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Abstract We describe the design of a knowledge-building environment and examine the role of knowledge-building portfolios in characterizing and scaffolding collaborative inquiry. Our goal is to examine collaborative knowledge building in the context of exploring the alignment of learning, collaboration, and assessment in computer forums. The key design principle involved turning over epistemic agency to students; guided by several knowledge-building principles, they were asked to identify clusters of computer notes that indicated knowledge-building episodes in the computer discourse. Three classes of 9th grade students in Hong Kong used Knowledge Forum in several conditions: Knowledge Forum only, Knowledge Forum with portfolios, and Knowledge Forum with portfolios and principles. Results showed: (1) Students working on portfolios guided by knowledge-building principles showed deeper inquiry and more conceptual understanding than their counterparts; (2) Students' knowledge-building discourse, reflected in portfolio scores, contributed to their domain understanding; and (3) Knowledge-building portfolios helped to assess and foster collective knowledge advances: A portfolio with multiple contributions from students is a group accomplishment that captures the distributed and progressive nature of knowledge building. Students extended their collective understanding by analyzing the discourse, and the portfolio scaffolded the complex interactions between individual and collective knowledge advancements.

Keywords Knowledge building · Assessment · Portfolios · Collaborative inquiry · Asynchronous networked environment

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Introduction

Helping students to engage in collaborative inquiry is now a major educational goal. Research based on the use of asynchronous networked environments has shown how these environments help students advance understanding and inquiry, construct knowledge socially, and develop subject-matter knowledge (e.g., CoVis Collaboratory Notebook: Edelson, Pea, & Gomez, 1996; CaMile: Guzdial, & Turns, 2000; Knowledge Forum: Scardamalia & Bereiter, 1994). In parallel with research in asynchronous networked environments, the use of online discussion forums at various levels of schooling is also increasing in popularity. Despite much progress, there remain questions regarding the alignment of assessment, instruction, and curriculum in computer-supported collaborative learning (CSCL) classrooms, and specifically about the design of assessment approaches to characterize and support learning and collaboration in the classroom context.

Whereas networked computer discussion is becoming increasingly popular, many challenges and difficulties exist pertaining to the quality and variability in student participation (Hewitt, 2003; Lipponen, Rahikainen, Lallimo, & Hakkarainen, 2003). There are also questions relating to teacher assessment of student learning and collaboration. Researchers have come to recognize that asking students to interact and discuss on computer forums does not necessarily lead to high-quality discourse (Kreijns, Kirschner, & Jochems, 2003). Hence, several questions arise: How can students best learn about inquiry and collaboration when engaging in computer-supported discourse? How can classroom assessments *characterize* and tap into the theoretical nature of the collaborative process while providing pedagogical support in *scaffolding* student understanding? How can we examine the problem of assessing individual and collective knowledge growth? This study examined the designs and roles of electronic portfolio assessments in characterizing and fostering knowledge building in the context of Knowledge Forum, a computer networked learning environment (Scardamalia & Bereiter, 2003).

Knowledge building as collective cognitive responsibility

The term *knowledge building* is now used commonly in the CSCL literature. In this paper, we use the model that defines knowledge building as "the production and continual improvement of ideas of value to a community." This definition emphasizes collective cognitive responsibility (Bereiter, 2002; Scardamalia & Bereiter, 2003). Similar to the process of scientific and scholarly inquiry, knowledge building places emphasis on ideas as conceptual artifacts that can be examined and improved by means of public discourse. In knowledge-building communities, members make progress not only in improving their personal knowledge but also in developing *collective* knowledge through progressive discourse (Scardamalia & Bereiter, 2003).

The theoretical perspective of knowledge building has evolved from decades of cognitive research on intentional learning (Bereiter & Scardamalia, 1989), processes of expertise (Bereiter & Scardamalia, 1993), and restructuring schools as knowledge-building communities (Scardamalia & Bereiter, 1994). With the emergence of the knowledge society, Bereiter (2002) critiqued the emphasis on the mind as a container and postulated a new model of the mind that views knowledge as a conceptual artifact that can be improved through collective work. Scardamalia and Bereiter (2003) argued that the goals of schooling need to go beyond the acculturation of knowledge and skills. Similar to research communities, schools in the 21st century are to focus on helping students to create and improve ideas, originate scientific new thoughts, and advance communal knowledge. Knowledge building is described as a third metaphor of learning that focuses on knowledge creation (Paavola, Lipponen, & Hakkarainen, 2004) in addition to the more common views of learning as "knowledge acquisition" and "participation" (Sfard, 1998).

The knowledge-building model is now being used extensively in schools as well as workplaces and organizations with a focus on knowledge work. It also contributes to the conceptual basis for the development of computer-supported collaborative learning. In particular, CSILE, now called Knowledge Forum, designed in the 1980s, was one of the forerunners of computer-networked environments. Over the past two decades, much research has been devoted to the design of Knowledge Forum and how to use it to support collaborative work with knowledge (Scardamalia & Bereiter, 1994; Scardamalia, Bereiter, McLean, Swallow, & Woodruff, 1989). A Knowledge Forum database is entirely created by participants. Using networked computers, a number of users can simultaneously create notes (text or graphics) to add to the database, search existing notes, comment on other students' notes, or organize notes into more complex structures. The communal database serves as an objectification of the community's advancing knowledge.

Features of Knowledge Forum are designed to help students reframe and advance ideas. For example, when writing a note in Knowledge Forum, students can add other notes as references, thereby creating an integrated web of notes (ideas) as their work proceeds. The visual linkages between ideas provide an important image for students, reflecting the interconnected and dialogical nature of knowledge that underpins the knowledge building perspective. Scaffolds or sentence starters such as 'My Theory' and 'I Need to Understand' are meta-cognitive prompts that can also be used to make the communicative intent of the information clear. For example, the scaffold 'My Theory' is intended to indicate that the information presented in the note is conjectural, and that it should be subjected to critique, testing, and application.

Whereas many advances have been made in research on knowledge building and Knowledge Forum (see review, Paavola et al., 2004; Scardamalia & Bereiter, 2003; Scardamalia, Bereiter, & Lamon, 1994; van Aalst, 2006), some important questions remain to be addressed: How can knowledge building be recognized, identified, and assessed? A major question about knowledge building pertains to characterizing and fostering collective knowledge advances and examining the complex interactions between individual and group understanding. Various approaches and techniques have been used by researchers in assessing knowledge building using quantitative tools, including the Analytic Toolkit (Burtis, 1998), social network analysis (e.g., Palonen & Hakkarainen, 2000), and qualitative discourse analyses of progressive inquiry (Hakkarainen, Lipponen, & Järvelä, 2002), problem-centered knowledge (Oshima, Scardamalia, & Bereiter, 1996), and knowledge-building principles (Scardamalia, 2002) to examine knowledge advances. Our own research efforts have been directed at designing and examining student assessments using *electronic portfolios* to characterize the *collective* and *progressive* nature of knowledge building while helping students to learn about collaborative inquiry (Chan & van Aalst, 2003; van Aalst & Chan, in press).

Learning, assessment, and collaboration

A major thrust of CSCL studies consists of quantitative and qualitative analysis of collaborative processes, and evaluation and assessment of systems and designs (e.g., Dillenbourg, Eurelings, & Hakkarainen, 2001; Koschmann, Hall, & Miyake, 2002; Stahl, 2002). Much less attention has been given to *formative*, *embedded*, and *transformative* assessments in collaborative inquiry, that is, how assessment can be used to *scaffold* students' collaborative inquiry and understanding. Analyses of online discourse in computer networked environments and forums are common. Current approaches focus on researcher designed tools and analyses, but few are designed to provide *scaffolds* or to foster *agency* for students in CSCL classrooms. Despite the popularity of forums and networks, investigators have come to the realization that putting students together does not mean they will engage in collaborative inquiry and deep discourse (Kreijns et al., 2003). Problems exist with low and variable participation rates and quality of discourse. In the following, we examine several issues regarding the alignment of learning, assessment, and collaboration.

Assessment of learning and assessment for learning

There have now been major changes in views of learning and instruction, and current views propose that assessment play the dual roles of scaffolding learning and measuring it (Black & Wiliam, 1998; Gipps, 2002; Shepard, 2000). Assessments need to be designed so they are integral to the instructional processes. The scaffolding aspect of assessment, sometimes called assessment *for* learning, involves designing assessments in ways that foster learning. Despite major shifts in assessment reforms, little work has been conducted in aligning learning, assessment, and collaboration in CSCL settings. Chan and van Aalst (2004) and Reeve (2000) have argued that even though high-level goals are professed in computer-based instruction, superficial knowledge is often emphasized in assessment. Students need to be given *agency* to assess their own and community knowledge advances. Assessment should be designed as a tool that both *measures* and *fosters* deeper inquiry and collaboration.

Assessment of individual and collective aspects of learning

CSCL approaches are primarily informed by learning theories that emphasize the social, distributed, and collective nature of learning (Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991; Salomon, 1993; Sfard, 1998). Collaboration is valued in a wide range of social constructivist learning approaches, and there has been much research progress on collaboration (Koschmann et al, 2002; Stahl, 2004). On the other hand, learning is nearly always evaluated at the level of individual learning outcomes in assessing the effectiveness of systems and designs (e.g., Dillenbourg et al., 2001). For example, Scardamalia et al. (1994) emphasized a public knowledge building discourse. Yet they provided only assessments such as reading levels and depth of explanation at the level of individual differences. This choice is problematic because when a theory is contributed to the public discourse and the community works on it, the theory no longer belongs just to the student who contributed it. It belongs to all in the community who worked on it. A major challenge in CSCL is to examine the relation between individual and social aspects of learning; we need to examine the notion of collective knowledge in theorizing knowledge building. Students' individual learning attainments are important; however, there is a need to examine how we can assess *collective aspects* of knowledge advances.

Assessment of content and process

Constructivist epistemology says that knowledge is constructed. If we want to prepare students for future learning—with less dependence on a teacher—we need to teach them to execute, monitor, and regulate the knowledge construction process. This would suggest that we must value not only what academic content is learned, but also how students achieve the learning. In higher education, there may be emphasis on constructivist teaching and learning using asynchronous networked environments, but when assessment is carried out, primarily discrete knowledge and skills are considered (Reeve, 2000). Even in more sophisticated environments involving peer learning, when group process is assessed, assessment tends to focus on superficial features, such as whether students are contributing "equally" to the group work. We submit that assessment should tap both the *collaborative process* and *knowledge products*.

Assessment of knowledge building and portfolios

This study aims to examine the roles of *student-directed portfolio assessment* in characterizing knowledge building and scaffolding collaboration and understanding. In the CSCL literature, there are several examples of student-directed assessment: self and peer-assessment in the Scientific and Mathematical Arenas for Refining Thinking (SMART) Environment (Vye et al., 1998), reflective thinking in Thinker Tools (White, Shimoda, & Fredericksen, 1999), and formative assessment in project-based learning (Barron et al., 1998). In our ongoing design research program, we are developing an innovative design using student-directed portfolio assessments to characterize and foster knowledge building. We asked students to prepare *portfolio notes* in Knowledge Forum. They selected exemplary notes from the computer discourse (similar to selection of best items for portfolios) and wrote a statement (reflection) explaining why they thought these were their best notes in evidence of knowledge building. To help them with the selection, they were provided with a set of knowledge-building principles as criteria. Specifically, a portfolio note included hyper-links to other computer notes providing evidence for the principles. A reader can follow the hyperlinks and move back and forth between the explanation and the referenced notes.

Currently, a major theme of CSCL research focuses on examining collaboration; analyses of group interactions are central for investigating student collaboration and sense making. Our own efforts have focused on developing this design called portfolios to capture the nature of *collective* knowledge advances. A portfolio note is a record of knowledge-building events made by students themselves to capture the high-points and trajectories of collaboration in the community. A portfolio is a group accomplishment with multiple contributions from students—it shows that knowledge is distributed and it emerges through collective inquiry. The principles and portfolio reflections are designed to mediate the interactions of individual and group understanding. Whereas portfolios commonly refer to an individual's best work, we pioneered the notion of knowledge-building portfolios for which students are asked to identify collective knowledge advances documenting the community's best work and progress.

In our initial work, we designed the use of knowledge-building principles and electronic portfolios for assessment in a graduate class (van Aalst & Chan, 2001). The portfolios were refined in a Grade 12 classroom using communal portfolios (Chan & van Aalst, 2003). To examine the portfolio design, we also examined other sources of data. We also investigated individual knowledge advances reflected in the computer notes for *depth of explanation* (Hakkarainen et al., 2002). Students' participation in database usage (e.g., notes read, written, linked, keywords) was assessed using server-log data with a program called the Analytic Toolkit developed by the Knowledge-Building Team (Burtis, 1998). Some of the database participation indices such as notes linked and keywords used are measures demonstrating collaborative work. Across different studies, we found that portfolio scores were correlated with participation and conceptual understanding (Chan & van Aalst, 2003). For example, student portfolio scores were significantly correlated with database participation ($r = .72$, $p < .05$) in the graduate course. They were also correlated with database participation ($r = .62$, $p < .05$) and conceptual understanding ($r = .62$, $p < .05$) in the Grade 12 study. Such results were further replicated with other Grade 12 students using science as the domain (see van Aalst & Chan, in press).

The present paper continues this line of inquiry addressing the problem of assessing individual and collective knowledge advances in evaluating and fostering collective knowledge building. Earlier studies showed correlation results; there is a need to conduct further studies to examine the roles of the knowledge-building principles and portfolios. There are several refinements in our design: *First*, the earlier studies were conducted with graduate students and Grade 12 students in small classes. We want to examine, here, whether electronic portfolios can be extended to younger students in larger classes, thus exploring its value as a teacher assessment approach. *Second*, earlier, we used four knowledge-building principles for note selection; we now extend the set of knowledge-building principles and we emphasize their use as scaffolds for student note writing as well as note selection. In particular, we asked students to write an essay on the basis of the portfolios, thus investigating the relations between collaborative processes and knowledge products. *Third*, our earlier studies included several components in the learning environment, and portfolio assessment was only one of them. Although it is typical of studies in technologically rich classrooms, the roles of knowledge-building principles and portfolios have not been specifically examined. In particular, it is not clear whether it is the portfolio task itself or the task augmented with the use of knowledge-building principles that brought about the positive effects. This paper describes our refined design for knowledge-building portfolios. Specifically, we examined differences among classrooms using Knowledge Forum only, Knowledge Forum with portfolios, and Knowledge Forum with portfolios guided by knowledge-building principles. While we recognize the complexity of classroom conditions, the comparison may help to illuminate the roles of knowledge building principles and portfolios.

In sum, the goal of the study was to design and examine a knowledge-building environment using portfolio assessments for characterizing and assessing collaboration and conceptual understanding. There were several objectives: (1) To examine whether students using portfolio assessments with knowledge-building principles showed more participation, deeper inquiry and conceptual understanding compared to their counterparts; (2) To examine different ways to assess knowledge building and investigate whether knowledge building inquiry and discourse contributed to students' conceptual understanding; and (3) To examine how knowledge-building principles and portfolios characterize and scaffold collective knowledge advances.

Method and design

Research design

This study is part of our ongoing design research program (Brown, 1992; Collins, Joseph, & Bielaczyc, 2004) that examines the theory and design of knowledge-building portfolios for addressing problems of assessment in CSCL. According to Collins et al. (2004), design research is formative and it is conducted to test and refine educational designs based on theoretical principles. A major characteristic of design experiment involves progressive refinement with iterative cycles in refining the design. As noted above, we have examined the design of the knowledge-building portfolios in a graduate course as well as in two other Grade 12 classes in geography and chemistry in Hong Kong (van Aalst & Chan, in press). This study can be considered a further iteration in our design research program that examines the roles of knowledge-building principles with a younger group of students. Although this study on its own may be presented as a design study with an emphasis on developing an innovative assessment pedagogy, we think it is important to stay close to the characteristics of design research that involve iterative cycles and refinement of designs over time.

This study is presented as an instructional experiment using a quasi-experimental design in classroom settings. Instructional experiments are commonly employed in research of learning sciences for testing theories. In this particular study, we sought to examine the theoretical perspective of how knowledge-building principles and portfolios might characterize and scaffold collective knowledge building and domain understanding. As it is difficult to allocate students randomly to different conditions, we employed a quasi-experimental approach typically used for classroom research with instructional interventions. We propose that it is useful to employ different methodologies in CSCL research. An instructional experiment with extensive quantitative and qualitative analyses will be a useful approach to address the research questions.

Participants

The participants were 119 students in four grade-nine Geography classes in a regular high school in Hong Kong, taught by the same teacher. Three of the classes were engaged in knowledge building using Knowledge Forum with different conditions. The fourth was a comparison class that was not using Knowledge Forum; students in this class were required to submit a paper and pencil portfolio. The students at this school had high–average abilities; they studied from English textbooks, and wrote in English in Knowledge Forum. Students were taught by an experienced geography teacher with over 12 years of teaching experience; he also had several years of experience using knowledge-building pedagogy and Knowledge Forum. This study involves close collaboration between researchers and teachers—the teacher's expertise in knowledge building plays important roles in designing and implementing the study.

The classroom setting

Knowledge Forum was implemented in the geography curriculum in the second semester of the year for several months (Feb–June). The teacher integrated knowledge-building pedagogy with the school curriculum; a number of curriculum units were taught including "Ocean in Trouble," "Rich and Poor," and "Saving our Rainforests." There are some differences with the implementation of knowledge building and Knowledge Forum in Asian classrooms compared to mainly North American classrooms. Typically, Asian students need to do homework after school and online discussion was conducted after school hours similar to that in tertiary settings. Teachers conducted lectures/class discussions during school hours and students were asked to deepen their understanding of the course materials on Knowledge Forum after school, and problems emerging in the computer discourse were discussed in class. All three classes using Knowledge Forum worked on Knowledge Forum discussion after school. Students in the comparison class also worked after school to control for time exposure to course materials; they needed to submit a paper-and-pencil portfolio that also included elements of collaboration. Specifically, students were required to include concept maps that consisted of both individually and collaboratively constructed maps and a group project related to the themes of the key question.

Design of the learning environment

The course was organized and informed by knowledge-building pedagogy: Students worked on Knowledge Forum as they generated questions, posed alternative theories and hypotheses, brought in new information, considered different students' views, and reconstructed their understandings. We augmented Knowledge Forum with our design on knowledge-building portfolio assessments. We describe the design of the knowledge-building environment as follows:

Developing a collaborative classroom culture

Before the implementation of Knowledge Forum, students were provided with learning experiences acculturating them into the practices of collaborative learning. Such learning experiences are particularly important for Asian students who are generally more familiar with the didactic mode of teaching. Several group learning activities were included, for example, jigsaw learning and collaborative concept mapping.

Developing knowledge-building inquiry on Knowledge Forum

Knowledge Forum was formally implemented in the three classes in early February. The teacher constructed the "Welcome View" with different topics for discussion and a view on assessment (except for the Knowledge Forum only class). Specifically, the Welcome View was called “World Problems & How to look after the World?” which constituted the key problem (topic question) of the year. Three sub views were included, namely, “Rich & Poor,” “World Ocean,” and “Tropical Rainforest.” The key problem was used as a thread throughout the course to link all the subtopics of the school curriculum (Fig. 1). The teacher designed Knowledge Forum to promote knowledge building while aligning the topics with the school curriculum.

The teacher also designed the curriculum incorporating notions of ‘majoring’ and ‘specialization’ related to the idea of the jigsaw approach in fostering communities of learners (Brown & Campione, 1994). For the first two months, students were divided into three groups assigned to majoring in one of the three topics. They were experts of a particular view and they pooled together their understanding in addressing the final question—“How to look after the world?” In designing the views, the teacher wrote an introduction to explain purposes of each particular view. In doing that, the teacher attempted to integrate classroom learning with Knowledge Forum work. As in other knowledge-building classrooms, students posed questions and problems, made conjectures, examined different explanations, and revised their ‘theories’ as they examined each others’ computer notes.

Deepening knowledge-building discourse and view management

As the number of notes proliferated over time, the teacher worked with students and identified several sub themes, note clusters, and questions that need further inquiry. Clusters of notes were moved into newly created views, such as “Ecosystem,” “Money is the solution?” and “Wealth Gap.” At other times, responses that include questions or answers to certain questions were selected from the database and then presented by the teacher to foster discussion among students in class. Very often these responses were related to the lesson for the day. These different activities were conducted in all three classes.

Portfolio assessment and knowledge-building principles

After the introduction of Knowledge Forum and some initial work, there were differences in the design across classes. Whereas students in the “Knowledge Forum” online class continued to engage in computer forum discussions, students in the “Knowledge Forum with portfolios” class were asked to produce an electronic portfolio consisting of the four best clusters of notes in the computer discourse with explanations for the selection. Students in the “Knowledge Forum with portfolios and principles” class were provided with additional scaffolds in portfolio instruction: They were provided with a set of knowledge-building principles to help them with note writing and note selection and were asked to explain how the selected notes illustrate the principles.

As part of their course assessment, students posted their portfolio notes in the Knowledge Forum database in the “Assessment View” (see Fig. 1). The portfolio note is a ‘rise-above’ note that makes reference to other notes in the database as well as the explanation for the discourse (Fig. 2). Students also had views wherein they worked on constructing the portfolio notes. In the literature on assessment, portfolio usually refers to students’ records and reflections on their best learning

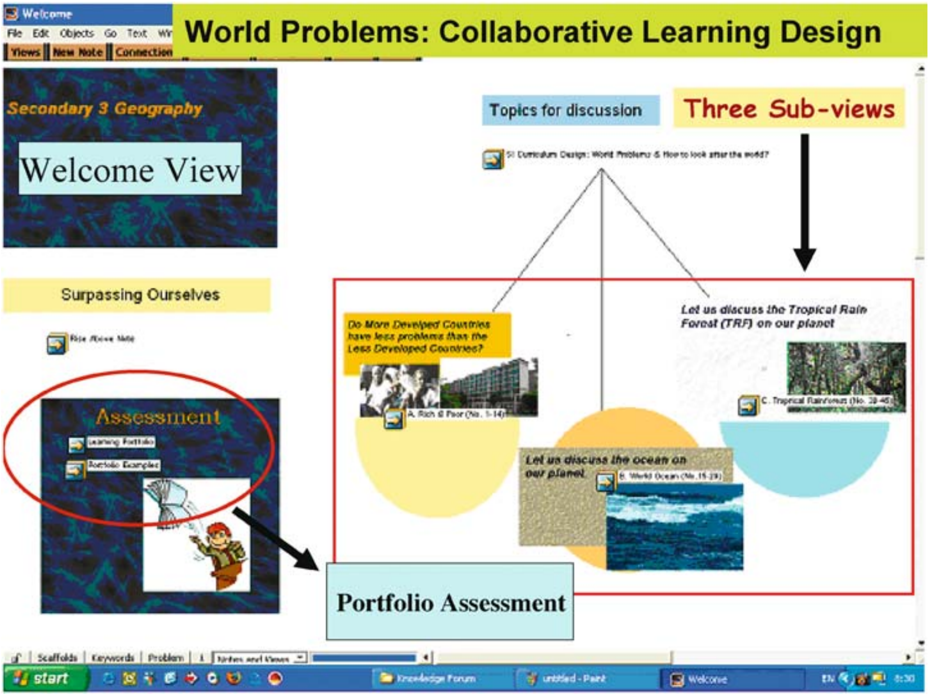

Fig. 1 The design of curriculum and assessment views in Knowledge Forum

experiences supported by artifacts and evidence (Wolf, Bixby, Glenn, & Gardner, 1991). In this study, knowledge-building portfolios refer to students' records and reflections on *individual* and *community* knowledge advances supported with evidence from the discourse guided by the knowledge-building principles.

Table 1 shows the instruction for the knowledge-building portfolio assessments. When working on the portfolio, students had to revisit the database and to look for note clusters that best demonstrate the knowledge-building principles. In examining the online contribution, students were engaged in a process of analyzing ideas and concepts contributed by classmates embedded in the discourse; there were also personal and collaborative knowledge reconstructions of understanding.

Current research on knowledge building includes a set of twelve principles aimed at elucidating the process and dynamics of knowledge building (Scardamalia, 2002). As the system is rather complex, we have developed a smaller set designed for use as pedagogical and assessment tools highlighting several key facets of knowledge building (Chan & van Aalst, 2003; van Aalst & Chan, in press). The principles we used are conceptually related to Scardamalia's knowledge building principles but they are more accessible to middle-school students. The description of the pedagogical knowledge building principles is as follows:

(1) *Working at the cutting edge*. This principle is based on the idea that a scholarly community works to advance its collective knowledge. For example, scientists do not work on problems of personal interest only, but on problems that can

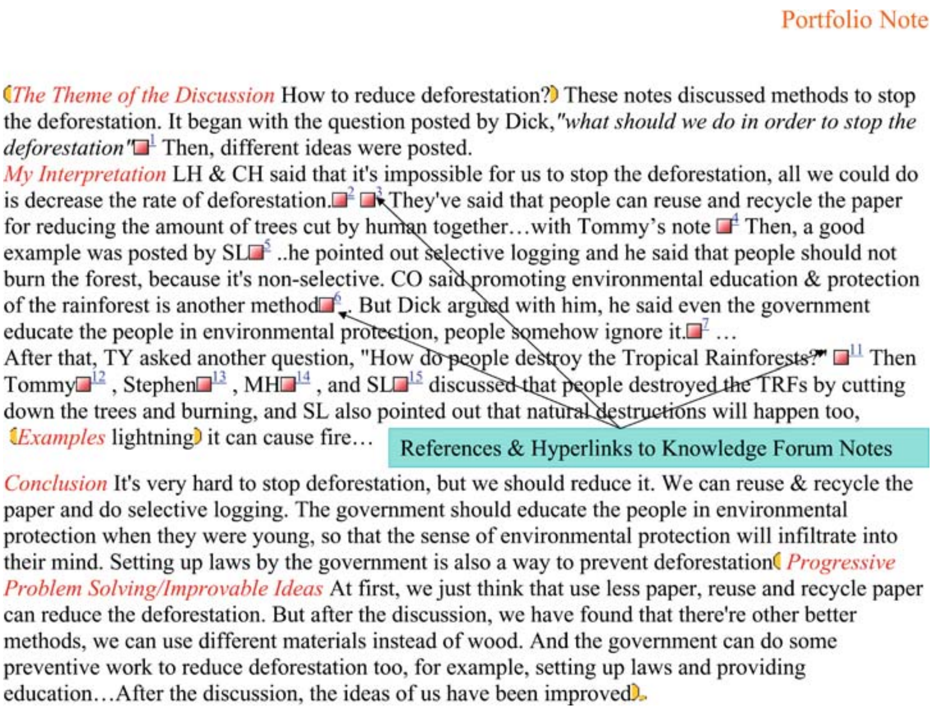

Fig. 2 An illustration of a portfolio note with scaffolds and references

contribute something new to a field. The problem may emerge from conflicting models, theories, and findings that require further explanation. Similar to the principle of "epistemic agency" (Scardamalia, 2002), this principle focuses on the importance of students charting their own knowledge advances. Some indicators in the discourse may help to show if students appreciate this aspect of a scholarly discourse. First, they must become familiar with previous work on the topic (i.e., some awareness of what the community has found out about the topic) as they frame problems of understanding. Second, the problems students formulate have become the community's problem. For example, there is evidence that the class has taken up the problems to some extent so there is community interest in the problem.

(2) *Progressive problem solving*. The basic idea of this principle is that when an expert understands a problem at one level, he or she reinvests learning resources into new learning (Bereiter & Scardamalia, 1993). In a scholarly community, we often find one study raises new questions that are explored in follow-up studies. The notion of progressive problem solving is analogous to the principle of "improvable ideas" focusing on progressive inquiry and refinement (Scardamalia, 2002). Indicators of progressive problem solving in computer discourse would include instances when students have solved certain problems but then reinvest their efforts in formulating and inquiring other problems for deeper understanding. Often students document the history of the problem and mark the progress of the idea.

Table 1 Teacher guidelines on knowledge-building principles and portfolios

Guidelines for knowledge-building portfolios

- You have to select FOUR best notes. One note may be defined as a cluster/group of notes. You need to use the "References" or "Note Reader" functions to complete the task. Use the scaffolds provided to write notes and when doing the portfolio.
- You need to write a summary for EACH note selected. The summary note should explain the reasons for choosing that particular cluster of notes. You need to organize the notes in a way that will help the readers to understand your work better. For example, you may give a theme of the selected note and state which principle(s) may be recognized in the note.
- Follow the five principles of note writing and note selection given below.

Principle One: Working at the cutting edge

- ○ Identify knowledge gaps, inconsistencies and ask productive questions
- ○ Pose problems that extend the edge of the understanding of the community
- ○ Pose problems with potential for continual discussion and inquiry

Principle Two: Progressive problem solving

- ○ Show continual efforts to grapple with problems posed by classmates
- ○ Pose notes that address the original problems and questions arising from them
- ○ Show sustained inquiry: Identify the problem, solve the problem and keep asking questions
- ○ Reinvest efforts to keep solving new problems and improving ideas

Principle Three: Collaborative effort

- ○ Use various Knowledge Forum functions such as 'references' and 'rise-above' to make knowledge accessible
- ○ Summarize different ideas and viewpoints and put them together as a better theory
- ○ Help classmates to extend and improve their understanding
- ○ Encourage classmates to write notes that follow the other principles

Principle Four: Monitoring own understanding

- ○ Explain what you did not know and what you have learned
- ○ Recognize discrepancies, misconceptions and new insights; trace your own paths of understanding
- ○ Show your new ways of looking at questions, ideas, and issues after examining other Knowledge Forum notes

Principle Five: Constructive uses of authoritative sources

- ○ Use information from different sources (e.g., Internet, newspapers) to support, explain, and refute ideas
- ○ Bring together classroom learning, information from different sources and Knowledge Forum notes
- ○ Provide contrasting or conflicting information to what is printed in the textbook/newspapers and/or critique information as presented

(3) *Collaborative effort*. This principle focuses on the importance of working on shared goals and values in developing "community knowledge" (Scardamalia, 2002). Collaborative effort is central to computer-supported collaborative learning but may have different manifestations. At more superficial levels, collaborative effort can be manifested as students writing notes in response to other notes. At higher levels, students are aware that knowledge construction is only possible because students can examine a problem from multiple perspectives; they may index their notes in better ways for retrieval, or contribute notes with new lines of thoughts so others can develop the ideas further. At more sophisticated levels, students contribute notes that integrate different notes and perspectives, for example, summarizing what has been learned about a problem and describing what still remains to be discussed or investigated. Collaborative

effort is more than responding to each others' notes; it is about building up community knowledge.

(4) *Monitoring own knowledge*. This principle is based on the idea that metacognitive understanding is required for knowledge building. Specifically, it requires students to have insights into their own and the community's knowledge advancement processes. Monitoring own knowledge is similar to progressive problem solving in that it documents the history of ideas or problems—but now the focus is placed on metacognitive processes. The idea of metacognition is related to the principle of "rise above" (Scardamalia, 2002), in which students move to higher levels of understanding. The indicator of this principle may include students identifying "high-points" of their own understanding. For example, can students identify events that help them understand something differently? What is some "Aha" experience that can help them 'rise above' to see things from other perspectives?

(5) *Constructive uses of authoritative sources*. This principle, as described by Scardamalia (2002), focuses on the importance of keeping in touch with the present state and growing edge of knowledge in the field. Whereas it is commonplace for students to refer to Internet or websites, we emphasize the constructive and evaluative uses of resources in scientific inquiry; students need to make reference to others' knowledge, build on this knowledge as well as critique authoritative sources of information. Some indicators in the computer discourse would include students identifying inconsistencies and gaps in knowledge sources and using resources effectively for extending communal understanding.

These principles involve both social and individual aspects of knowledge building. For example, working at the cutting edge requires that students individually identify gaps in their understanding, but it also requires a social responsibility to raise problems that have not yet been solved by the community. In collaborative efforts, students individually do their best to learn the information they encounter, but they also have a responsibility to share what they know where it is needed for the community to make progress. This set of knowledge-building principles is still complex but we have developed guidelines and provided examples to help students use them in assessing their computer discourse. We have adapted the guidelines from earlier studies with high-school students, so they could be more accessible to middle-school students.

Data sources

Analytic toolkit and database participation

The Analytic Toolkit (ATK, Burtis, 1998) provides an overview of student participation using information on database participation. Several quantitative indices include: (a) notes created; (b) notes read; (c) scaffold uses—scaffolds are thinking prompts, e.g., "My Theory," "I need to understand," to guide writing and collaboration; (d) note revision—revision is an important meta-cognitive process; (e) percentage of notes linked; and (f) percentage of keywords—keywords can help others to search the notes in the database. Some of these indices such as number of

Table 2 The rating scheme for depth of inquiry

Rating	Description
1	Questions on definitions and simple clarification
2	Questions asking for factual, topical and general information
3	Questions identifying specific gaps and asking for open-ended responses and different viewpoints
4	Explanation-based questions—Focus on problems not topics; identifies sources of inconsistencies; generates conjectures and possible explanations

notes linked, read, and keywords reflect certain kinds of group processes in database participation.

Depth of inquiry and depth of explanation

Computer notes consisting of student responses and questions were examined for assessing individual inquiry, based on earlier research on problem-centred inquiry (Chan, 2001; Chan, Burtis, & Bereiter, 1997) and depth of explanation (Hakkarainen et al., 2002). Students' questions were coded on a 4-point scale for *depth of inquiry* (Table 2), and students' responses were coded on a 7-point scale to distinguish the levels of *depth of explanation* (Table 3). These scales were constructed following principles and procedures used in protocol analyses (e.g., Chi, 1997) involving an interactive process of top–down and bottom–up approaches. Primarily, the researchers use some conceptual frameworks to inform them, and through examining the responses, categories and continuums are generated to capture different processes and patterns emerging from the data. Construct validation is usually used to examine the relations between these generated measures and other variables. Both scales of inquiry and explanations were constructed as a continuum consisting of simple descriptive responses to complex explanatory responses. All students' responses and questions were scored by the first author and a second rater independently scored 30% of the sample. The inter-rater reliability of depth of inquiry and depth of explanation were .78 and .83, respectively, based on Pearson Correlation.

Table 3 The rating scheme for depth of explanation

Rating	Description
1	Repeat or simply restate a fact or a statement that has been made
2	Give factual information and general description; responses are usually centered on facts and topics; 'cut and paste' is used rather than making own interpretations
3	Give responses and make inferences supported with some relevant information
4	Make assertions supported with explanation, evidence and relevant examples
5	Refocus discussion or highlight key conceptual issues for further inquiry; bring out other aspects of issues for discussion
6	Recognize high points in discourse; metacognitive, show personal reflection
7	Synthesize different points of views and make a 'rise-above' summary

Knowledge-building portfolios

Students were asked to prepare a portfolio of four clusters of notes in which they provided evidence for knowledge-building principles (i.e., working at the cutting edge, progressive problem solving, collaborative effort, monitoring own knowledge, constructive uses of resources). In their selection, students were asked to include their own notes as well as others' notes from the database. Students were also required to write an explanatory statement for each cluster on why these notes best demonstrated evidence of knowledge building. Portfolios were coded on both explanation and evidence of knowledge building based on selected notes using a 6-point scale (Table 4). All students' portfolios were scored by the first author, and a second rater independently scored 30% of the portfolios. The inter-rater reliability was .88 based on Pearson Correlation.

Table 4 The rating scheme for portfolios

Rating	Descriptors and Indices
1	• Identify the theme of a cluster • Make very brief or no description of the cluster
2	• Make brief analysis with little conclusion • Make general statement without referencing to others' notes • Give superficial interpretation of notes with own judgment • Give personal views with limited referencing to the note clusters
3	• Provide a very brief description of the discussion • Indicate agreement or disagreement to the discussion without much explanation • Attempt to weigh the relevance of an argument but fail to incorporate relevant aspects • Make some interpretation but fail to make reference to the relevant notes selected
4	• Provide a brief description of the discourse with shallow personal elaboration or evaluation • Identify different strands of discussion but with very brief description • Attempt to reinterpret and understand the note content • Attempt to provide a brief comment on the discussion • Draw relevant conclusions • Make good selection of notes as related to curiosity and inquiry • Show personal reflection and identify high points with elaboration
5	• Provide a detailed description of the discourse • Identify groups of ideas and classify arguments within a discourse • Construct explanations showing reflection • Build in own interpretation when analyzing the discourse • Deduce the logic of an argument in a discussion thread • Evaluate the quality of notes; draw relevant and appropriate conclusions
6	• Identify the key question and critical turning points • Identify misconception/knowledge gaps in the discourse • Articulate the growth of ideas (agreement, disagreement, and alternative solutions) in the discussion thread identified • Add own interpretation while articulating the growth of ideas • Evaluate the applicability of a solution generated for the questions • Summarize and synthesize the diverse ideas/arguments in the discourse • Demonstrate the interaction between community knowledge and individual knowledge • Draw conclusions that contribute to personal and collective knowledge advancement

Conceptual understanding

To assess students' conceptual understanding of the domain in question, students in all classrooms were administered the following writing task: "We have been exploring three major world problems, namely 'Rich and Poor,' 'Ocean in Trouble,' and 'Deforestation.' In about 300 words, express your view on the following question: Who and how should we look after the World?" Students' responses to the writing task were coded using writing rubrics used in the school and other criteria constructed by the teacher (Table 5). All the students' essays were scored by the first author and a second rater independently scored 30% of the essays. The inter-rater reliability was .88 based on Pearson Correlation.

Results

This study was conducted in classrooms and therefore it was not possible to allocate students randomly to different conditions. As noted above, a quasi-experimental design was employed. In the study, students were working collaboratively on the computer discussion, hence there are also possible problems with the lack of independence of the observations. To correct for different sources of possible errors, we have set the alpha level at a more stringent level (.01) for statistically significant differences.

Class differences on participation, inquiry, and conceptual understanding

Participation and collaboration in database usage

We first examined students' overall contributions and collaboration based on database participation in Knowledge Forum. The general descriptive picture from Analytic Toolkit (ATK) indicated a substantial usage of the databases: There were totals of 661, 302, and 1090 written notes respectively, contributed by the three classes (Knowledge Forum, Knowledge Forum with portfolio, and Knowledge Forum with portfolio and principles). The average numbers of notes written were 17.4, 8.4, and 28.7 for the three classes respectively in the semester.

Table 5 The rating scheme for the writing task

Descriptors
• Discussion based on at least two out of the three world problems • Able to highlight some of the causes of the world problems • Clear standpoint on ways of solving the world problems, i.e., co-operation or individual country work • Realize the importance of citizen's role • Suggest relevant solutions, such as international cooperation, for solving the problems • Evaluate the difficulties of implementing the suggested solutions • Argument supported with relevant examples • Credits will be awarded for quoting local examples

To simplify the presentation, the Analytic Toolkit indices were combined using factor analysis. Two factors were obtained: Factor One called *ATK Knowledge Building Inquiry Index* (i.e., notes created, notes read, scaffold uses, note revision) explained 42.6% of the variance, and Factor Two called *ATK Knowledge Building Visual Organization* Index (keyword use, notes linked) explained 10.1% of the variance.

To examine differences across the three classes, a MANCOVA was conducted on the database participation indices (ATK), depth of inquiry and depth of explanations, controlling for differences in academic achievement (Hong Kong Attainment Test scores). Overall MANCOVA results showed significant differences across class, $F(14,202) = 5.82$, $p < .001, \eta^2 = .29$. Univariate analyses on database usage in Knowledge Forum showed significant differences for ATK Inquiry across classes, $F(2, 107) = 7.96$, $p < .001, \eta^2 = .13$. Paired-comparisons indicated that the Knowledge Forum class with portfolio and principles as well as the Knowledge Forum class with portfolio had higher ATK Inquiry scores than the Knowledge Forum class. There were no significant differences for the Visual Organization index across classes (Table 6).

Depth of inquiry and depth of explanation

The entire set of database notes, including questions and responses, was scored using the two rating scales (see Tables 2 & 3) developed based on previous research on knowledge building (Chan et al., 1997; Hakkarainen et al., 2002). We examined differences on frequency and quality of questions across classes (see Table 6). MANCOVA showed significant differences (see above) and univariate analyses indicated significant differences on total number of questions, $F(2, 107) = 13.18$, $p < .001, \eta^2 = .20$, and total number of high-level questions, $F(2, 107) = 16.18$, $p < .001, \eta^2 = .23$. Paired-comparison analyses showed that the Knowledge Forum class with portfolio and principles had significantly higher mean scores than both the Knowledge Forum and the Knowledge Forum portfolio classes (see Table 6).

Table 6 Scores on participation (ATK), inquiry, and explanation across three classes

	Knowledge forum (*n* = 36)	Knowledge forum with portfolio (*n*=37)	Knowledge forum with portfolio and principles (*n*= 38)
ATK inquiry	−.45 (.37)	.03 (.83)	.44 (1.2)
ATK visual organization	−.17 (.82)	0.01 (.96)	.18 (.92)
Total number of questions	2.28 (1.93)	5.03 (6.42)	10.84 (10.7)
Number of high-level questions	.39 (.99)	.89 (3.5)	5.53 (6.4)
Depth of inquiry	1.85 (1.34)	2.24 (1.33)	3.59 (1.6)
Number of high-level explanations	3.4 (4.9)	2.6 (5.9)	23.7 (35.7)
Depth of explanation	3.55 (1.21)	3.01 (1.25)	4.33 (2.15)

In addition, an overall weighted score called Depth of Inquiry was computed based on both quality and frequency of questions. For example, a student writing six questions (one question at level 2, three questions at level 3, and two questions at level 4) was given an overall weighted score of 3.2. Multivariate analyses were significant and univariate analyses also showed differences on the weighted scores of depth of inquiry, $F(2, 107) = 8.61$, $p < .001$, $\eta^2 = .14$. Paired-comparison analyses showed that the Knowledge Forum class with portfolio and principles had significantly higher mean scores than both the Knowledge Forum only and the Knowledge Forum portfolio classes (see Table 6).

Students' written responses were scored and examined for differences across classes. We first examined the number of high-level responses (explanations). Multivariate analyses and Univariate analyses showed significant differences across classes, $F(2, 107) = 10.66$, $p < .001$, $\eta^2 = .17$; paired-comparisons showed that the Knowledge Forum class with portfolio and principles had significantly higher mean scores than the other two classes. Based on both frequency and quality, an overall weighted score called *Depth of Explanation* was computed. Univariate analyses of variance controlling for differences in academic achievements showed significant differences, $F(2,107) = 6.2$, $p < .01$, $\eta^2 = .10$. Paired-comparison analyses showed that the Knowledge Forum class with portfolios and principles had higher scores than the Knowledge Forum portfolio and Knowledge Forum class (see Table 6).

Taken together, these results suggest that students scaffolded with knowledge-building principles and portfolios participated more in the database and they also constructed better questions and deeper responses.

Conceptual understanding

The mean scores of conceptual understanding based on a writing task were 5.5 for the regular class, 5.2 for Knowledge Forum class, 5.2 for the Knowledge Forum with portfolios, and 7.0 for the Knowledge Forum class with portfolio and principles. An ANCOVA controlling for differences in academic achievement indicated that significant differences were obtained favoring Knowledge Forum with portfolios and principle class over the other classes, $F(3, 145) = 10.95$, $p < .001$, $\eta^2 = .19$.

Relations among participation, inquiry, knowledge-building portfolios and conceptual understanding

We also examined the relations between students' portfolio scores with other measures for the two classes that completed the portfolio assessments ($n = 58$). Portfolios were rated on explanation, conceptual quality, and the selection of note clusters (see Table 4). Partial correlations controlling for achievement (Hong Kong Attainment Test) indicated that different measures were correlated (Table 7). Knowledge building portfolio ratings were significantly correlated with ATK inquiry ($r = .44$, $p < .001$), ATK visual organization ($r = .39$, $p < .01$), and explanation scores ($r = .46$, $p < .001$). As well, knowledge building portfolio ratings were significantly correlated with essay writing reflecting conceptual understanding ($r = .42$, $p < .01$).

In order to examine the relative contributions of individual inquiry and collective inquiry scores, a multiple regression analysis was carried out using conceptual understanding (essay scores) as the dependent variable (Table 8). The variables were

Table 7 Partial correlation among participation (ATK), inquiry, explanation, portfolio scores, and conceptual understanding controlling for academic achievement for KF portfolio and KF portfolio-principles classes.

	ATK inquiry	ATK visual organization	High-level question	High-level explanation	Portfolio scores
ATK visual organization	.58***				
High-level questions	.11	.00			
High-level explanation	.62***	.31*	.04		
Portfolio scores	.44***	.39**	.14	.46***	
Conceptual understanding	.15	.03	.34**	.41**	.42**

Note: * $p < .05$, ** $p < .01$; *** $p < .001$.

entered using a hierarchical regression analysis method; first, academic achievement scores were entered, followed by ATK Inquiry scores, followed by explanation and question scores (individual inquiry), and lastly by knowledge-building portfolio scores (collective inquiry). The results of the analysis show that academic achievements contributed significantly to conceptual understanding, $R^2 = .33$, $F\,(1, 56) = 26.9$, $p < .001$. When ATK inquiry scores were added, there were small increment and nonsignificant changes ($R^2 = .34$). When both explanation and inquiry scores (individual inquiry) were added, they contributed an additional 19% of variance to conceptual understanding with significant change, $R^2 = .53$, $F\ (4, 53) = 10.57$, $p < .001$. Finally, when the portfolio scores (collective inquiry) were entered an additional 4% of variance to conceptual understanding was explained, $R^2 = .57$, $F\ (5,\ 52) = 5.3$, $p < .05$. These findings indicated that collective portfolio scores contributed to conceptual understanding over and above academic achievement, database participation, and individual inquiry scores. Taken together, these findings indicated that portfolio scores reflecting collaborative knowledge advances predicted students' conceptual understanding.

Table 8 Multiple regression of academic achievement, participation (ATK), inquiry and explanation, and portfolio scores on conceptual understanding

	R	R^2	R^2 Change
Step one			
Academic achievement	.57	.33	.33***
Step two			
ATK database usage	.58	.34	.014
Step three			
Explanation scores			
Inquiry scores	.73	.53	.19**
Step four			
Portfolio scores	.76	.57	.04*

Note: * $p < .05$; ** $p < .01$; and *** $p < .001$.

Characterizing individual and collective knowledge advances

Students were asked to produce four clusters of notes with explanations in their portfolios. We examined examples of portfolio notes to investigate how portfolios helped to characterize collective aspects of knowledge building and to scaffold students understanding.

Portfolios with and without knowledge-building principles

Two examples are provided here to illustrate the differences of portfolio notes with and without principles. Table 9 shows an example of a portfolio note illustrating how knowledge-building portfolios might help to identify and characterize knowledge-building episodes in the community, and how they scaffold the student's reflection and understanding. At the beginning, Student #1 referred to a question he had posed, "Do shipwrecks add pollution to the world's oceans?" Instead of asking a typical textbook question, Student #1 posed what might be called an "authentic

Table 9 An example of a portfolio note with knowledge-building principles

[The Theme of the Discussion] The effects of chemicals on the oceans... It began with the question "Do shipwrecks [such as] the Titanic add pollution to the world's oceans?".
[My Interpretation] **At first, I thought that my question was quite debatable.[1] But in the end, I thought that shipwrecks weren't as harmful as they seemed to be**. I thought that after decomposition of oil spills, the oceans could return to their initial form, **but this idea was heavily criticized by my classmates**. They all thought that shipwrecks brought serious threats to the oceans.[2,3] ...They said that if oil was spilt into the oceans, it could kill many animals before the oil could be decomposed. Mr. Lee told us that if a certain species is killed, it might break the food chain. Therefore, oil spills are quite dangerous to our oceans. **I was [shown] that oil spills were far more serious than I ever expected**. Then CW corrected a stupid mistake made by me. He told me that the Titanic ran on coal not oil. Therefore I realized I actually had a problem with my question.
Then, the first evolution came. ER suddenly asked if the oil from an oil spill is an ocean resource.[4] Naturally, CW answered this question[5]
Here's the second evolution. CY started to argue that tankers carrying chemicals are more dangerous than oil tankers,[6] CW and I didn't agree though.[7] We thought that although cyanide is more poisonous than oil, cyanide is soluble in water. Therefore, its effects on the oceans are less than those of oil.[8] WY agreed with this,[9] SL too. He said that oil is difficult to clean up, and could kill heaps of wildlife, **but I still had my questions... Are oil spills really that bad to the oceans?** After 50 years or so, the oil would start to decompose and the corals would grow on the shipwreck, it'd become an artificial reef, what's the problem with that?[10] CW agreed with me that shipwrecks aren't really that bad in the long term "*water wave will wash the oil and make them into smaller particles and decompose them in the following years!*"[11]
TY also pointed out that pollution is proportional. Oil spills could help the environment—"*the resources used up" and the curve of the pollution is proportional. So if we can control the use of the resource, we can also reduce the level of pollution~*"[12]
[Principle 2 Improvable Ideas/Progressive Problem Solving] I [think] that this is a principle 2 note because in this cluster of notes, ***[Reasons]*** **In the beginning, I was asking about shipwrecks, soon the discussion turned to chemicals and finally a new concept was pointed out (pollution is proportional). Every time there was a question, we'd solve it, think of another question and solve that as [we] get better answers and more questions.**

Note: The superscripts are hyperlinks to other computer notes in the database. The Italics are made by the authors for emphasis.

problem" (Scardamalia, 2002) that interested the students. Student #1 identified diverse ideas from his classmates and explained how they differed from his views. In examining the discourse, Student #1 also became more aware of the 'mistakes' he had ("Titantic used coal not oil"). The portfolio note illustrated how the students made sense as they worked collaboratively on the problem, pushing for new understanding, rather than having premature closure commonly seen in school tasks.

As Student #1 pursued the problem with others, he wrote that he had the 'first evolution' [insight] when someone asked whether an oil spill can be a resource. He then described another evolution when the classmates discussed whether oil spills or chemical pollutions are more serious. Further inquiry of the problem led to improved ideas and new realizations—"proportionality" and control of resources as ways to control pollution. The portfolio note helps demonstrate that knowledge building involves a problem-centered collaborative inquiry process where new ideas are examined, debated, and improved upon. The student also explained how the portfolio note illustrated the principle of progressive problem solving in collaborative knowledge building. "At first, I was asking about shipwrecks, soon the discussion turned to chemicals and finally a new concept was pointed out (pollution is proportional). Every time there was a question, we'd solve it, think of another question and solve that as well to get better answers and more questions." The portfolio note suggests that knowledge does not reside in one student; it traces the trajectory of collaboration illustrating the distributed and progressive nature of knowledge building.

We provide an example of a different kind of portfolio note in which students also found exemplary notes from the class on the same theme without having been given the scaffolds of the knowledge-building principles (Table 10). In this example, the selection of question is different: Student #2 identified a note that asked quite a general question—"Where does an oil spill come from?" The student then wrote he found three notes that answered the question and the problem was considered solved. The same situation occurred again. This time the question was more interesting but Student #2 still used the strategy of finding three notes that answered the question and

Table 10 An example of a portfolio note without knowledge-building principles

[The Theme of the Discussion] *This topic is ocean in trouble*. The question is "*Oil spill is a kind of pollution. But where does it come from? From an accident of a ship or from nature?*"[1] This is a simple question, I don't think nature can make oil spill occur.[2,3,4]

These three notes have answered the big question of oil spill. Oil [comes] from the ground and [it is] transported by ship. But some accidents have happened [and] the oil spills on the surface of ocean. Oil spill is a serious problem of pollution; it kill[s] the marine wildlife and make[s] the world problem [creating] lack of fishes.

The other most interesting note comes from "*Why a small amount of oil will be formed when it is raining?*"[5] The rain contains oil, I think this is silly to say "Oil Rain!". ***There are three answer[s] to the notes***, that include:"*Internet says that the rain may contain a small amount of oil.*"[6] "*, the car fumes contain some toxic chemicals, and a little amount of oil may still be in the smoke. So, the smoke goes up and [gets into] the rain.*"[7] and "*the soil is fat and may contain oil,so when rainwater come through,oil may [be] flushed away with the rainwater...*"[8]

I think the acceptable answer is [that] smoke with water vapor is absorbed by the Sun, and [it]condenses to from cloud [and] finally forms rain.

Note: The superscripts are hyperlinks to other computer notes in the database.

found the most acceptable one. The notion of improvable idea or collective advances cannot be found in this note. Instead the student seemed to be more engaged in a form of premature closure focusing on finding the correct answers.

Portfolio note selection and collective knowledge advances

We also examined students' portfolios to identify patterns of portfolio note selection. It would be useful to see if students tended to select similar clusters of notes because this may illustrate areas of growing knowledge in the community. We examined all portfolio note clusters in the knowledge-building portfolio class. Altogether, there were 19 themes (clusters) identified from the view "Tropical Rainforest," 9 themes (clusters) from the view "Rich and Poor" and 7 themes (clusters) from the view "Ocean in Trouble." Students actively made references to other students' computer notes in portfolio notes. For the clusters on "Tropical Rainforest," the number of referenced notes ranged from 2–25 (Mean=8.6 notes); for the clusters on "Rich and Poor," the number of referenced notes ranged from 8–12 (Mean=10), and for the clusters on "Ocean in Trouble," the number of references notes ranged from 5–15 (Mean=9.6). There was also some tendency for students to select similar themes and clusters, for example, the most popular cluster of discussion was selected by eight students, two other clusters by seven students, and seven clusters selected by at least 5–6 students as their portfolio notes. These patterns may suggest some convergence in students' growing knowledge.

The most popular cluster of notes in this community was about the problems faced by more developed (MDCs) and less developed (LDCs) countries; eight students chose this theme as best notes. We included excerpts from two of the portfolio notes to illustrate collective knowledge advances.

Student #3 first provided the context and theme of the discussion; he then set out to identify common themes as well as different views in the community. Student #3 wrote:

> The following cluster of notes was started with a question from CS [on] "*What are the problems that both the more developed countries and less developed countries have*?"[1] For the discussion on the topic of wealth gaps, all classmates agreed that the problem of wealth gap must be solved. I have also found that classmates are separated into two 'parties' on the methods of helping the less developed countries (LDCs), one intending to help them *with giving them money* from the more developed countries (MDCs), [and] another intends to help them to solve the essential problems, such as providing economic advice etc. (Note: The superscripts are hyperlinks to other computer notes in the database.)

Interestingly, Student #3 referred to 'parties' that implied some diverse but common understandings among the classmates. He identified the two opposing themes (theories) and began to analyze and to synthesize their views:

> [The] main points listed by the party which intends to help LDCs by providing direct help [include]: 1) Donate money—"*donate some money to the poor countries,*"[3] "*rich countries should donate money to poor countries*"[4]; 2) Provide Loans—"*provide loans to the less developed countries,*"[5] 3) Provide

> goods—"*provide some medicine, food, and clothings to the less developed countries*."[5]

As Student #3 identified common themes in the discourse, he also made interpretations to refine and improve the ideas. Specifically, he used a scaffold in his note to show a 'rise-above' effort in the pooling of ideas.

> [*Putting our knowledge together*] Advantages: These methods can help the less developed countries directly since the government can use the money freely without any restriction. It is an excellent short term measure for solving the economic problems. The disadvantage is that if the (more developed countries) MDCs give money to the (less developed countries) LDCs for a long period of time, this will cause the governments of the LDCs to rely on others and they will not be self-developing....(Note: The italicized words in square brackets refer to the use of a scaffold in Knowledge Forum)

Student #3 continued and examined the alternate view (theory) proposed by the other party. He wrote:

> [The] main points listed by the party which intends to help LDCs by solving the essential problems are: 1) help them to develop their industries and economy—"*help the poor countries to develop their industries*,"[8] 2) Give advice—"*MDCs should give economic advice to those LDCs*,"[10] 3) Fair trade—"*Ensuring fair trade among countries can also help LDCs to develop.*"[11]

> [*Putting our knowledge together*] It is a very good middle to long term measure. If proper ways are practiced, the less developed countries will become developed countries which do not need to rely on help from the more developed countries. The disadvantage is that it greatly depends on the willingness and cooperation of the more developed countries...There are also problems because some bad governments of less developed countries may view the infrastructure as their own property....Here is a website that provides an example of the situation...

The student was not merely describing what individual students wrote, he was describing key themes and how ideas developed in the discourse. There was also interaction between individual and collective knowledge growth—He came up with a concluding statement still referencing another student's note and wrote:

> [*Conclusion*] I can see [the] same ideas from the above points—help the less developed countries and minimize the wealth gap in order to increase the overall living standard and "*it helps the world towards prosperity*."[14]

It could be seen that as a commonly selected cluster, the discourse consisted of conflicting and similar views as well as rich ideas for sparking progress. Excerpts from another student on the same cluster are included. There could be different interpretations of the discourse but a similar emphasis was placed on collective knowledge. Student #4 wrote:

> The notes that answered CS's question which I call the *first* level provided vivid explanation of the problems between the MDC and LDC...The *second* level were notes that gave solution[s] for these problems—KH has pointed out some of the solutions, such as providing them food, clothing, medicine. TY pointed out rather than giving money, [one] should give them educational materials, and KH also pointed out providing the infrastructure is an essential task for helping them. The *third* level that my classmates pointed out are important issues and turning points—The first [question] argued about the political system and [how] it affects the country. Another question pointed out the problem of money as solution... could LDCs manage money when they lack knowledge... Also if the wealth gap is [an] important factor that affects the system?

Student #4 referred to a knowledge-building principle to characterize the discourse:

> [*Working at the cutting edge*] I think discussing those level 3 questions have important potentials for debating...[Although] there is no answer to them yet such as how to make a good structure or policy for solving a problem... the note SL raised, that [discussed] the political system of a certain country is really important. I think these level 3 questions need [further] investigation of new themes...

It was interesting to see how Student #4 analyzed the collective work of his classmates; he differentiated and identified that certain questions were more of cutting-edge problems. There could be different interpretations of the computer discussion. When students identified common themes and different 'theories,' built on and extended the ideas, the portfolio note became a conceptual artifact of collective knowledge. As well, the popular clusters can also show teachers the growing frontier of the class' collective knowledge.

Discussion

We have described a knowledge-building environment augmented with the use of portfolios and knowledge-building principles to characterize and scaffold collaborative inquiry. Primarily we turned over agency to students asking them to assess their own and the community's knowledge advances in the computer discourse, using electronic portfolio. We extended our earlier work from graduate students and senior-secondary students to middle-school students in large classes. We used knowledge-building principles more intensively as both note writing and note selection. The findings show that students provided with knowledge-building principles as scaffolds participated more and engaged in deeper inquiry. Consistent with our earlier work (Chan & van Aalst, 2003; van Aalst & Chan, in press), the present findings showed that portfolios contributed to students' conceptual understanding.

Knowledge building portfolios for characterizing and scaffolding collaborative inquiry

We first examine the roles of knowledge-building principles and portfolios and consider how they may characterize and scaffold collaborative inquiry. A major theme in CSCL focuses on examining collaboration and the interactions between individual and collective knowledge advances. We propose that the portfolio is an innovative design that captures the distributed nature of cognition and taps into the phenomena of collective knowledge building. The CSCL literature has many examples focusing on detailed and microscopic analyses of group interactions. We provided another approach examining collaborative knowledge building drawing from student work in the database over a longer period of time. Portfolios are not just learning products; they reflect group cognition and they demonstrate how students make sense and produce meaning collaboratively. A portfolio note is a group accomplishment with multiple contributions from students; it is also more than an additive account as it shows how knowledge emerges and advances in the community. In analyzing the online discourse, students can make the community's progress explicit and visible to themselves and others. As well, our data suggest that there is interplay of individual and collective knowledge growth (see for example, excerpts from students #1 and #3). As students engage in analyzing the community discourse, they also reconstruct their own understanding.

This study had several conditions and our results show that students, provided with knowledge-building principles, participated more in database usage and engaged in deeper inquiry than their counterparts. A system of knowledge-building principles was postulated by Scardamalia (2002) for theorizing the dynamics and processes of knowledge building. Thus far, researchers have used the framework of knowledge-building principles to analyze databases. We have, however, adapted the principles and turned over the responsibility to students for identifying knowledge-building episodes in their computer discourse. In doing this, knowledge-building principles have become more than analysis tools; they are also pedagogical and assessment tools for characterizing and scaffolding knowledge building.

In addition to characterizing collective knowledge advances, we propose that knowledge building portfolios scaffold and mediate the discourse. When students work on identifying knowledge building episodes through portfolios, the principles and portfolios become a scaffold that help students to recognize and make sense of productive discourse. As students see different models, they are more able to move towards producing better notes and engaging in deeper discourse. Protocol examples indicated that Student #1 was able to use the principle 'progressive problem solving' to explain how ideas evolved and improved over time. By contrast, Student #2 was merely identifying good answers to questions classmates posed. Without knowledge-building principles or other criteria, students could easily see collaboration merely as an activity to produce correct answers. That may explain why many students are reluctant to participate in discussion on networked environments. Knowledge-building principles as scaffolds may help students understand what constitutes progressive discourse. As the goal of knowledge building is improvable ideas (Scardamalia & Bereiter, 2003), we made that explicit to students, and that could then become a goal of the community.

Alignment of learning, assessment, and collaboration

We designed an environment intended to address certain gaps for designing assessment in CSCL classrooms. Earlier, we noted three of these issues.

Assessment of learning and assessment for learning

The knowledge-building portfolios play dual roles of characterizing and fostering collaboration. Commonly, assessment is concerned with analyzing the collaborative process or evaluating what students have learned. Knowledge-building portfolio assessment is designed so that self- and peer-assessments foster inquiry and understanding. As shown above in the protocol examples, by identifying exemplary clusters of notes and providing explanations, students must browse through the database and synthesize their own and collective understanding. Fragmented understanding, scattered discussion, and superficial work might be avoided. The assessment approach examines collaboration as well as providing a tool for deepening inquiry.

Assessment of individual and collective advances

A major thrust of interest among CSCL researchers is to theorize and examine the social aspects of learning. We designed knowledge-building portfolios that capture both individual and collective aspects of knowledge building. In using the knowledge-building assessment, the student was not merely describing his or her personal work; he or she was describing how a problem was addressed by a group of students, what views they held, what misconceptions were identified, what critical incidents took place, and how the idea was gradually improved. Knowledge building postulated by Scardamalia and Bereiter (2003) is analogous to scientific inquiry in scholarly and scientific communities. Even middle-school students can be engaged in a process similar to the writing of scholarly reviews when someone integrates differing ideas and studies to provide the 'state of knowledge' for a certain problem and theme. As Bereiter (2002) argued, ideas are improved and new insights emerge in productive discourse but they cannot be attributed to any individual or even an additive account of individuals' contributions. Knowledge-building portfolios may help capture the emergent process of such collective knowledge advances.

Assessment of processes and content

A common misalignment in CSCL classrooms is that while students are asked to collaborate, they are often assessed only on content in classroom assessment (Reeve, 2000). Using knowledge-building portfolios, we aligned assessment and instruction focusing on both the development of *content* and *inquiry*. Similar to regular portfolios asking students to choose some best artifacts and provide an explanation for the selection, we asked students to select computer notes, organize them according to themes, and describe the development of ideas. At the same time, the explanatory statement helped students to engage in reflective inquiry as they needed to reflect on their understanding of the knowledge-building process.

The portfolio examples showed that content and process were both assessed. For example, the portfolio excerpts showed how students were engaged in the knowledge-building process (e.g., progressive problem solving). At the same time, they also provided rich information about how students gained subject-matter knowledge (e.g., oil spills as resources, proportionality, control of resources). The knowledge-building portfolios integrate both content and process and show how students were able to develop collaborative inquiry in the context of understanding deep domain knowledge. Using self and peer assessments to examine both content and process is particularly important when considering their roles in official assessment. Also, this study demonstrated that portfolio assessment and collective portfolio scores contributed to essay writing scores tested in school examinations. Although it is useful to identify knowledge-building processes from portfolios, it was also important to demonstrate that such processes are related to other external standards.

This study has implications related to problems with online discourse. Earlier we noted problems and challenges of low and variable participation rates (Hewitt, 2003; Kreijns et al. 2003; Lipponen et al., 2003) and problems with teacher assessment. The portfolio approach may be a way to address these problems in that students need to write some notes before they have enough notes to complete the portfolio; or at least, students would carry out substantial reading of others' notes when putting together a portfolio. We also noted the difficulties of teachers having to read hundreds or even thousands of notes. The two-pronged approach of the Analytic Toolkit and the portfolios provide an overview—a synthesis of what goes on in the computer discourse—which can help teachers recognize and assess overall participation as well as critical incidents of knowledge building in the community. They would be able to identify areas where students may have problems and what progress they have made.

More generally, this study has pedagogical implications for designing student assessment to foster collaborative knowledge building in CSCL environments. Primarily, assessments need to be formative, process-oriented, collaborative, and integrated with instruction in CSCL. First, formative assessment needs to be designed to support learning and collaboration (Bransford, Brown, & Cocking, 1999; Chan & van Aalst, 2004; Shepard, 2000). For example, electronic portfolio assessment does not just take place at the end of the course; it incorporates note contributions that are ongoing activities in the community. Different assessments could be designed to measure and *elicit* deep understanding and metacognition. Second, assessments of CSCL should incorporate both individual and collective aspects of learning. A different culture needs to be developed. Teachers may let students know that demonstrating collaboration and helping others learn are valued just as much, if not more than, correct answers. Third, we examine both processes and products. We employ electronic portfolios wherein students identify high points of their learning, assessing both content and process (subject matter, reflection, and collaboration). Fourth, using the notions of self and peer assessments, it would be important to turn over the responsibility of assessment to students so they can have increased agency as they *examine their own progress*. Fifth, students also need to be provided with *criteria* for understanding the goals of learning and assessment (White et al., 1999). Assessment criteria of expectations can help scaffold student knowledge advances.

It may be useful to note the limitations of this study that point to further research. First, we acknowledge concerns with choice of research design and recognize there are methodological limitations with quasi-experimental design. We reiterate that this study is part of a larger study of design research, and it is appropriate in this case for conducting instructional experiments in classroom studies. We have conducted statistical analyses as though students were independently drawn from different groups. It might be more appropriate to conduct different analyses because students are nested within classrooms. We acknowledge issues with the units of analyses; however, our approach is commonly used in quasi-experimental classroom studies because students cannot be easily assigned randomly. There might also be concerns with teacher-and researcher-constructed scales and complexity in coding. Further work will be conducted to refine these scales.

Second, there were large differences on note contribution among the three classes; students in the Knowledge Forum knowledge-building portfolio class wrote a substantially higher number of notes compared to others. As students were provided with the principles for both note selection and note writing, it is possible that they were more actively engaged in writing notes. Because we were testing the design of portfolios, teacher effects could not be totally excluded. We did find that within the same class, high ATK indices were related to portfolio scores suggesting some construct validity of these measures.

Due to the complexity of classroom life, comparison of design conditions across classrooms necessarily faces many problems common in technology studies (Collins et al., 2004) and we recognize the limitations. Although the quantitative findings are included, caution must be exercised in interpreting them. These different design conditions, however, help us to understand more fully the roles of knowledge-building principles and portfolios. In our current work, we use different designs to examine the complexity of assessment of knowledge building in classrooms. Teacher factors also play key roles in developing innovative designs, and roles of teachers will be examined more systematically.

In sum, we have extended our earlier work examining assessments in CSCL and demonstrated more clearly the roles of knowledge-building principles and portfolios. Our study addresses key issues in CSCL with the portfolios demonstrating the distributed, progressive, and collective nature of knowledge building. A portfolio is a group accomplishment with multiple contributions from the community reflecting the trajectory of knowledge growth. Students made sense and constructed their collective understanding through analyzing the online discourse, and the portfolio mediated the interaction between individual and collective knowledge advances. Our design also showed that when students are provided with the principles, they become more aware of what productive discourse entails; the principles are scaffolds for their knowledge-building progressive inquiry. Our approach of making knowledge building explicit to students is consistent with current emphasis on alignment of learning with assessment (e.g., Bransford et al., 1999; Shepard, 2000). We have extended the idea of the portfolio as assessing individual to community progress and demonstrated how knowledge-building portfolios may characterize and scaffold collective knowledge advances. How individual and community knowledge advances interact remain key questions that need to be investigated.

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