamalia and Bereiter (2006) put it, a civilisation-wide human effort to extent the frontier of what is known. Knowledge creation is not something left to experts, but students need to learn the process by which knowledge is created. It is in fact the kind of learning I said experts do in the previous section.

Of course, students are unlikely to make major breakthroughs in a scientific field, but it is important to recall that these are relatively rare even for scientists. Most scientific advances are rather modest and require substantial work to establish. For example, the discovery of radium by Marie and Pierre Curie established radium as an element in the periodic table of elements and opened up the door to establishing a theory positing that atoms have structure (i.e., that they are not the smallest, indivisible pieces of matter), but working out a theory required many years of research. And clearly students are not going to rediscover major scientific laws, some of which have required hundreds if not thousands of years of human effort to discover and understand. Nevertheless, students working as a community can significantly advance the knowledge of that community and tackle some problems that are historically significant. Scardamalia and Bereiter (2006) refer to a student comment that the 19th century scientist Mendel "worked on Karen's problem," to suggest that the work of Karen is on a continuing line with that of Mendel, although it no longer is a current frontier in science. Another often-cited example is that primary school students, in their study of light, became puzzled why refraction in raindrops, which are small, could give rise to a rainbow, which spans the sky. Although the students did not work out a fully satisfactory answer to this problem, they were able to ask better questions about the science phenomena and in the process articulated more coherent and powerful knowledge about light (C Bereiter & Scardamalia, 2010). They did develop some insights that were novel for their community. As Scardamalia and Bereiter (2006) point out, the fact that the insights students achieve may not be new to the world at large does not alter the nature of the process.

In education, it is often assumed that students must accumulate a vast amount of knowledge before they can engage in knowledge building/creation, and opportunities for knowledge-creation processes often do not occur until students are advanced undergraduate students or even graduate students. Advocates of knowledge building argue that this is the wrong approach: children need to develop proficiency in and understanding of knowledge building from an early age.

Design mode and belief mode

Bereiter (2002) has suggested that ideas should be regarded as “real” things, similar to bicycles and mobile telephones. We may ask about a mobile telephone for what purposes it can be used, how it can be tested, and how it can be modified, and we should ask similar questions about ideas. Therefore, one of the most important principles of knowledge building is that *all ideas are improvable*. Knowledge building then becomes similar to designing: Knowledge builders attempt to build knowledge that is “more useful” than the knowledge with which they start. Usefulness here can be evaluated in terms of the range of observations that can be explained by an idea, the extent to which an idea can lead to testable predictions, and so forth. In this respect, the idea of gravity as causing objects near the earth to fall to the ground is less powerful than an idea of gravity that can also account for the orbits of planets. A theory that comes with a clear understanding of what it does and does not explain is a more developed theory than one that provides only a vague conjecture of “the way things might be.” Bereiter and Scardamalia (2003) have introduced the notion of “design-mode discourse” to emphasise that knowledge building is like designing. In this case, rather than material objects we are designing useful theories. Designing is an open-ended journey. A designer does not say, “We have the mobile telephone! Let’s move to something else.” Rather, a manufacturer takes the best prototype that the design process has yielded into production and marketing, but the design work necessary for the next iteration of the concept begins almost immediately. Similarly, knowledge building must be seen as an open-ended process.

Bereiter and Scardamalia (2003) contrast design-mode discourse with *belief-mode* discourse, the goal of which is to change the beliefs of students, and which is very common in education. An example is the effort that is invested in convincing students that their own ideas about science are flawed and should be replaced by those of scientists. Belief-mode discourse is useful for disseminating a view but not very useful for changing the viewpoint to be disseminated. Debate and lecturing are formats that emphasise belief-mode discourse. In some attempts at knowledge building, belief-mode discourse is evident when many students state their agreement with a viewpoint during a process of consensus reaching, but the viewpoint itself is not modified. Belief-mode discourse is more closed than design-mode. When the audience has been convinced, the discourse needs to stop.

The distinction between design-mode and belief-mode, although articulated only in the last 10 years, is fundamental to understanding knowledge building. It is similar to an earlier distinction between two models of writing: knowledge telling and knowledge construction. Just as belief-mode discourse may not change ideas, so does knowledge telling transfer existing ideas to written form without changing them (Scardamalia, Bereiter, & Lamon, 1994).

Examples

I this section, I describe three examples of knowledge building in secondary schools in Canada and Hong Kong. The examples all are early attempts by the teachers and students, and were carried out in public schools.

Example one: Inquiry project assigned by teacher

A Canadian teacher began to explore knowledge building in a Year 10 Social Studies course, in which students were asked to investigate environmental problems and suggest solutions. The teacher provided several problems including the Chernobyl nuclear accident, deforestation, pine beetle infestation, and air quality in major cities in the region. Students were asked to investigate the extent and causes of the problem and suggest solutions; each group selected one problem, searched for information, and wrote on Knowledge Forum to build knowledge throughout the curriculum unit on environmental problems, which lasted three weeks. At the end of the unit, the students individually completed a learning portfolio in which they reflected on what they had personally learned from their inquiry. Students spent most class time during the unit on the project, either on Knowledge Forum or face-to-face activities. The teacher implemented the same unit in two versions of the course: regular and honours. In this example, all groups in both classes were able to complete their inquiry to a reasonable standard, and the teacher considered knowledge building to be an appropriate way to address the curriculum.

This example was a promising first attempt at knowledge building. Clearly teachers will not invest a large amount of curriculum in a new approach without knowing how to support it in the classroom, how students will like it, and whether the results will be acceptable. From this perspective, a three-week unit was a good design. Apart from being given a choice of problems to investigate and an expected outcome (a solution), the groups of students had to *articulate* the problem, figure out how to investigate it, make sense of the information they encountered, and come to a conclusion about the solution they recommended. These freedoms are consistent with knowledge building, but in the time available there was limited opportunity for progressive problem solving—i.e., digging deeper and deeper into the problem. The design to have students work in fixed groups also had its limitations because it means that students were interacting with the ideas of relatively few other students. Perhaps most important, this approach was suitable for an inquiry-based unit, but it would be difficult to extend it to the remainder of a course. For the teacher, this approach was a relatively safe first attempt. He was already experienced teaching inquiry-based learning and could modify his previous approach; he used his assessment from his previous approach to evaluate the individual learning of his students.

Since knowledge building requires much self-directed learning, collaboration, inquiry, and reflection, it would be useful to compare the results of the regular and honors class. Teachers often object to approaches that require self-directed learning, collaboration, and reflection, saying that only their best students can engage in them and benefit from them. This question was studied by Hui Niu, who investigated the interaction patterns of all the groups, evaluated writing on Knowledge Forum using a set of knowledge-building principles as criteria, and evaluated the learning portfolios (Niu & van Aalst, 2009).

Indeed, Niu found that the honours class outperformed the regular class by almost a standard deviation in all three of the analyses, which is consistent with what one would expect for a comparison between honours and regular courses. However, the results for the knowledge-building principles were still acceptable for the regular class. The largest difference between the honours and regular classes was for *progressive problem solving* (3.0 vs. 2.3 on a scale from 1 to 3), and the smallest for *identifying high points* (2.0 vs. 1.8). The *qualitative differences* were that students in the honours class tended to write longer and more articulate notes than students in the regular class—and sometimes more metacognitive. However, students in the regular class appeared to be able to accomplish *together* what many students in the honours class were able to accomplish alone. For example, a student in the honours class might write a single note to articulate a problem, whereas a group in the regular class would do it collaboratively in a series of notes. A student in the honours class might self-evaluate an idea metacognitively, but students in the regular class tended to raise questions and comment on the ideas of others. Overall, the results for the regular class thus were promising, and perhaps more interactive qualitatively than in the honours class.

Example two: More extensive inquiry project

In a variation on the previous approach, a Year 10 and Year 11 class collaborated to investigate aspects of the SARS outbreak in 2003; the Year 10 class was taking a course on personal development, which included carrying out an inquiry, and the Year 11 class was taking a course on computers in a global society. In both classes there was considerable freedom regarding the *content* of the inquiries. SARS and avian flu was a topic that had recently been in the news, and the teacher expected that they would be topics that would capture the interest of students. The two classes were divided into four groups of approximately 10 students, with an equal number of students from each class in each group.

The project lasted eight weeks. In the first two weeks the groups located information and read widely to formulate a set of the problems they wanted to investigate, and to select the most promising ones. In the next four weeks they carried out their chosen inquiries, and in the last two weeks they prepared summary notes in Knowledge Forum on the problems they had investigated. It was explained that knowledge resulting from collaborative inquiry is a shared achievement, thus all students who contributed to work on a problem should be co-authors of the summary note. Further, students only needed to write summary notes for problems on which they felt they had made some progress. The summary notes reported on problems such as how the media handled the SARS outbreak, how the corona virus is spread, and why children are less likely to be infected than adults. An example of a summary note is shown in Figure 1.

Research Question What were China and Canada's implications in the outbreak of Severe Acute Respiratory syndrome? How did the people in power handle the situation politically and economically?

Background Since the deadly epidemic was first introduced to the world in April last year, more than 80 lives had already been lost. Within a span of 9 months, the casualties doubled. … Concerned with the potential effects of an outbreak, China prohibited the use of surgical masks, and downplayed the deadly virus, stating that it had been under control, when it was really getting worse. Unaware of the crisis at hand, SARS carriers continued to exit the country. …

Innumerous people have been affected by this epidemic crisis. … The world as a whole needs to understand that a single careless mistake could affect the lives of millions around the world.

Method We were able to put together a solid list of websites, which we thought would be helpful for this topic. After creating 3 research questions, we divided into 3 groups, which independently attacked the chosen question. Using some of the information posted in the Preliminary Research view, I was able to obtain a full understanding of the question. We generally looked at the way the government reacted and handled the SARS outbreak. (…)

Findings Already suffering from severe deflation, the emergence of SARS further devastated Hong Kong's economy. Once known for its vibrant economy, "The Pearl of the Orient" consistently reached the $170-billion-a-year mark, but this mysterious virus has brought the city to the brink of recession. (…) Its main industry of tourism took a major blow, crumbling since the world Health Organization (WHO) issued a warning against traveling to Hong Kong and Guangdong. (…) It must be noted, however, that SARS did not cause the decline of Hong Kong's economy. The economy has suffered ever since its return to communist China. (…)

Importance of Findings … We must look at SARS as a dress rehearsal for future outbreaks. (…) If we refused to deal with the problems at hand, we can be sure to expect substantial mortality rates when a next influenza strikes, which is expected to emerge within a decade.

Despite the amount of time we have spent on our subject, our knowledge is still fairly limited. China's decision to delay its revelation of SARS looks very suspect, as it seems very obvious that such an immense secrecy would eventually hurt the nation. On the whole, we simply do not know enough about the politics about its decision, and we can only base our opinions on certain news articles and facts we have gathered during this research.

Figure 1. Sample summary note co-authored by three students. For brevity only approximately half of the Findings and Importance of Findings sections are shown. The latter shows the students were aware of the limitations of the knowledge they had articulated.

The teacher did not *assign* the inquiry projects. Instead, it was explained to students that problems to some extent emerge from students' interests and preliminary study, and are articulated by a community. It was a more risky design for the teacher because, unlike in the first example, the teacher did not know in advance what the inquiry questions would be, and did not have the subject matter knowledge necessary for evaluating the correctness of students' knowledge. The teacher's main role was to guide the overall process, provide encouragements, and be helpful to students as needed. The design had three stages, as already explained, with suggestions and deadlines for each.

Research on this example (van Aalst, 2009) showed that the four groups were approximately equivalent in terms of prior knowledge about SARS and the level of participation on Knowledge Forum (note creation, linking, and reading). However, there still were differences between the quality of the summary notes created by the different groups, and the nature of the interaction on Knowledge Forum. The knowledge quality (number of points, evidence or examples to support points, and absence of misconceptions) of the summary notes of one group was significantly better than that of the other three groups. The other groups were less effective for different reasons, as summarised in Table 1. Group A—the most successful one—used much social commentary to maintain a sense of community, asked many questions, contributed many ideas of different kinds (opinions, conjectures, and more elaborated theories), and linked ideas. Group B invested little effort on social relations to maintain a sense of community, and had some difficulty managing amicable online relationships. Group C invested considerable effort into the social relationships and agency, but took twice as long as the other groups to formulate inquiry questions and, as a result, accomplished less. Group D was the least interactive; it shared much information but contributed relatively few ideas. However, this group had good insights into the significance of what it had learned. One other issue that separated the groups was the nature of the problems the groups selected, and the extent to which they focused on them. Surprisingly, individual differences in prior knowledge and motivation did not seem to have played a role, but the different performances of the groups suggest different roles for the teacher in supporting the groups.

Table 1. Instances of various types of interactions in the SARS database

Differences among groups	Type of interaction	Group A	Group B	Group C	Group D	Total
Large	Social, to maintain community	60	13	29	9	111
	Questions	36	15	4	10	65
Medium	Ideas	63	46	30	32	171
	Information	42	31	15	36	124
Small	Linking	74	42	43	47	206
	Planning, reflection	31	17	14	11	98
	Deepening inquiry, rise above	23	17	14	11	65
	Total	329	181	165	165	840

Note: Numbers refer to the instances of each type of interaction; the number of computer notes was 399, so on average there were approximately two instances per note. Adapted from J. van Aalst (2009), Distinguishing knowledge-sharing, knowledge-construction, and knowledge-creation discourses, *International Journal of Computer-Supported Collaborative Learning*, *4*, 259–287, Tables 4 and 5.

Example 3: A more integrated approach

The previous examples demonstrate aspects of knowledge building, but they are both projects; there is little chance of addressing a whole curriculum this way. How might we achieve a more extensible approach?

The third example is an attempt to integrate work on Knowledge Forum with the ongoing classroom work—throughout the curriculum. This approach relies on classroom teaching that emphasises students' active engagement with content, collaborative talk, inquiry, and sense making. These features are often found in classrooms in which the teaching is informed by constructivism. From the conversations started in the course of this kind of classroom work problems of understanding emerge, which students primarily pursue in Knowledge Forum. The teacher and students may create views (the spaces in which notes are placed) in Knowledge Forum to extend inquiries and discussions started in class. Students locate information and engage in collaborative inquiry to deepen their understanding, to integrate concepts introduced in different lessons into a coherent framework, and so on. Students' work on Knowledge Forum is never very far removed from the content introduced during class sessions, but the specific problems and solutions discussed in Knowledge Forum nevertheless emerge from the students' own engagement with the content. The teacher monitors work in Knowledge Forum, and periodically allows class time to enable students to informally summarise progress or deal with emerging questions quickly (e.g., deciding whether further inquiry is necessary on a question). Teachers of a variety of subjects including science, geography, English, and Chinese have implemented this approach in Canada and Hong Kong. Figure 2 shows a view in Knowledge Forum maintained by a student from a Grade 12 physical geography class in Hong Kong.

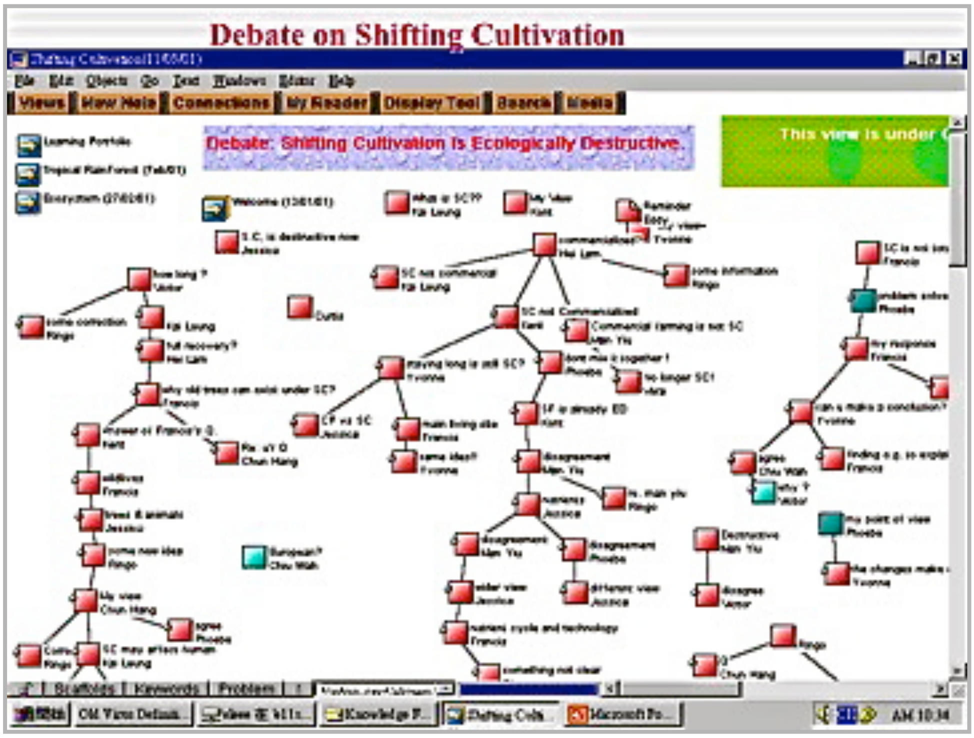

Figure 2. Sample view in Knowledge Forum. Square icons represent notes; lines indicate that one note is a response to ("builds on") another.

Creating a knowledge-building environment

The features of knowledge building are described by a system of principles (Scardamalia, 2002), as summarised in Table 2. These principles are important for teachers to understand because they provide concepts and vocabulary for thinking and talking about the nature of knowledge building. They provide a *framework* teachers can use to create a knowledge-building environment but don't instruct them how to do it. For example, the principle *epistemic agency* states that students "set forth their ideas and negotiate a fit between personal ideas and ideas of others, … [and] deal with problems of goals, motivation, evaluation, and long-range planning" (p. 79), but there are many things a teacher can and should do to encourage it. Shifting the balance of power in classroom talk from the traditional IRE structure (the teacher Initiates dialog, a student Responds, and the teacher Evaluates the Response) to more collaborative talk is just one. The community interested in knowledge building has resisted suggesting procedures because it is known that procedures are often implemented without adhering to the principles that give rise to them (Brown & Campione, 1996). And, of course, teachers know that what works in one situation may not work in another. It is essential that teachers develop understanding of the principles, but this understanding is at least in part *tacit*, being embedded in the practices teachers have created, enacted, and reflected upon, and it develops over considerable time.

Table 2. Knowledge-building principles

Real ideas, authentic problems	Problems of understanding arise from students' attempts to understand their world. Ideas are as real as things touched and felt.
Improvable ideas	All ideas are treated as improvable. Students work continuously to improve the quality, coherence, and utility of ideas.
Idea diversity	To understand an idea is to understand all the ideas that surround it, including those that stand in contrast with it. Two heads are better than one.
Rise above	Knowledge building involves working toward more inclusive principles and higher-level conceptualization of problems.
Epistemic agency	Students introduce their ideas and negotiate a fit between personal ideas and the ideas of others. They set goals and deal with problems of motivation, evaluation, and long-range planning.
Community knowledge, collective responsibility	Contributions to shared, top-level community goals are as important as personal goals and achievements.
Democratizing knowledge	All students contribute to the community's goals. Student diversity does not lead to a separation along have/have-not lines in knowledge building.
Symmetric knowledge advancement	When two students interact both learn from the interaction. The same applies to sub-communities.
Pervasive knowledge building	Knowledge building is not confined to particular occasions but pervades intellectual life. Not just in English, but in other subjects and out of school.
Constructive use of authoritative sources	To know a subject is to be in touch with the present state and growing edge of knowledge in it. This requires knowledge of authoritative sources, and a critical stance to it.
Knowledge-building discourse	The discourse of knowledge building results in more than knowledge sharing; the knowledge itself is transformed by the process.
Embedded and transformative assessment	Assessment is part of the effort to advance knowledge. It is used to identify problems as the work proceeds, and is embedded in the day-to-day work of students.

Note: Adapted from M. Scardamalia, Collective cognitive responsibility. In B. Smith (Ed.), *Liberal Education in a Knowledge Society*. Chicago, IL, Open Court, 2002, Table 4.1, pp. 78–82.

With the foregoing qualification, some general remarks can be made about the design of knowledge-building environments. First, I think that the approach of Example 3 is currently the most promising option for rendering knowledge building the major way educational goals are addressed in secondary school. Although current curricula tend to be "a mile wide and an inch deep," teachers are contractually *obliged* to implement them; any pedagogical approach that does not put this issue front and centre is destined to be an add-on to an existing approach. Of course, projects such as the ones I have described can be useful as part of a coherent pedagogical approach that addresses the whole curriculum, but they are not sufficient by themselves.

One of the main difficulties with existing curricula, or at least the course syllabi developed in schools and based on them, is the emphasis on rather detailed content, which tends to be examined at the lower levels of Bloom's revised taxonomy (i.e., remembering and understanding) and lacks coherence. In contrast, knowledge building, with its emphasis on authentic problems, synthesis, and rise above, is more attuned to higher-order thinking, including applying, analysing, evaluating, and creating. However, some recent developments are more amenable to knowledge building. The National Research Council's report, *A Framework for K-12 Science Education,* recommends significant reductions in content and focus on the practices, cross-cutting concepts, and disciplinary ideas that all citizens should learn, and emphasises that understanding and skills develop gradually throughout K-12 education (NRC, 2012). The NRC refers to "learning progressions." Likewise, in New Zealand, 21st century skills such as collaboration and self-directed learning are emphasised.

A second general point is that although knowledge building requires significant changes to the classroom environment, many of them are not germane to knowledge building itself. Acting on the recommendations of the NRC report *How People Learn* is already a good start: draw out and build on students' existing understanding; teach some content in depth, so that students see how important concepts work in multiple situations; and help students to learn metacognitive skills and knowledge together with specific subject matter knowledge (Bransford, Brown, & Cocking, 1999). Collaboration can help to address these goals. For example, collaborative talk in the classroom or Knowledge Forum can powerfully reveal how students think about concepts, deal with disconfirming evidence, and solve problems. Metacognitive skills may also be more feasible when students collaborate: While a student may not be able to see a way to question his own idea, another student, having different knowledge, may be able to do so. Psychological safety is essential; for example, it is important that a student does not see a constructive comment from another student as an attack on his or her ability or talent. There is effort by researchers and educators to develop pedagogical approaches along the lines sketched here. Knowledge building is unique in its reliance on community-level goals in addition to personal ones, and in its emphasis on how far we can go rather than on reaching a predetermined endpoint.

A significant challenge for knowledge building is finding “authentic problems.” Students in secondary schools are not necessarily very interested in the cognitively demanding work that knowledge building requires. However, if students become interested in a problem they often are more willing to invest such effort. The teacher may try to guess student interests, as in Example 1, but this strategy often fails. Interest develops gradually, thus it seems most profitable for teachers to collaborate with the students to articulate problems that are interesting to the students and have sufficient academic promise. This is what the teacher in Example 2 attempted. It is important to realize though that even with collaboration between the teacher and students the process can still fail. But that is just what happens in knowledge-creating organisations—many good ideas do not become prototypes, and fewer still become viable products (Gundling, 2000). The “trick” for the teacher is to create an environment where this kind of failure can be endured, be a source of learning, and is accompanied by sufficient successes. This level of uncertainty in the pedagogical design process is somewhat difficult for teachers to accept, but the successes are exciting.

Assessment

The assessment of 21st century skills is regarded as one of the biggest challenges for technology-enhanced education, as evidenced by the Assessment and Teaching of 21st Century Skills, which involved Cisco, Microsoft, Intel, and a variety of well-known academics. Here I offer some thoughts on assessment as it relates to knowledge building.

External examinations can be very comprehensive in their coverage of the syllabus, and often focus on the lower levels of the Bloom taxonomy. This situation is problematic because teachers and students are unlikely to invest time in processes that do not have tangible benefits for performance on examinations. I refer to this kind of examination situation as "You have been taught, let's see if you know it." Examinations of this kind can be a deterrent to knowledge building.

However, another type of examination is possible—one that integrates content in guided inquiries. Indeed some partial examples already exist. In the Netherlands, government examinations tend to present situations and ask students to work through a series of tasks to develop an understanding of that situation. For example, in the 2011 HAVO (Year 11) examination in mathematics, students were presented information about a company that provides drinking water, including local applicable tariffs, and asked to calculate an annual drinking water bill of a typical family; to extend the inquiry, students were then provided information about the water consumption of dishwashing machines, how the Central Bureau for Statistics estimates the consumption of drinking water by dishwashing machines, and how this can be corrected for the fact that not every person has access to a dishwashing machine. Interestingly, the task explains *how to read* out some of the information: "In this graph you can see, for example, that in 2001 ($t = 6$), on average over all people residing in the Netherlands, consumed approximately 2.4 liters of drinking water per person per day for dishwashing machines." Although the task did not do this, students could have been asked to bring these results back to the question they started with, to estimate the impact of using a dishwashing machine on a family's drinking water bill. What is striking about this examination task is that it leads students to learn about how a family's drinking water bill is determined and requires them to use their mathematical knowledge in the process; it *provides* many of the necessary facts but *requires* transferrable knowledge of core mathematical concepts and skills. I call this type of examination task "Let's see how you do on this novel problem." It is impossible to study for this kind of task by covering every conceivable situation; instead the assumption is that after having studied mathematics and having carried out mathematical practices, students should be able to perform acceptably.

Beyond formal and external examinations, I think it is important to document evidence of a wide range of skills and dispositions that can be associated with knowledge building. We can return to the process of expertise discussed earlier, and document whether there is evidence that the students know the limits of knowledge in their class, and that at least some students engage in progressive problem solving, and aim to advance the state of knowledge in the class. We have utilised portfolio notes in Knowledge Forum, which enable students to document and reflect on these kinds of evidence. In addition, one can measure such skills as students' ability to negotiate collective goals; set and achieve personal goals; seek, interpret, and use information; synthesise the class's discourse; and so on (Lee, Chan, & van Aalst, 2006). Though in some cases reliable instruments need to be developed, in others more informal and teacher-developed rubrics can be used to document the variety of impacts of knowledge building on student development. The assessment environment in New Zealand seems open to knowledge building by teachers, to develop a cadre of assessment strategies that can lead the way in showing how knowledge building can be assessed.

Conclusion

In summary, this article has explored knowledge building as an educational model for the 21st century. I have emphasised three contrasts that are used extensively in the literature on knowledge building: between experts and experienced non-experts, between learning and knowledge building, and between design-mode and belief-mode discourse. I next discussed three examples of attempts at knowledge building in public secondary schools in Canada and Hong Kong. Though the examples varied in the extent to which they integrated the use of Knowledge Forum with classroom teaching, they all were examples of teachers' first attempts, and should thus be taken as improvable examples of practice. Finally, I briefly explored the implications for curriculum development and assessment. I highlighted an examination style that I think could lead to greater alignment of knowledge building and external examinations, and pointed out that it is necessary to go beyond what external examinations measure to assess skills and knowledge that are more germane to knowledge building.

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