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Student-Directed Assessment of Knowledge Building Using Electronic Portfolios

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Despite emphasis and progress in developing collaborative inquiry in computer-supported collaborative learning research, little attention has been given to examining how collective learning can be assessed in computer-supported collaborative learning classrooms, and how students can have agency in assessing their own collaborative process. We propose that assessments should capture both individual and collective aspects of learning and be designed in ways that foster collaboration. We describe the design of student-directed electronic portfolio assessments to characterize and “scaffold” collaborative inquiry using Knowledge Forum™. Our design involved asking students to identify exemplary notes in the computer discourse depicting knowledge building episodes using four knowledge building principles as criteria. We report three studies that examined the designs and roles of knowledge building portfolios with graduate and Grade 12 students in Hong Kong and Canada. The findings suggest that knowledge building portfolios help to characterize collective knowledge advances and foster domain understanding. We discuss lessons learned regarding how knowledge building may be fostered and provide principles for designing assessments that can be used to evaluate and foster deep inquiry in asynchronous online discussion environments.

In the last 2 decades, paradigmatic shifts have taken place in learning theories and instructional approaches. Contemporary learning theories emphasize that learning is social, distributed, and collective (Bereiter, 2002; Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991; Salomon, 1993; Sfard, 1998). Learning is no longer considered a solitary activity; it is situated in real-world contexts and meaningful

activities (Cognition & Technology Group at Vanderbilt, 1997), involves peer scaffolding in cognitive apprenticeships (Collins, Brown, & Newman, 1989), and is supported by learning communities in which members share "diverse expertise" (Barab, Kling, & Gray, 2004; Bielaczyc & Collins, 1999). Collaborative inquiry has emerged as a major educational goal (Edelson, Gordin, & Pea, 1999; National Research Council [NRC], 1996), and an important strand of research on computer-supported collaborative learning (CSCL) has been to investigate how educational technology can be used to support it (Dillenbourg, Eurelings, & Hakkarainen, 2001; Koschman, 1996; Koschmann, Hall, & Miyake, 2002; Stahl, 2002).

Despite much progress in CSCL research emphasizing social interactions, many questions remain regarding the assessment of collective aspects of learning and the integration of assessment, learning, and collaboration. Research on CSCL has emphasized detailed analysis of collaborative processes (Dillenbourg et al., 2001; Koschmann et al., 2002; Stahl, 2002), often overlooking learning outcomes. Studies that have examined learning outcomes have tended to focus on individual learning outcomes rather than collective knowledge growth (Dillenbourg et al., 2001). We propose that assessment theories need to be aligned with theories of learning and collaboration (Bransford, Brown, & Cocking, 1999; Shepard, 2000). With current emphasis on the distributed and collective nature of learning (Bereiter, 2002; Bielaczyc & Collins, 1999; Brown & Campione, 1994; Salomon, 1993; Scardamalia, 2002; Stahl, 2006) and metaphors of learning emphasizing cognitive, situational, and knowledge creation perspectives (Greeno, Reder, & Simon, 2000; Paavola, Lipponen & Hakkarainen, 2004; Sfard, 1998), there is a need to examine ways to assess both individual and collective aspects of learning.

The roles of assessment in scaffolding (or guiding) learning are well known (Bransford et al., 1999; NRC, 1996; Shepard, 2000), and there is considerable interest in the context of school reforms in assessment tasks that can scaffold learning (Black & Wiliam, 1998; Gipps, 2002; Shepard, 2000). Nevertheless, assessment practices in CSCL classrooms continue to emphasize measuring learning that is already achieved, neglecting the role they can play to guide or scaffold learning. Relatively little attention has been given to formative assessment in promoting collaborative inquiry in CSCL classrooms. This is problematic for the field of CSCL because it means that the potential of CSCL environments to scaffold learning remains underutilized. For example, CSCL environments produce stable traces of collaborative activities, which students could use to reflect on their collaborative learning process as part of efforts to improve learning outcomes. Although researchers recognize the need to understand the role of collaboration in learning (Stahl, 2006), we propose that students need to play a more significant role in assessing their own collaboration; designs for assessment are needed that foster student agency in collaborative learning.

This article describes our efforts over several years to design, implement, and improve an assessment approach designed to capture both individual and collective aspects of knowledge building, a specific model of collaborative inquiry (Bereiter, 2002; Scardamalia, 2002; Scardamalia & Bereiter, 2006). First, we highlight the importance of collaborative inquiry from the theoretical perspective of CSCL and knowledge building and discuss issues related to assessment of CSCL. Following that, we describe the rationale and elements of knowledge building portfolios—electronic portfolios designed by students and located within the online discussion environment. Then, three classroom studies that examined the evolution and roles of the knowledge building portfolios are reported. Although the studies were conducted in the context of knowledge building, we discuss principles for designing assessments that are applicable to other examples of CSCL.

BACKGROUND

Knowledge Building as Collective Cognitive Responsibility

The general term “knowledge building” has been used loosely in the CSCL literature (Stahl, 2002). According to Scardamalia and Bereiter (2006), the fundamental aspects of knowledge building include “improvable ideas” and “collective cognitive responsibility.” As in scientific inquiry, ideas are viewed as conceptual artifacts that can be examined and improved by means of public discourse within a knowledge building community.

With the advent of the knowledge-based era, Scardamalia and Bereiter (2006) propose that students need to develop competence at knowledge building. As collaborative inquiry, knowledge building encompasses the characteristics and cognitive benefits of scientific inquiry (see Edelson et al., 1999) and learning how to learn (van Aalst, 2006). However, collaboration in knowledge building goes beyond working with others; it encompasses notions of collective cognitive responsibility and advancing the frontier of knowledge. Similar to scientific communities, when students engage in knowledge building discourse they pose “cutting edge questions” that help the community to advance its collective understanding. They take on progressive problem solving, in which they progressively seek to understand problems at deeper levels. Students make progress not only by improving their personal ideas but through their contribution to collective knowledge advances. Scardamalia (2002) has articulated a system of twelve knowledge building principles that all point toward students in a community (e.g., a class) engaging in progressive discourse to improve collective understanding.

To support working with knowledge, Scardamalia and colleagues have developed a computer-supported knowledge building environment called Knowledge Forum™ (see www.knowledgeforum.com). A Knowledge Forum database is created by students: Using networked computers, students can 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 (Figure 1). Knowledge Forum is designed to help students to refine, 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 progresses. 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. Knowledge Forum includes scaffolds: metacognitive prompts (sentence starters) such as "My Theory" and "I Need to Understand" that students can use to make the communicative intent of information clear. For example, the scaffold "My Theory" indicates that the information presented in the note is conjectural, thus should be subjected to critique, testing, and application.

A class of students engaged in knowledge building usually starts with a general exploration of the topic to be studied. The goal is to enable the class to articulate questions and ideas they have about the topic and to delineate the general scope of what they attempt to accomplish. Students may contribute their ideas to the data-

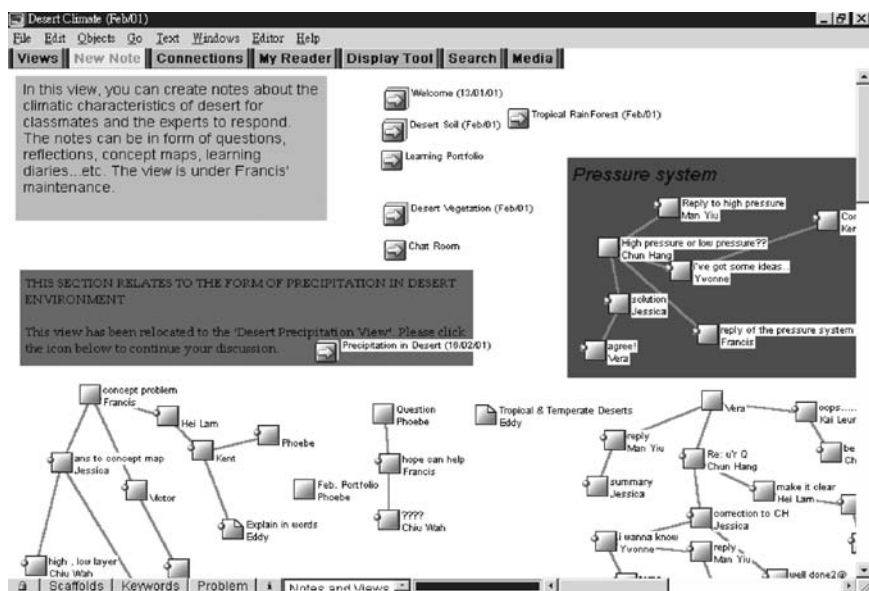


FIGURE 1 A workspace (view) in Knowledge Forum (Study 2).

base and talk to each other about them. With some assistance from the teacher, the class may settle on a general plan for what it hopes to accomplish in the unit. From this point, students work collaboratively and progressively to understand problems the class has formulated. Students have a responsibility to make their ideas available to the knowledge building community and to help each other improve the community's ideas.

Learning, Collaboration, and Assessment in CSCL

The CSCL field focuses on the development and study of technology-enhanced approaches to collaborative inquiry. CSCL approaches are based on social constructivism, highlighting individual and distributed aspects of cognition, and often involve writing into a computer-supported asynchronous discussion environment. Research on CSCL has focused on the collaborative nature of learning and on the content of what is learned (e.g., "CoVis Collaboratory Notebook", Edelson, Pea, & Gomez, 1996; "CaMile", Guzdial, & Turns, 2000a; "Knowledge Forum", Scardamalia & Bereiter, 2006). Despite much progress, many questions remain regarding assessment of collaborative learning and integration of assessment, learning, and collaboration. In the following, we describe three issues (see Chan & van Aalst, 2004).

Assessment of Learning Versus Assessment for Learning

There have been major shifts in paradigms of learning and instruction, and current views propose that instruction and assessment are integrally related (Bransford et al., 1999; NRC, 1996; Shepard, 2000). Assessment can play dual roles of measuring and scaffolding learning (Black & Wiliam, 1998; Shepard, 2000). The use of assessment in scaffolding learning, sometimes called Assessment for Learning (Black & Wiliam, 1998), involves designing assessments in ways that foster learning. Despite emphasis on formative assessment in school (Bransford et al., 1999; Shepard, 2000), little work has been done to align learning, assessment, and collaboration in CSCL classrooms. Misalignments often exist. For example, students are often asked to contribute to the computer discussion forums, but their contributions are not assessed. Students need to be given the agency to assess their own and the community's knowledge advances. Assessment should be designed as a tool that both measures and fosters learning.

Assessment of Individual Versus Collective Learning

Collaboration is valued in a wide range of social constructivist learning approaches, and there has been much research on assessment of collaborative processes (e.g., Koschmann et al., 2002; Roschelle, 1992). At the same time, in

assessing the effectiveness of systems and designs outcomes are evaluated at the level of individual students. This emphasis on the individual is problematic because when a theory is improved collaboratively by means of a public discourse, it no longer belongs to the person who first contributed it but to everyone in the community who has contributed to the discourse. With the changes toward social constructivist models of learning, we need to develop social constructivist assessment emphasizing both individual and collective learning. In addition to the analyses of individual achievements and collaborative processes, there could be an additional dimension: What has the community learned collectively?

Assessment of Content Versus Deep Inquiry

To prepare students for future learning, with less dependence on a teacher, students need to learn how to execute, monitor, and regulate the learning process. This would suggest that we must value not only what academic content is learned, but also how students achieve learning. Often, although there may be emphasis on constructivist learning using asynchronous networked environments, assessment of student learning focuses mostly on discrete knowledge and skills. Even in more sophisticated environments involving peer learning in which group processes are assessed, the assessments tend to focus on superficial features such as whether students are contributing “equally” to the group work. In this article, we explore assessment procedures that refer to a more sophisticated epistemology about learning and collaboration. For example, a student’s view that knowledge can be improved should be evident from the student’s effort to improve his or her own theories or those of other students. An understanding that knowledge is a result of a community discourse should be matched by evidence for progressive problem solving and efforts to help others understand the communal problems of understanding. Assessment should be able to probe both collaborative processes and knowledge products.

We aimed to develop an assessment approach that begins to address the aforementioned classroom challenges and issues. In the literature on CSCL, there are not many examples, but here we refer to several that illustrate the role assessments can play in scaffolding students’ scientific inquiry. In Scientific and Mathematical Arenas for Refining Thinking classrooms, students complete multiple cycles of work and revision in the context of student projects. In each phase of a project, students access the Web to provide and receive feedback on their work; they can also hear responses from “Kids Online” and craft responses to these participants (Vye et al., 1998). The role of formative assessment is emphasized as a design principle in related studies on project-based learning (Barron et al., 1998). In another line of study promoting scientific inquiry, Hickey, Kindfield, Horwitz, and Christie (2003) designed classroom assessments to align instruction, curriculum, and as-

assessment. In ThinkerTools, a microworld environment designed to foster metacognition and scientific understanding (White & Fredericksen, 1998), students work through the inquiry cycles required for developing increasingly complex conceptual models in science. In addition to the inquiry cycles that scaffold scientific inquiry, ThinkerTools included a set of assessment criteria to help students to reflect on the process of inquiry and communication. Students used these criteria in a process called “reflective assessment” in which they evaluated their own and others’ research; they rated their own and others’ research on each criterion as well as justify their ratings describing the work. Research on ThinkerTools showed that these reflective assessments helped students to build scientific understanding. Similarly, reflective assessment and rubrics were used effectively in studies designed to help students coordinate evidence in scientific inquiry (Toth, Suthers, & Lesgold, 2002).

We explored the design of electronic portfolio assessments to characterize and foster collaborative inquiry in the context of knowledge building. In the arts, a portfolio is a collection of artifacts that the artist uses to explain the development of an artistic idea, work with a medium, and so forth. In education, students select artifacts to document their best learning evidence or their journey of learning (Wolf, Bixby, Glenn, & Gardner, 1991). Portfolios usually consist of a selection of best items (e.g., papers, diaries, drawings) accompanied by a reflection statement explaining why students have selected these items as exemplary or significant work. There is extensive literature on portfolio assessments (e.g., Wolf et al., 1991), including electronic portfolios (Young & Figgins, 2002). Another approach is the Progress Portfolio that structures opportunities for learners to organize, reflect on, and revise project artifacts at various phases of their project-based learning (Land & Zembal-Saul, 2003). Students build a portfolio that documents both the artifacts they collect during the inquiry and a record of the process by which they evaluate and monitor their progress. The Progress Portfolio provides a trace of student investigation for reflection—it records ongoing progress and prompts reflection on inquiry.

CSCL research premised on social constructivist theories emphasizes social interactions in learning, but much less attention has been given to the assessment of *collective* learning, a major goal advocated in the knowledge building model that emphasizes advancing the community’s understanding (Scardamalia & Bereiter, 2006). In addition, despite potential for student understanding, not much research has been conducted to explore students’ own roles in carrying out assessment in CSCL. To address these questions, this study investigated the question of assessing the collective nature of learning in the context of knowledge building on Knowledge Forum and of designing assessment to foster collective knowledge advances. Currently most research on portfolios (paper & electronic) is concerned with reflection on individual learning and progress (e.g., Progress Portfolio). This study focused on designing portfolios to capture collective learning in computer-dis-

course and as a tool to foster domain understanding. The portfolio task asked students to assess their own knowledge advances in the communal database to maximize their agency, reflection, and collaborative inquiry. As our goal was to foster knowledge building, we embedded assessment with instruction and provided a set of knowledge building principles that students could use to identify knowledge building episodes. We addressed the following questions:

1. What are the elements and designs of the knowledge building portfolio approach?
2. How can collective knowledge building be assessed using student portfolios? How is knowledge building characterized and manifested in a portfolio?
3. What are the roles of student portfolios in scaffolding knowledge building and domain understanding? How might knowledge building be fostered?

DESIGN OF ASSESSMENT APPROACH: KNOWLEDGE BUILDING PORTFOLIOS

In this section, we describe the rationale for designing social constructivist assessments and the components of the assessment approach, including the portfolio task and knowledge building principles.

Rationale for the Assessment Approach

Fundamentally, we propose that the design of effective learning environments should integrate learning theory, instruction, and assessment (Bransford et al., 1999; Shepard, 2000). First, assessments need to capture both individual and collective aspects of learning. Second, assessments need to be formative and embedded within instruction; they should be designed as learning events that align with instruction. Third, it is important to assess both processes and learning products. Fourth, whereas teachers or researchers are usually the assessors of student learning and collaboration, we propose it would be beneficial to design assessments that students can use to examine their own progress. Fifth, as students are given more agency in assessing their own learning and progress in CSCL environments, they also need to be provided with criteria for understanding the goals of learning and assessment (White & Fredericksen, 1998). Criteria describing what students are expected to do or learn can be provided to students to scaffold their knowledge advances. We employed electronic portfolios in which students identify high points of their learning, assessing both content and process (subject matter, reflection, & collaboration). We considered both individual and collective aspects of knowledge advances in parallel with social constructivist views of learning.

Components of the Assessment Approach: Knowledge Building Portfolios

Using the previously discussed rationale, we designed a portfolio task guided by a set of four knowledge building principles.

Portfolio Task

We asked students to prepare electronic portfolios in Knowledge Forum as formal course assessments. The portfolio is a metanote via which the portfolio was accessed in Knowledge Forum. Specifically, a portfolio note included hyper-links to other computer notes (Figure 2), and we asked students to make selection of notes illustrating knowledge building. The selection of notes in the electronic portfolios is similar to the selection of best items in regular portfolios. In addition to selecting notes, the student needed to write an explanation as to why he or she thought the selected notes provided evidence for knowledge building. To aide the selection of notes for the portfolio, students were provided with a set of four knowledge building principles as criteria. As an example, the author of the portfolio note shown in Figure 2 explained that she had found a cluster of notes about "shifting cultivation" that illustrated the knowledge building principle of progressive problem solving. She then articulated how these notes (ideas) developed over

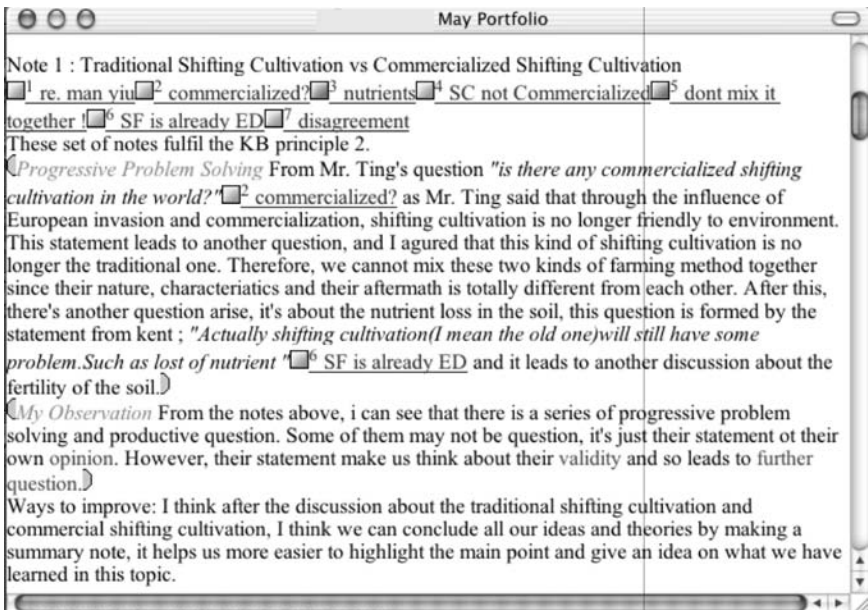


FIGURE 2 Example of a portfolio note (Study 2).

time. In doing so, she was reflecting on the progress of ideas in the community (i.e., her class). A reader can follow the hyper-links and move back and forth between the explanation and the referenced notes. The icons within the content window of the portfolio note represent the links to other notes. The figure also shows scaffolds (sentence starters) specifically designed for the portfolio task, making clear which portion of the text pertains to a specific principle.

The portfolio task differed from other examples of portfolios: Most portfolios include a range of different kinds of artifacts. Nevertheless, we called it a portfolio note as it shared many features with regular portfolios: The artifacts (i.e., notes referenced) were selected by the student, and the portfolio represented high points of individual and community learning and tracked the growth and development of learning over time.

Knowledge Building Principles

The students were provided with a set of knowledge building principles as scaffolds to help them with the portfolio task. The knowledge building principles provided students with a lens for assessing (i.e., identifying) knowledge building; they also provided scaffolds that students could use to keep their inquiry on track. Scardamalia (2002) proposed a system of twelve principles aimed at elucidating the processes and dynamics of knowledge building, which has been used in studies of knowledge building (Law & Wong, 2003; Niu, 2006). However, we considered this system too complex to serve as a framework for student assessment in the context of teaching and developed a smaller system; we changed the description to make it more accessible to students, but the central ideas are similar. Clearly, this smaller system is not as comprehensive as Scardamalia's, but we assumed that it would be sufficiently comprehensive for our purpose. The principles we used are described following.

Working at the cutting edge. This principle reflects that a scholarly community works to advance its collective knowledge; it states that individual community members are accountable for the intellectual advancements of the learning community. For example, scientists do not work on problems of only personal interest but on problems that can contribute something new to a field. Several elements seem relevant for working at the cutting edge and we relate them to Scardamalia's (2002) principles. First, students articulate their ideas and identify personal gaps in their understanding. Scardamalia refers to this aspect of working at the cutting edge as "epistemic agency". Epistemic agency is a metacognitive ability and shifts the responsibility for setting learning goals from the teacher to students; it is an important component of learning to learn. Second, students evaluate emerging questions and ideas relative to the community's learning goals and relative to what others have found out before about them. Third, students work to-

ward the community's shared and emergent learning goals. These three elements can be used to identify the extent to which students are working at the cutting edge.

Progressive problem solving. Progressive problem solving is a central aspect of the process by which experts create new knowledge (Bereiter & Scardamalia, 1993). The idea is that when an expert understands a problem at one level, he or she continues to pursue it and reinvests cognitive resources into new learning. In a scientific community, one study often raises new problems that are investigated in follow-up studies that extend understanding of how a scientific theory is working in diverse conditions. Progressive problem solving can be evident in a knowledge building discourse if there are distinct problem solving episodes. For example, a class of students may first develop a basic understanding of chemical kinetics based on an empirical study in which it articulates a model that explains the available data. Subsequently, the class may fill in some gaps in this simple model: It may investigate the influence of the ambient temperature on the reaction rate or extend the model to more complicated reactions that involve more reactants. In such episodes, the conceptual artifacts created by the discourse undergo considerable development. The basic model of kinetics is replaced by a model that includes mechanisms for controlling the reaction rate, which is then replaced by another model that additionally explains the kinetics of complex networks with multiple reaction rates. Progressive problem solving is related to the notion that ideas are conceptual artifacts that can be improved. Scardamalia (2002) has referred to evidence that ideas are treated as one determinant of knowledge building.

Collaborative effort. Collaborative effort is the effort students make to help each other understand the problem under study. Collaborative effort is frequently discussed in CSCL, and we propose several levels at which it may be evident in notes contributed to an online discussion. Level 1: Students write notes in response to other notes; they raise questions, extend theories, and provide examples or relevant information. Level 2: Students have some awareness that peers who may read their notes may be missing contextual information; they provide clues to help their peers to make sense of the note. Students may include scaffolds, link notes to earlier notes, and provide clues in the text of the note. Level 3: Students are aware that knowledge construction is possible because students can examine a problem from multiple perspectives, for example, by comparing two theories. Level 4: Students contribute some notes that integrate a number of other notes, for example, summarizing what has been learned about a problem and describing what still remains to be discussed or investigated.

Identifying high points. Whereas progressive problem solving focuses on the development of the community's ideas, the principle "identifying high points" focuses on metacognition and development of students' understanding. This prin-

ciple states that students are able to identify and describe the events that have enabled them to make personal growth in the context of communal knowledge advances. As with the other principles, levels of sophistication can be articulated. At the most basic level, students are able to identify individual notes that show a new idea; at a higher level, student may realize “I had an ‘aha’ in this note;” and at yet higher levels, students explain the progression of understandings they had on the way to their current understanding in fuller detail.

DESIGN, IMPLEMENATION, AND EVALUATION OF CLASSROOM STUDIES

The three studies show how the assessment approach was developed in three successive implementations. The portfolio design was first implemented in a graduate course on knowledge building (Study 1). Following this, one of the teachers taking the graduate course adapted the approach for implementation in a twelfth grade physical geography course (Study 2). The teacher refined the approach and the instructions to make them more accessible to his students. Some modifications also resulted from preliminary analysis of the data from Study 1 (van Aalst & Chan, 2001) and the teacher’s reflection of his own experience in the graduate course. We focused more directly on *collective* learning and explored its relation to domain understanding. Finally, the design was tested at another school in a twelfth grade chemistry course (Study 3). This teacher devoted less time to knowledge building during the school year and had not taken a course on knowledge building prior to his implementation; he used the work of the teacher of Study 2 as a model but did not substantially modify the model.

The second and third studies were two implementations in different secondary school settings that both built on lessons learned from the first implementation; the third implementation provides evidence for the usability of the assessment approach in secondary schools above what the second implementation provides. As we will see in more detail later, each study examined the guiding questions at progressively deeper levels. Study 1 examined only questions 1 and 2. During Study 2, it became apparent that the students recognized the utility of the portfolio task for *scaffolding* knowledge building—not just characterizing it. This study therefore additionally explored the scaffolding role of the portfolio task (guiding question 3). Study 3 extended these analyses in another secondary school setting using a quasi-experimental design in which the teacher taught both the experimental class and the comparison class. This gradual improvement of methodology reflects the evolution of the research program. The first implementation was based on a prototype, so limited resources were applied to evaluations of the design; as interest in the approach increased we sought to understand the design more deeply.

Study 1: Exploring Knowledge Building Through Portfolios in a Graduate Course

Background and Goals

The goal of Study 1 was to design an approach to assess and identify individual and collective aspects of knowledge building using knowledge building portfolios. We introduced the portfolio task and the four principles for characterizing the knowledge building process in a graduate course focusing on knowledge building theory and practice. We explored the following questions in this study: Could students use these principles to identify knowledge building episodes? Which ones were more or less difficult? How was knowledge building manifested in the discourse? Were the portfolio scores, reflective of knowledge building process, related to other measures?

Participants

The participants were 12 graduate students enrolled in a one semester joint course on knowledge building. For practical reasons, the course was cotaught by the authors with cohorts in Vancouver and Hong Kong. The cohorts had local weekly face to face classes, shared a Knowledge Forum database, and participated in several videoconferences. Most participants were practicing teachers in elementary and high schools with teaching experience ranging from 4 to 20 years; 3 of the participants were full-time graduate students working in the area of educational technology and had some previous exposure to knowledge building and Knowledge Forum.

Instructional Design

The goals of the course included helping students to learn the literature on knowledge building and to participate in a knowledge building discourse. During the first 10 weeks of the course, the students discussed weekly readings and classroom examples in their face to face classes and the shared Knowledge Forum database; approximately 30 minutes were used per class meeting for reviewing the database and writing new notes, but both cohorts also worked on Knowledge Forum between classes. Sometimes, a discussion would move from the database to a face to face discussion, but the converse also occurred.

After approximately 4 weeks, the students studied the Knowledge Forum databases of four high school and university classes; the teachers and some of the high school students who had created these databases participated in the discussion of emerging questions in the course database and videoconferences. The virtual visits allowed the (graduate) students to ask practical questions about knowledge building in specific contexts and to test their own conjectures of how knowledge building would work in practice.

Assessment consisted of two components: an individual project and the knowledge building portfolio. After the students had had a chance to read and write some notes, the course instructors discussed their expectations for online work and the idea of developing portfolios to demonstrate the students' efforts at knowledge building; they then developed some criteria for evaluating the portfolios with the students. This work was completed by the 3rd week, and the portfolios were based on work completed after that time. The instructions and criteria used for the portfolios are shown in Table 1.

TABLE 1
Instruction for Knowledge Building Portfolio (Study 1)

Principle 1: **Working at the "cutting edge"**. There are two parts to it: (1) Students are able to evaluate the limits of their understanding (e.g., knowledge gaps; inconsistencies) and identify / formulate questions that could advance their understanding. But (2) it is not just personal knowledge but the community's knowledge that must be advanced. Everyone in the community has a responsibility for the quality of the discourse, so if "deep" questions are not raised or taken up by anyone this reflects a lack of evidence for this principle.

Principle 2: **Progressive problem solving**. This involves the reinvestment of learning resources in new learning. When a problem is understood at one level, it can lead to new questions and theories. The focus here is on the idea. Can you demonstrate that an idea has undergone development as the discussion progressed, and can you show that a note you wrote played an important role in this development. You don't have to be the original contributor of the idea, but you must have participated at least once in its evolution.

Principle 3: **Collaborative effort**. A very important aspect of knowledge building is the idea that knowledge is not static but always subject to possible improvement. Thus with the notes you submit you should provide evidence that you helped others advance their understanding. This principle tries to get at something that is primarily social in character. If you believe that knowledge can be improved by means of discourse, then what are you doing to help others to advance their understanding? Notes that provide constructive feedback, relevant information, or insight from your own inquiry to specific community members could be evidence that you are not only concerned about your own learning but also that of others.

Principle 4: **Identifying high points**. Students can identify the high point of where they have been during their knowledge building efforts. Examples may include notes that demonstrate insights and new ways of looking at things; and how your personal understanding has been shaped by both your own writing, class discussion and writing by others.

Note: **Portfolio instruction**. Students submit eight notes from six weeks of work in KF, together with the one note in which the student explains how the submitted notes meet the criteria (below). This note will have links to the other eight notes (e.g. Rise-above). The notes are evaluated as collections rather than on a note-by-note basis. The onus is on students to provide evidence in support of four KB principles in their submissions. A mark out of 6 will be given for each KB principle:

5-6: Strong evidence for the principle without a lot of evidence against it.

3-4: More evidence in support of than against the principle.

1-2: Eight notes are submitted, but they lack convincing evidence in support of the principle.

0: Assignment is not completed

Results

Before presenting the quantitative results, we discuss excerpts from two portfolios to illustrate how students recognized and described knowledge building episodes; the excerpts selected illustrate collective aspects of knowledge building.

Working at the cutting edge. In the first example, Stephen describes a knowledge building episode in which he and other participants worked at the cutting edge, pursuing the notion of diverse expertise introduced in a course reading. Stephen wrote the following:

(*Working at the cutting edge*) My note was written as a reaction to the reading of Brown and Campione. The idea of promoting diversity in a classroom goes against traditional teaching beliefs that all students should master the same material at the same rate, and all students work on the same problems. Notes by Tiffany, Harry, Brian, and Patricia point out the value of having weaker students as part of the classroom community. My school is wondering how we will cope with the loss of our modified math 9 classes. The Ministry of Education has outlawed Math 9A (modified math classes) next year all students must take the same level of math in Math 9². The ideas in this view [discussion area] will certainly be pertinent to math teachers in BC, for me this is operating at the cutting edge. In³ Note 3 I raised the question, can all students be experts? This has twenty follow-up notes in the community. (Excerpt 1, Stephen; the superscripts represent hyperlinks to other notes in Knowledge Forum)

Stephen explained that he posed a question about student diversity that contradicted common beliefs, and other students posted responses to address the apparent contradiction. The example shows pursuit of an idea of interest and value to the community (there were 20 follow-up notes). However, when we examined the cluster of notes Stephen referred to note, it became evident that another student (Randy) played an important role: Many of the notes in the cluster are linked directly to *his* note. This shows that working at the cutting edge is at the same time an individual and a collective phenomenon. Without the notes by Stephen and Randy, the cluster of 20 notes would not have been created, but we cannot attribute working at the cutting edge to any student in particular. Rather, it is a property of all students who contributed to the discussion.

Collaborative effort. As students kept contributing to Knowledge Forum, computer notes proliferated over time during the semester making it difficult to follow the discourse. Without being asked to do so by the instructors, Arthur analyzed a view (discussion area) on one of the readings, created a new view from it

that held notes of current interest, and attempted to provide a summary note of the new view. As shown in the portfolio note, rather than just writing comments or questions typical in online discussions, Arthur attempted to synthesize and capture the central theme of the community discourse. In his portfolio note, Arthur wrote:

It is very enjoyable to read [the] discussion of the issue about individual mind and communal knowledge. It gives me an opportunity to organize what I have learnt in this course and deepen my understanding of the World 3 concept. Although I originally have some idea, but [it] has only been enriched with discussion here ... Two main themes appear in the discussion. The first is what the main concern of collaborative learning [is] – the communal knowledge or the individual mind (Brian¹, Cathy², Angela³, Robert⁴). The second is how to foster collaborative learning among students and teachers; [the] special concern is on teacher training (Kitty⁵, Cathy⁶, Harry⁷ Patricia⁸, Robert⁹). I will try to sum up the first theme here ... (Excerpt 2, Arthur; superscripts refer to links to other notes)

This portfolio note illustrates how the students collaborated and made collective knowledge advances. Collaborative effort was manifested not merely as two or more students writing to each other on some topics. Rather, it was an activity aimed at tracking and assessing what the community understood at that point and making the knowledge building process more accessible for the whole community. In this specific case, the student was not simply describing what he understood; he was describing and analyzing the key themes of discourse in the community.

Quantitative Analyses

Each student submitted a portfolio linking to eight of his or her own notes on Knowledge Forum. We rated the portfolios to examine evidence for the knowledge building principles. We also examined the relations of the portfolio scores reflecting knowledge building processes with students' participation and database usage on Knowledge Forum.

Portfolio ratings. The notes submitted by students as evidence were assessed using a 6-point scale (Table 1). We examined the set of notes for each principle rather than examine each note separately. A rating of 1 or 2 was assigned if an attempt was made to complete the portfolio but that little evidence could be found in the notes for the principles, a rating of 3 or 4 if the evidence was mixed, and a rating of 5 or 6 if the notes consistently showed strong evidence for the principles. All portfolios were rated independently by the two instructors; the interrater reliability was .62 (Pearson correlation). The low reliability reflects our incomplete under-

standing of the knowledge building principles during this study—something to be improved on in the follow-up studies.

The results are shown in Table 2; for convenience of presentation, the raw scores have been converted to percentages, and similar results for Studies 2 and 3 are included in the same table. For Study 1, the data indicate that there was some evidence that students understood the principles, with the mean scores ranging from 48.3% (progressive problem solving) to 71.7% (collaborative effort). A multivariate analysis of variance of the ratings for the four principles showed that progressive problem solving was statistically lower than all the other principles, $F(3, 30) = 4.47, p = .01, \eta^2 = .31$, suggesting that progressive problem solving was more difficult than the other principles for this community.

Trends in participation in Knowledge Forum (Analytic Toolkit indexes).

The Analytic Toolkit (ATK; Burtis, 1998) was used to retrieve server log files. Similar to overviews of class activity analyzed by Guzdial and Turns (2000b), ATK indexes provide basic quantitative information about participation and database usage of Knowledge Forum. The following ATK indexes were analyzed: (a) number of notes created, (b) percentage of notes that are linked to other notes, (c) Percentage of notes with keywords, (d) percentage of notes in the database read, (e) number of notes with scaffolds (e.g., I need to understand, my theory), and (f) number of revisions per note. Keywords help to index the database and can make notes more accessible; revision is important to knowledge building because ideas need to be revisited and reconstructed.

Findings for the knowledge building ATK indexes obtained from server logs are presented in Table 3. For convenience of presentation, findings for Studies 2 and 3

Table 2
Mean (SD) Portfolio Scores (Percentages of Maximum Scores)

Study	Class Size	Cutting Edge		Progressive Problem Solving		Collaborative Effort		High Point/Monitoring Understanding	
		M	SD	M	SD	M	SD	M	SD
1	12	61.7	10.5	48.3	20.2	71.7	16.2	65.0	32.2
2	7 (high)	74.3	18.6	70.0	18.6	77.1	15.7	57.1	31.6
	7 (low)	41.3	32.3	36.3	33.2	48.6	22.9	56.2	23.9
	14 (total)	57.8	30.5	53.2	31.0	62.9	24.0	56.7	26.9
3	13 (high-gain)	88.8	13.1	77.3	23.6	81.8	11.7	77.3	20.8
	11 (low-gain)	67.3	18.8	55.8	18.1	75.0	14.4	63.5	28.2
	24 (total)	77.0	19.4	65.5	23.1	78.0	13.4	69.8	25.5

Note. Principle 1 = working at the cutting edge; principle 2 = progressive problem solving; principle 3 = collaborative effort; principle 4 = identifying high points. Standard deviations are shown in parentheses.

Table 3
*Participation on Knowledge Forum: Means and Standard Deviation
 of Analytic Toolkit (ATK) Indices*

<i>Study</i>	<i>Class Size</i>	<i>Weeks on KF</i>	<i>Notes Written</i>	<i>% Notes Linked</i>	<i>% Notes with Keywords</i>	<i>% Notes Read</i>	<i>Revisions</i>	<i>Scaffold Uses</i>
1	12	10	24.4 (8.3)	84.2 (13.1)	48.5 (16.8)	45.1 (15.9)	11.6 (11.2)	23.0 (17.1)
2	14	18	58.9 (16.6)	86.3 (4.1)	53.2 (12.7)	66.6 (8.7)	48.2 (22.9)	60.8 (30.0)
3	24	10	11.4 (5.9)	81.0 (17.7)	73.1 (16.2)	64.4 (17.9)	5.2 (7.5)	6.9 (6.4)

are included in the same table. Although no comparison data were available, these findings generally indicate relatively sophisticated use of Knowledge Forum, with a large percentage of notes linked to other notes, significant use of keywords, and acceptable reading of other notes (all relative to a standard worked out collaboratively with the students). The standard deviations were generally less than .5 of the means suggesting participation was generally even. Analysis indicated that most of these indexes increased over time, suggesting improvements in participation and the use of Knowledge Forum features. For example, the number of note revisions was approximately 2.2 during the first 6 weeks, but increased to 7.1 in the last 3 weeks (averages over all students). For the number of notes written, these numbers were 4.5, 8.0, and 11.0, respectively. As one student explained in his portfolio note, it required some students several weeks to become comfortable with Knowledge Forum and discussing ideas online.

Relation between portfolio ratings and ATK indexes. We examined the relations between participation on Knowledge Forum (ATK) with portfolios scores. Because the sample was too small to analyze separately for all six ATK indexes, the ATK indexes were combined using factor analysis. Notes created, percentage of notes in database read, number of revisions, and number of scaffold uses loaded onto a single factor, explaining 61.5% of the variance (Eigenvalue 3.69); the factor score was correlated with the portfolio score for collaborative effort, $r = .72$, $p < .05$. The percentage of notes with links and with keywords loaded onto a second factor, explaining an additional 21.8% of the variance (Eigenvalue 1.30).

Discussion and Issues Raised

Study 1 led to some important insights about knowledge building. The students were generally able to use the knowledge building principles to identify knowl-

edge building episodes, and their portfolios revealed individual as well as collective aspects of knowledge building. For example, the portfolio by Stephen indicated the importance of individual contributions, but it also showed that working at the cutting edge could not be attributed to any student in particular. The example of collaborative effort in the portfolio of Arthur showed that collaborative effort can be much more than responding to other students' notes—Arthur synthesized the discourse, providing a service to the whole community. This example also showed that although teachers generally wish to respond to students' notes, students may be able to synthesize diverse ideas and knowledge advances in the community.

One challenge we met in Study 1 was that we did not know in advance how each of the principles could be recognized in the Knowledge Forum database. As a result, the instructions for developing the portfolios were abstract, and we were not able to provide examples of portfolios. This problem may also have contributed to the low interrater reliability. Our understanding of the principles also developed considerably as a result of analyzing the portfolios. Initially, we thought of working at the cutting edge as an individual responsibility, expecting every student to be a primary author in at least a few examples. We now think that was an unrealistic expectation and view working at the cutting edge as a property of the community. It is interesting to note that many students spontaneously discussed not only their own work but also that of their peers, as they attempted to demonstrate evidence for the principles. As one participant aptly put, "it was difficult to put together a portfolio where you identified your best work because my note was good only in the context of the other notes in the discourse." Based on such realizations, a member of the class, the teacher of Study 2, collaborated with the researchers and improved the design of the portfolios (details are described later).

We faced other challenges. Regarding progressive problem solving, there was some evidence for idea improvement in the portfolios, but little evidence to suggest one problem being resolved and leading to follow-up problems. Relative failure to identify good examples of progressive problem solving was widespread as the ratings for this principle were statistically lower than for the other principles. Reflection on this revealed two insights. First, the purpose of discussion in Knowledge Forum in this course was primarily to extend class discussions of the literature, that is, to understand the weekly readings. The readings were not situated in problems that the class was attempting to solve. Second, as one student explained during a class, she "had been used to reading an article in preparation for class, discussing it in class, and moving on to the next article." As another student explained during a videoconference:

When I did the [portfolio] evaluation, what really stuck out to me was that myself individually, as well as us collaboratively, we really didn't do a lot of progressive problem solving. ... Um, my strategy, when I was working on Knowledge Forum, was to go into a new view and work on it, and read lots of notes, and get really into it, and *as soon as the next view was posted I would-*

*n't really return to the old view, I'd focus all my energy on the new view. And eh so I really realized, after doing the evaluation, that *this wasn't a good strategy to use in knowledge building*. (Cindy, Excerpt 3, videoconference transcript)*

These findings may shed light on problems of superficial discussion in web-based forums in tertiary courses. Often the students' intent was to discuss the readings assigned that week and move onto another reading next week: There was no authentic problem and no need for progressive problem solving.

Study 2: Designing Portfolios for Assessing Collective Knowledge Growth in a High School Geography Course

Background and Goals

Study 2 was the first implementation of the portfolio design in a secondary school. Based on lessons we learned from Study 1, we modified the designs of knowledge building portfolios in several ways. First, we now understood that evidence for knowledge building principles would be distributed over a cluster of notes, so we asked students to identify clusters of notes in which they participated even though they were not necessarily the main authors. The teacher stated in the portfolio assessment instruction that the students were to identify the best work of the community reflecting knowledge building episodes. The teacher also modified the level of description of the principles to make them more accessible to high school students. Second, the teacher focused on problems of understanding rather than weekly readings or unconnected curriculum topics. He included an instructional design linking the online database and classroom work; he also worked with students on identifying themes and using emergent questions to foster progressive problem solving. In addition to these instructional changes, we also changed the research design. In Study 1, we did not assess students' domain knowledge; at this point, we explored the relation between the portfolio scores and domain understanding. In part, this change reflected the contextual situation—in Hong Kong teachers often want to know how a new educational approach will influence student performance on public examinations. From a theoretical perspective, too, it was important to investigate the relation between the portfolio ratings focusing on the knowledge building process and knowledge building products—conceptual understanding.

Accordingly, the goals included (a) implementing the portfolio design in a secondary school setting and in a different domain, (b) designing and examining the use of portfolio assessments focusing more directly on collective aspects of knowledge building, (c) designing for integrated classroom and online work to support progressive problem solving, and (d) examining relations among portfolio ratings,

participation in Knowledge Forum, and conceptual understanding. We extended our goals from Study 1 to Study 2, addressing the research questions of using portfolios to assess the collective nature of knowledge building (research questions 1 & 2) and to examine their role in scaffolding on subject matter understanding (research question 3).

Participants

The participants consisted of 14 Grade 12 students in a geography classroom in Hong Kong with average to high overall achievement and receiving instruction in English; they did not have previous experience with Knowledge Forum. The teacher had completed a Masters degree focusing on instructional psychology and had been a participant in the graduate course of Study 1. A comparison group of 9 students, drawn from another school with a similar background, was included. Both groups studied the same curriculum units set by the Ministry of Education in Hong Kong. Comparison students were taught by a teacher who also had a Masters degree and comparable years of teaching experience.

Instructional Design

The prescribed curriculum included topics on physical landscape, climate, and earth sciences, as well as an emphasis on inquiry. The teacher developed an instructional sequence with four phases focusing on integration of learning, assessment, and collaboration.

Phase 1: Developing a collaborative culture using peer and self-assessments. The instructional design started with the development of a collaborative culture in the classroom. Even before the introduction of Knowledge Forum, students began to acculturate the practice of assessing their own and peers' understanding in classroom discussion. Various classroom tasks were designed to help students to build on and challenge others' views in group contexts. The students learned to view collaboration as something taking place both in the classroom and the database. This phase lasted approximately 3 months.

Phase 2: Introduction to Knowledge Forum. After the initial phase, the students were introduced to Knowledge Forum. The teacher set up a view (i.e., a discussion area) for each major topic with a focus question initiating the students' inquiry. The students began by addressing the focus question and formulating key problems, using the Internet and available books for research, and creating additional views as the need for them arose. The computer discourse provided an avenue for formative assessment as students inquired into their own and others' understanding. Based on what we learned from Study 1, we focused on problems rather than topics: The teacher worked with students in developing questions and problems that connected across different topics for sustained inquiry. Classroom dis-

cussion and computer discourse were integrated, for example, students assessed the quality of their work on Knowledge Forum in class meetings; they commented on each other's work and explained which computer notes helped their understanding best and why. This phase lasted approximately 6 weeks.

Phase 3: Portfolio without knowledge building principles. The teacher initiated a preliminary portfolio task asking students to assess each other's work. The teacher was trying out different strategies and this preliminary task took place before more formalized collaboration with the researchers. The students identified computer notes that they thought were exemplary in the database; however, they were not provided the knowledge building principles for identifying knowledge building episodes. As students' portfolios were submitted, the teacher realized that there was much focus on the adequacy of content. We show one example:

^{1 2 3}I choose these three notes because of the following reasons: 1) The question is good; it helps me to think about the reason of the high pressure system in the desert.¹ 2) Valerie's answer can explain the high pressure system in the desert. Because of the global general circulation system, the deserts are under the influence of the Hadley cell and Ferrel Cell. As a result, there is a high pressure system in the desert.² 3) When I answer the question, I learn something about the scale. ... if we want to get marks, I need to give a more suitable answer. Later when I answer the question, I have to think about the scale.³ (Excerpt 4, Katherine)

Although this portfolio note indicated some elaboration of ideas, the focus was on the content and correctness of answers. The teacher thought more could be done to improve such portfolios in terms of collaborative inquiry. A more formalized collaboration was developed between the researchers and the teacher at this point.

Phase 4: Portfolio with knowledge building principles. Drawing from lessons learned from Study 1, we designed portfolio instruction focusing more directly on collective aspects of knowledge building. Instead of discussing single notes or one's own best notes as artifacts, the students were to submit clusters of notes, drawn from their own as well as other students' notes. These modifications reflect a better understanding of knowledge building discourse as a collective phenomenon, developed by the teacher and researchers in Study 1. We now moved from a portfolio focusing on the best work of an individual to a portfolio focusing on the best work and progress of the community.

As in Study 1, the students based their note selection on the knowledge building principles. The teacher improved the descriptions of these principles to make them more accessible to high school students. For example, working at the cutting edge was explained as writing productive questions and productive responses that gen-

erate widespread interest and many responses; collaborative effort was explained as synthesizing diverse viewpoints and producing a summary statement (Table 4). The instructions for this set of portfolios also included other modifications designed to improve the quality of the portfolio notes. The students were asked to organize the notes thematically to help readers to understand their work better.

Results: Discussion of Portfolio Note Examples

As in Study 1, we discuss excerpts from two portfolios to illustrate how the students identified and engaged in knowledge building.

Progressive problem solving. This principle focuses on students engaging in sustained problem solving as opposed to premature closure. In this example, the

TABLE 4
Teacher Instruction on Knowledge-Building Portfolio Assessment

1. You have to select eight best notes together with a summary note that explains why and how you have selected the eight notes.
2. You need to use the 'references' and 'note reader' functions to complete the tasks. Use 'scaffolds' to write note and complete the portfolio.
3. One note is defined as a cluster of notes. The eight notes selected will include notes posed by yourself as well as your classmates.
4. You need to write a summary for each selected note. The summary note should explain the reasons for choosing that particular cluster. You need to organize the notes to help the readers understand your work better, for example, give a theme of the selected notes and state which principle(s) can be identified.
Principles and criteria for selecting notes
1. Working at cutting edge Identify knowledge gaps and inconsistencies and formulate productive questions Generate a series of discussion (interest many people) Productive inquiry leading to the extension of community knowledge
2. Progressive problem solving Show continual efforts in grappling with problems posed by classmates; a cyclical process of problem formulation and resolution Deepening and sustained inquiry; show evidence of the development, evolution, and improvement of an idea
3. Collaborative effort Help classmates and the community extend knowledge Make knowledge more accessible to community through summarizing various ideas and different perspectives Use various functions such as rise-above, view maintenance to make community knowledge more accessible
4. Identifying high point Recognize any 'aha' experience in new learning Show misconceptions and new insights and different ways of looking at things Trace own journey of understanding and knowledge building efforts

student summarized her understanding and identified progress of what took place in the discourse. Knowledge building involves both process and products; in this example, the focus was on how ideas improved collectively.

Continental Drift—Principle 2 (*Progressive Problem Solving*). This set of notes is related to continental drift. It shows [the] development of deepening understanding of the topic. *At first, we were only able to give simple definitions* like “continental drift is the movement of plate due to convection currents”.¹ Then, there were more clear and specific descriptions. Nelson’s note told us that Continental Drift was not only the movement of plates but also the phenomenon that earth crusts are splitting, colliding and moving side by side.² *Then here raised another question*: “What [are] the differences/ relationships between/ of Continental Drift and Plate Tectonics?”³ Principle 2 can be realized here. We can observe a continuous effort in solving the problem and new related questions have been raised. *Polly realized that there is confusion between Continental drift and Plate tectonics. Then, there were new suggestions.* Some writers explained that continental drift can only [show] there was plate movement but not how the plates moved. Sea-floor spreading must be introduced in order to explain the movement of the plates.^{5,6} *Then, the two theories were combined* to support the Plate Tectonics theory, which can explain the formation and distribution of some landform features found today.⁸ From this, we can have a better and a deeper understanding the whole Plate Tectonics theory. *I think Polly’s note has played an important role here in driving the other writers to further investigate into the two theories.* (Excerpt 5, Valerie)

This portfolio note was quite different from the earlier ones that did not refer to knowledge building principles and focused on content (Excerpt 4). Now the student was describing and assessing her own as well as the community’s advances in understanding theories of plate tectonics and continental drift; she was documenting personal as well as collective progress in understanding. She made a careful analysis of how the class had moved from a basic question (i.e., definition of continental drift) to a deeper inquiry. After discussing the initial problem (“What is continental drift?”) and progressively refining the definitions, the students reinvested their efforts and formulated related problems (“What are the differences/relationships between continental drift and plate tectonics?”). Confusions and gaps of understanding were also identified as students inquired into new problems that led to the integration of theories (“Two theories are combined”). As well, important milestones of inquiry were documented (“Polly’s note has played an important role in driving other classmates to further investigate the two theories”). The example documented the evolution of questions—how one big question led to other re-

lated questions, and how ideas were improved when students were involved in deeper inquiry.

Identifying high points. This principle focuses on students assessing and monitoring their own knowledge advances; the focus is on metacognition. It is also interesting to note a shift from personal reflection in Study 1 to reflection on the progress of the community in this study:

Note – Shape of Continents (*High Points*) For principle 4, *when I looked at Kai Leung's question⁴⁷ about the shape of continent at the first time, I was wholly shocked* as his question seemed to be simple *but I have never thought of it*. As Wilson thinks that notwithstanding the change in distribution of continent, at the same time, the shape such as coastline of continent is somewhat changed with time. *I just wonder* the changes in shape [are] mainly due to the plate movement, *but Robert⁴⁸ suggests* another factor, that is, by wave erosion and weathering. I appreciate[d] Robert's answers, since at the beginning when reading his answer, *same as Yvonne,⁴⁹ I just react[ed] doubtfully* as I think erosion may be too minor in changing the shape of continent. But when I call back my memory from Form Four (Grade 10) and think seriously, *Robert's answer may be possible* since erosion continuously occurs and this will enhance the cracks of coastline and after [millions] of years, the change of coastline is observable. At the same time, *I⁵⁰ also suggest* that earthquake may also contribute to the changes of continent's shape because of its strong vibrancy due to the sudden release of energy. Lastly, Yvonne⁵¹ extends my idea by saying that plate movement can indirectly, lead to the changes since earthquake often associates with the movement of plate. Actually, I appreciate[d] this set of discussion since *we are discussing something that we are not told in textbooks. This problem is solved by ourselves*. (Excerpt 6, Peter)

This portfolio entry provides some evidence of the metacognitive aspects of knowledge building as the student revealed insight into his thinking process (e.g., "I was wholly shocked"). There was some evidence indicating how the student negotiated fit between his idea and other conflicting perspectives. The student also documented the evolution of questions, problems, debates, and discourse; and he was able to provide evidence of how the discourse helped him to see things from different perspectives. Finally, there was reflection on communal understanding as the student noted how class members worked collectively to solve the problem.

Student Reflections on the Principles and Portfolios

Some students spontaneously wrote a reflection after they had completed the portfolios. A quote from a student portfolio is included here to illustrate how

knowledge building portfolios may scaffold students to engage in deeper collaborative inquiry. The student not only mentioned how she benefited personally but also how the community improved:

These four principles *not only help me to choose the notes but also in creating new notes*. In order to make good notes, *we can follow the principles* when we are raising questions, giving explanations, or drawing conclusions... *These benefits can be observed in the 3 new views*: In our notes, many of us tried to raise some controversial questions that aim to collect different points of views; many of us have shown great efforts in solving others' problem by suggesting new and developing existing ideas. Besides, in many of the notes, the writers will try to make their own theories after raising questions. This shows the active participation and the improvement in note-writing of our classmates. (Excerpt 7, Valerie)

Quantitative Analyses

Portfolio ratings. Each student submitted, for course evaluation, a portfolio consisting of eight clusters of notes each accompanied with an explanatory statement of why and how that selected cluster evidenced knowledge building principles. The teacher rated each selected cluster of notes examining both explanation and the selected notes using a 3-point scale: Portfolio notes repeating teacher guidelines with limited evidence of the principle were rated 1, portfolio notes focusing on content and ideas with some evidence of principles were rated 2, and portfolio notes synthesizing ideas and focusing on idea and discourse development were rated 3. We counted the number of explanations in each selected cluster for a given principle and calculated an average score for each principle. A second rater independently rated a sample of the portfolio (30%). The interrater reliability was 0.72 (Pearson correlation). We converted the portfolio ratings to percentages for comparability across the three studies. We report mean portfolio ratings for the whole class as well as for students classified into high-low groups based on their scores on conceptual understanding. As shown in Table 2, students of both high-low groups demonstrated that they were generally able to provide evidence and explain knowledge building episodes in the discourse.

Trends in participation in Knowledge Forum (ATK indexes). Table 3 shows the class means and standard deviations of the ATK scores over the 18 weeks the students worked on Knowledge Forum. The use of Knowledge Forum features was similar to Study 1, particularly the high frequency of linked notes, notes with keywords, and scaffold uses; the students read a larger proportion of the database (66.6%, compared with 45.1% in Study 1).

We also examined changes in student participation on Knowledge Forum (ATK indexes) in two periods (each of about 9 weeks) early and later in the semester. As in Study 1, there were improvements on most of the ATK indexes. For example, the average use of scaffolds increased from 19.0 to 42.4, and the number of notes created increased from 26.3 to 34.9. These findings suggest that the students had increased their participation on Knowledge Forum.

Conceptual understanding (between-group analyses). To assess conceptual understanding of physical geography, students in the Knowledge Forum portfolio class and the comparison group were administered two writing tasks. The first task was an essay writing task taken from the public examination paper in Hong Kong, and the second required students to write about what they had learned about a selected topic. The students' responses to the two writing tasks were coded using a rating scheme developed by the teacher, who had used the scale with other teachers in his school. All the essays were rated independently by the teacher and a graduate student; the interrater reliabilities were .70 and .83 (Pearson correlation). To control for differences in students' academic achievement, we included students' public examination results in geography in the previous year as a covariate in the analyses. Grades on these examinations are used for university placement and are considered a good indicator of academic achievement; for geography scores they also indicate students' prior knowledge regarding the subject matter.

The average percentage scores (standard deviations) were 73.6 (22.0) and 44.5 (20.3) on Writing Task One (Essay Question), and 83.3 (17.3) and 57.3 (25.1) on Writing Task Two (New Learning), for Knowledge Forum Portfolio and Comparison groups respectively. A multivariate analysis of covariance controlling for achievement scores showed significant differences favoring the Knowledge Forum students on both Essay Scores, $F(1, 22) = 14.5, p < .001$; and Learning Scores, $F(1, 22) = 10.3, p < .005$. These findings indicated that students in the experimental class outperformed the students in the comparison group on domain understanding.

Relations among portfolio ratings, participation (ATK), and conceptual understanding (within-group analyses). The set of ATK indexes were combined using factor analysis, with a single factor explaining 57.6% of the variances with an Eigenvalue of 3.45. Correlation coefficients were analyzed to examine the overall relations among ATK participation, knowledge building portfolio scores, and conceptual understanding controlling for differences in prior academic achievement. The participation (ATK) scores were significantly correlated with the portfolio scores, $r = .62, p < .05$. The portfolio scores were significantly correlated with the writing scores assessing conceptual understanding, $r = .67, p < .05$.

Discussion and Issues Raised

The findings were encouraging. First, examples of portfolios indicated relatively high levels of understanding of the principles. We classified students into two groups (high-low) using conceptual understanding as a measure of student learning. Both the high-low conceptual understanding groups revealed some understanding of all the knowledge building principles, although the high-conceptual understanding group outperformed the low-conceptual understanding group on the portfolio ratings. These findings suggest that high school students were capable of using the knowledge building portfolios and examining their own knowledge advances in computer discourse. Second, the differences between the ratings for progressive problem solving and the other principles were not as large as in Study 1 (see Table 2). We attributed this to the design of Knowledge Forum work: In Study 1, the discussion mainly evolved around weekly readings rather than authentic problems. With lessons learned from that implementation, we focused more on the emergence of problems. Although the teacher had started the views (discussion areas) on Knowledge Forum, much of the discussion and subsequent views emerged from problems the students framed and wanted to research. Another aspect of the design that may have contributed to this was that the students were introduced to knowledge building more slowly, beginning to develop a collaborative culture early in the school year, before Knowledge Forum and the portfolio design were introduced. As well, the students based the portfolios on what they considered the community's best work rather than their own best work, as they had done in Study 1. Third, there appeared to be a significant relation between portfolios and subject matter understanding. Students who used Knowledge Forum outperformed students in the comparison group on conceptual understanding (between-group analyses), and significant correlations were obtained among portfolio scores and conceptual understanding scores (within-group analyses), both analyses controlling for differences in academic achievements. As in Study 1, the portfolio ratings appeared to be related to ATK participation indexes on Knowledge Forum.

The students' portfolios and reflections further indicated that some students understood the potential of the principles for scaffolding the knowledge building process. We had not originally thought of them that way, and the findings of Study 2 led us to think about the portfolio approach in broader terms—as scaffolding as well as characterizing knowledge building. The teacher also commented that the portfolio approach made his job of monitoring the students' progress more manageable. Instead of reading and responding to all the notes, the teacher studied the students' portfolios. The teacher can manage the task of reading the database by focusing on key knowledge building episodes, and the students gain agency as they learn to recognize knowledge building and high points of community work. In other words, the portfolio approach can be a pedagogical tool that enables the teacher and students to focus attention on improving the knowledge building discourse.

Study 2 left several further challenges and questions. For example, the analysis of the relation between the portfolio ratings and conceptual understanding was a post hoc analysis and used a small comparison group. The differences between-groups could be attributed to many different variables—in particular to teacher effects. It also remained unclear whether the design could be applied in another subject, such as science. Study 3 addressed some of these issues.

Study 3: Examining Portfolios as Scaffolds for Scientific Understanding in a Secondary School Chemistry Class

Background and Goals

The goals of Study 3 were twofold. (a) We wanted to examine the roles of portfolios on conceptual understanding more systematically. Study 3 used a quasi-experimental design with pre- and posttests of domain knowledge. The hypothesis was that the experimental group would outperform the comparison group on conceptual understanding. (b) We wanted to replicate the instructional design of Study 2 in another subject with another teacher who did not play a major role in designing the portfolio (as the teacher in Study 2 did).

Participants

The participants were 47 female students taking Grade 12 chemistry at a Catholic girls' school in Hong Kong; there were 24 students in the experimental class and 23 students in the comparison class. Students in both classes had similar academic achievement with respect to their performance in the territory-wide public examination (Hong Kong Certification of Education Examination). The two classes were taught by the same teacher. The lessons were conducted in English, and the experimental students wrote notes in English on Knowledge Forum—primarily after school, as in Studies 1 and 2. Students in the comparison class completed assigned reading and writing after class instead of writing on Knowledge Forum.

Instructional Design

The students studied biochemistry for a period of 10 weeks occurring in the second semester. As in Studies 1 and 2, the curricular goals included developing conceptual understanding in chemistry as well as collaborative inquiry. The teacher adopted much of the instructional design of Study 2, beginning by developing a collaborative culture, then by teaching the students how to use Knowledge Forum to deepen their understanding, and finally by introducing the knowledge building portfolio as a course assessment. However, the teacher also made several significant changes to the instructional design. First, the students used Knowledge Forum for only 10 weeks, compared with 18 weeks in Study 2. Second, the students completed only one set of portfolios—with the principles. Overall, the teacher invested

less time in Knowledge Forum than the teacher of Study 2. The primary reason for this was that whereas in Study 2 the teacher explored the design of the portfolio assessment with one class, in Study 3 the teacher used a more systematic approach to replicate the findings of Study 2 using two classes, one as a comparison group. From ethical and research perspectives (quasi-experimental design), he needed to spend similar amounts of time with the two classes on the topics studied. Third, he changed how the portfolios were to be completed in Knowledge Forum. In Study 2, students first introduced a cluster of notes and then discussed the evidence for each of the principles in that cluster of notes, discussing eight clusters that way. In Study 3, students wrote four separate sets of notes; in each selection, they discussed the evidence a single cluster of notes showed for one principle. This change was not a refinement of the procedure in Study 2, but reflected a different teacher preference. The teacher of Study 2 was comfortable with a holistic and flexible style in which students could decide which principles to focus on when discussing a cluster of notes; the teacher of Study 3 preferred a more systematic style in which students analyzed one principle at a time. That change made the portfolio assessment more integral and usable in classroom settings.

Results

Before presenting the quantitative results, we discuss an excerpt from one portfolio note to show that the students produced portfolio entries of comparable quality to those in Study 2.

Principle 3 (*Collaborative effort*) Solubility of Cis- and Trans-Isomers.^{15 16 17 18 19 20 21} This topic [solubility of Cis- and Trans-Isomers] was actively discussed by many of our classmates. It shows our continuous effort to find out a correct explanation to Jenny's question, that is, the relation between the inter/intra-molecular H bonds and solubility of geometric isomers.¹⁵

First, a pioneer idea was proposed by Vivian in which she suggested that the breaking of more intermolecular H bonds in trans isomers hinders effective H bonds with water molecules and so resulting in lower solubility. This can provide a new way of looking at the problem.¹⁶ Consequently, this [idea] was criticized by Annie, clarifying her misconceptions on conditions for solubility.¹⁷ Jenny also pointed out what remained to be discussed, the explanation for the experimental results.¹⁸ A *summary note* was later posted by Annie which sums up various ideas of group-mates and the basic theory.¹⁹ Then, Marilyn and Sheila expressed her opinions and raised questions after considering the ideas generated in several previous notes.^{20 21}

All in all, the question raised is very effective in improving *community knowledge*. Because many other important chemistry issues and aspects, e.g., boiling point, dipole moment, which branch out from the original ques-

tion were discussed. Some chemical terms and concepts which look familiar and simple, e.g., “like dissolves like” is clarified. So, this deepens our understanding on this topic. (Excerpt 8, Mary)

This example illustrates how the student recognized collective learning in the community. Different ideas in the discourse were presented and synthesized, and they were linked to conclusions supported with the relevant ideas in the selected notes. Knowledge advances were contributed by various members and shared understanding emerged from collective work.

Quantitative Analyses

Portfolio ratings. The students submitted a portfolio consisting of four sets of notes; each consisted of an explanation and a cluster of selected notes from the database to illustrate each of the four principles. Each set of notes was coded using a 4-point scale. We examined both the explanation and the notes referred to in the explanations. A rating scheme with a finer gradation than in study 2 was used: Level 1 responses merely repeated the teachers’ description of the principles, Level 2 responses focused on the content described in each note, Level 3 responses indicated multiple perspectives demonstrated by the notes, and Level 4 responses focused more specifically on discourse development and growth in ideas. A second rater independently rated a sample (approximately 30%) of the portfolio notes; the interrater reliability was 0.78 (Pearson correlation). We report the portfolio ratings of the whole class as well as ratings for the high-gain and low-gain groups based on scores of conceptual understanding (see Table 2).

Trends in participation in Knowledge Forum (ATK indexes). Participation on Knowledge Forum was examined using the ATK (Table 3). Possibly because of the shorter time on Knowledge Forum, several of the ATK indexes were lower than in Study 2. Nevertheless, the other indexes (e.g., the percentage of notes with links & the percentage of notes in the database read) were similar. Compared with the literature on participation in online discussions (e.g., Guzdial & Turns, 2000a; Hewitt, 2003), the students were actively engaged on Knowledge Forum. We also examined ATK indexes over two 5-week periods to explore changes, but did not find improvements, possibly due to the shorter duration of the work on Knowledge Forum.

Conceptual understanding (between-group analysis). Conceptual understanding was assessed using a two-part instrument. Part 1 included seven examination questions from a public examination paper (Advanced-Level Examination). This type of question was used to assess whether the students could achieve the Advanced Level standard in solving organic chemistry problems. Part 2 included

five questions designed by the teacher to assess students' conceptual understanding of the fundamentals of organic chemistry. The paper took 1 hr to complete.

Responses on the A-Level examination questions were scored using the marking schemes provided from the Hong Kong Examination Authority. Responses on the conceptual-based questions were coded on a 5-point scale designed by the teacher to assess students' different levels of understanding. The 94 sets of answer scripts were rated by the teacher; 30 sets were rated independently by another high school chemistry teacher. The interrater reliability was .88 (Pearson correlation).

The average percentage scores (standard deviations) on examination questions on pre- and posttests were 10.17 (4.93) and 42.58 (9.61) for the experimental group and 12.96 (7.79) and 44.17 (12.85) for the comparison group. An analysis of covariance of the examination question scores using pretest scores and academic achievements as covariates revealed no group differences. For the conceptual change questions, the percentage scores (standard deviations) for pre- and posttests were 8.69 (3.40) and 35.14 (11.47) for Knowledge Forum portfolio students and 8.33 (2.61) and 27.83 (9.62) for comparison students. An analysis of covariance indicated statistically significant but small differences, $F(1, 44) = 4.96$, $p < .05$, $\eta^2 = 0.10$. These results indicated that the students in the experimental group outperformed the students in the comparison group on conceptual understanding scores.

Relations among portfolio ratings, participation on Knowledge Forum (ATK), and conceptual understanding (within-group analysis). The overall relations among different measures for knowledge building and conceptual understanding were examined. First, the scores for the four principles were added to form an overall knowledge building portfolio score. The set of ATK indexes were also combined using factor analysis; the six indexes loaded on the same factor with an Eigenvalue of 2.76 accounting for 45.92% of the variance. Analyses indicated that participation on Knowledge Forum (ATK) indexes were significantly correlated with portfolio scores, $r = .42$, $p < .05$. Significant correlations were also obtained between portfolio scores with gains in examination questions, $r = .78$, $p < .01$ and with gains in conceptual questions, $r = .67$, $p < .01$. Taken together, both the between-group analysis (group comparison) and the within-group analysis (correlation) suggest that students' portfolio scores were related to students' gains in conceptual understanding. They also replicated the findings in Study 2.

Discussion and Issues Raised

Study 3 improved our understanding of the roles of the knowledge building portfolios. First, it extended the work begun in Study 2 in another subject, taught by another teacher. The portfolios suggested similar levels of quality. Further, we said that the extent of the intervention was more modest than in Study 2; it thus

suggests the possibility of other teachers implementing knowledge building with portfolios. Although the question needs further investigation, the robustness under varying degrees of intervention is important to the scalability of the design (Collins, Joseph, & Bielaczyc, 2004; Fishman, Marx, Blumenfeld, Krajcik, & Soloway, 2004).

Second, the analysis of conceptual understanding indicated that the work with Knowledge Forum did not compromise gains on exam question scores—it revealed a modest advantage for the Knowledge Forum class for conceptual questions. We also found statistically significant correlations between portfolio ratings and gain scores on exam questions and on conceptual questions. These findings are potentially important because in Hong Kong—and many other school systems—conceptual understanding and performance on public exams are crucial factors influencing teachers' willingness to innovate in their classrooms. However, more research is needed to disentangle the effects due to the various components of the instructional design. As with the common concerns with studies in CSCL classrooms, there are many interacting factors that influence learning in the classroom, and in this study we could not separate, for example, the effect due to the portfolios from the effect of Knowledge Forum by itself. These results at least represent the combination of Knowledge Forum together with portfolio assessments. As in Studies 1 and 2, there were significant correlations between ATK indexes and portfolio ratings.

DISCUSSION AND CONCLUSION

We began this article by examining the problems and challenges facing the assessment of collaborative learning, in particular the alignment of learning, collaboration, and assessment in CSCL classrooms. Our goals were to design assessment procedures that were primarily conducted by students, could be used to probe individual as well as collective aspects of learning, could be used to evaluate both process and product, and could be used to evaluate achievement as well as scaffold (guide) future learning. In addition, we sought to understand what the portfolios could reveal about the nature of knowledge building. We explored these goals in three studies in which students created electronic portfolios based on their efforts at knowledge building. The studies contribute to the research program on knowledge building, but they also have implications for other approaches to collaborative learning within social constructivist paradigms.

In Study 1, we explored the use of four knowledge building principles in a graduate class on knowledge building. Some of these principles described collective features of knowledge building, but the assessment task remained focused on individual responsibilities; we expected all students to be primary authors in episodes showing working at the cutting edge. Nevertheless, the students spontaneously re-

ferred to other participants' computer notes when describing knowledge building events. In Study 2 we improved the design, and students identified the exemplary work of the class rather than focusing on their own best notes when identifying knowledge building. We learned that the knowledge building portfolio not only helped students to recognize knowledge building, but they also helped students to decide how to make further contributions to the Knowledge Forum database and appeared to facilitate domain understanding. In Study 3, we examined conceptual understanding using a quasi-experimental research design. We learned in Studies 2 and 3 that the time spent on Knowledge Forum and whatever misconceptions may have been present in the Knowledge Forum notes did not adversely influence domain understanding; indeed in Study 3, there was a small effect in favor of the experimental condition.

In the next sections, we discuss how the portfolios helped to characterize and scaffold knowledge building, we discuss how the approach we developed addresses the issues with assessment in CSCL classrooms as identified in the introduction, we propose design principles for assessment in CSCL classrooms, and we outline implications for further research.

Characterizing and Scaffolding Knowledge Building With Portfolios

We first examine the roles of portfolios in characterizing and assessing collective knowledge building and then consider the effects of the portfolio tasks on collaborative inquiry and domain understanding.

Portfolios for Characterizing Collective Knowledge Building

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. The portfolios are not just learning products; they reflect distributed cognition, and they demonstrate how students make progress and advance their community knowledge collectively. A portfolio note is more than an individual achievement; it 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. Our findings also suggest that there is interplay between individual and col-

lective knowledge growth. As students engage in analyzing the community discourse, they also reconstruct their own understanding.

The portfolio approach was designed to examine more clearly the nature and distinctive characteristics of knowledge building. The portfolios provided evidence suggesting that students were engaged in knowledge building inquiry as in scientific communities. Using the knowledge building principles, we were able to tap into different aspects of knowledge building. The students' portfolio statements suggested that some students formulated cutting edge problems to advance the community's understanding; some wrote summary accounts integrating fragmented views into a better theory for sharing with others in the community (collaborative effort). When some general questions had been addressed, the students continued to pose related questions for deepening their inquiry (progressive problem solving). The portfolio also suggested how students were able to identify others' contributions and different milestones that guided an advance in the discourse (monitoring knowledge advances). Even high school students were able to work as a scientific community including writing integrative reviews, identifying different perspectives, and pointing out milestones that propelled the development of knowledge in the community.

The assessment approach also provided information about the possible developmental trajectory of knowledge building. Across all three studies, the students scored higher on collaborative effort than on progressive problem solving. Possibly, collaborative effort is easier to attain and develops before progressive problem solving. However, although some principles may be easier to achieve than others, we learned from the studies that there could be various ways to foster knowledge building. For example, we were able to obtain higher scores on progressive problem solving when we refined the design in Studies 2 and 3. Instead of focusing on readings and topics, sustained inquiry and progressive problem solving could be facilitated by providing authentic problems and encouraging questions to emerge from student-directed inquiry.

Portfolios as Scaffolds for Collaborative Knowledge Building

We also learned that the portfolio approach was effective in fostering collaborative inquiry and domain understanding. Different sources of evidence were obtained about its roles. First, we found a relatively high level of participation on Knowledge Forum based on the ATK indexes. Although there are no norms, the participation rates for the three studies were considerably higher than those reported in the literature (Guzdial & Turns, 2000a; Lipponen, Rahikainen, Lallimo, & Hakkarainen, 2003). Second, use of portfolios was related to domain understanding. In Study 2, we included a posttest only design and found that students in the experimental class outperformed students in the comparison group on tests of

conceptual understanding. These results were replicated in Study 3 in another domain using a planned quasi-experimental design. Knowledge building portfolio scores were correlated with conceptual understanding in both studies. Subsequent to the studies, we learned that students in both Studies 2 and 3 performed better on public examinations than similar classes at their schools in previous years. Third, the protocols we discussed suggest that the students were involved in deep collaborative inquiry. Study 2 showed that when students wrote portfolios without knowledge building principles, the portfolio entries were shallow and focused on content. However, when students used the knowledge building principles as scaffolds to guide them with note selection, they created portfolio notes indicating more sophisticated collaborative inquiry.

Through refining our design of portfolios, we learned the portfolio assessment approach was useful in scaffolding collective learning and domain understanding. As students browsed the database to identify knowledge building episodes, they synthesized different views, examined various models of thinking, and reflected on their individual and collective understanding. The portfolio design made the goal of learning as collective knowledge building explicit to the students through using the set of knowledge building principles.

As the studies evolved, we learned that some students did not write enough notes on their own that could depict knowledge building. In later studies, we changed the design; instead of contributing notes written by themselves as main authors, we asked students to identify and recognize computer notes in the community discourse that depicted knowledge building. We suggest that this approach of *identifying* knowledge building may constitute an important step toward developing knowledge building practice. Before students can engage in knowledge building, they benefit from recognizing knowledge building incidents. This idea is consistent with research on metacognition and cognitive strategy instruction. For example, King (1995) stated that recognizing good questions is a prerequisite to posing good questions. From a social constructivist perspective, we need to help students to recognize that knowledge building is a distributive process; identifying community progress is also an important part of the developmental process needed to guide students toward more mature knowledge building practice.

Addressing Misalignments in Learning and Assessment in CSCL

In this section, we discuss how the design of knowledge building portfolios address classroom problems and issues of misalignment of learning, collaboration, and assessment.

Assessment of Learning and Assessment for Learning

Commonly, classroom assessment focuses on the content knowledge students have learned. The knowledge building portfolios provided rich data sources to ex-

amine how students collaborate; at the same time, they were designed to foster collaborative inquiry and understanding. We integrated the portfolios with instruction as course assessments and made the learning goals and the nature of knowledge building explicit for students. As shown in the portfolio examples, in identifying exemplary clusters of notes and providing explanations, students must browse the database and synthesize their own and collective understanding. Other researchers have noted low and variable participation, fragmented understanding, scattered discussion, and superficial work (Guzdial & Turns, 2000a; Lipponen et al., 2003). We suggest these problems may be alleviated by the approach we developed. The assessment approach examines collaboration and provides a tool for deepening collaborative inquiry.

Assessment of Individual and Collective Learning

Despite emphasis given to collaborative processes and interactions, assessment and evaluation are usually limited to individual learning outcomes. The knowledge building portfolios we designed capture both individual and collective aspects of knowledge building. As shown in the portfolio examples, the student was not merely describing his or her personal work; he or she was describing how a group of students addressed a problem, what views it held, what misconceptions it identified, what critical incidents took place, and how ideas were gradually improved. Knowledge building postulated by Bereiter and Scardamalia (1996) is analogous to scientific inquiry in scholarly and scientific communities. Even high school students can be engaged in a process similar to the writing of scholarly reviews when someone integrates differing ideas to provide an overview of the “state of knowledge” in the community.

Assessing Both Content and Deep Inquiry

A common misalignment in CSCL classrooms is that students are asked to collaborate but primarily assessed on content (Reeve, 2000). It is perhaps not surprising that online discussions are scattered and fragmented. Using knowledge building portfolios, we aligned assessment and instruction focusing on both the development of content and inquiry. Regarding content, students selected computer notes, organized them according to themes, and described the development of ideas. Regarding inquiry, the explanatory statement helped students to reflect on their understanding of the knowledge building process. The knowledge building portfolios integrate both content and process and show how students can develop collaborative inquiry in the context of understanding deep domain knowledge.

Design Principles for Assessment in CSCL Classrooms

The assessment approach we developed is not limited to knowledge building or to the specific discussion environment we used. In this section, we present five design

principles that we propose capture the most important features of our approach to integrating learning, assessment, and collaboration.

We do not intend to suggest these principles are warranted fully by deductive or inductive reasoning from our evidence. Instead, having completed the study, the principles together provide what we consider the most promising approach for taking efforts to align learning, assessment, and collaboration. For a discussion of the epistemological status of design principles see Bell, Hoadley, and Linn (2004, p. 81).

*Assessment Principle 1:
Develop a Culture of Collaboration*

A culture emphasizing collaboration is needed that permeates both instruction and assessment in online and classroom settings. Developing such a culture typically requires a shift of emphasis from individual and competitive assessment to assessment that emphasizes collaboration and the contribution to others students' learning (e.g., peer assessments, collaborative knowledge products). It also requires that online discussion is integrated with the other activities in which the class is engaged—collaboration should be valued in both online discourse and classroom work. Teachers may let the class know that demonstrating collaboration and helping others learn are valued as much as providing the correct answers. Computer discussion needs to go beyond giving correct answers and teach students how members of a community can work together to improve their ideas. Students can be asked to identify what they have learned, how they have improved, and how other classmates have helped them learn on computer forums.

²This description of “collaborative culture” is general and is intended to convey that collaboration must be valued and supported. Kolodner et al. (2003) have given an explicit description of how to support such conditions in the classroom. Key to their approach is the use of a set of social practices (e.g., gallery walks, poster presentations) that focus on building scientific understanding in the context of investigations that support the project challenge on which students are working. Repeated participation and reflection on these practices helps students to develop fluency in carrying them out and to come to appreciate their value.

*Assessment Principle 2: Embed Assessment
in Learning Activities*

Assessment and learning are two sides of the same coin (NRC, 1996; Shepard, 2000). That means that assessment is not an activity that stands apart from learning—that is, coming at the end of learning—but one that is part of the learning process. Finding out what has been achieved and what still remains to be done are as much a part of learning as reading and doing an experiment. Scardamalia (2002) refers to assessment as being concurrent with learning and embedded in it.

We propose that assessment needs to be formative and aligned with learning goals. In our studies, the students wrote notes regularly and provided regular peer and self-assessments (comments in Knowledge Forum); all these notes were potential artifacts for the portfolios. The ongoing activities of note contribution were integral and embedded within the course assessment using portfolios. To encourage students to participate and to help them understand what to write, online discussion was integrated with classroom discourse. When the teachers provided feedback to students they did not merely write notes to individual students, but provided various examples of computer notes as models and asked the students to discuss these computer notes in class (see Study 2). After such activities, the students emulated the examples and began to write notes of better quality.

*Assessment Principle 3: Make Students Assessors
and Maximize Student Agency*

A key feature of our design was that students were given the agency to assess their own contributions to Knowledge Forum. Assessment is commonly seen as the job of the researcher (analysis) or of the teacher (evaluation). We turned the job over to the students. Having students assess their own learning and collaboration is an important component of what Scardamalia (2002) calls epistemic agency.

The fact that students are doing the analysis is important for several reasons. When students take on the responsibility of analyzing their own contributions, it is likely to lead to increased participation. We also expect asking students to assess their own work to have benefits on their metacognitive development, as they have to examine the high points of their contributions; such a notion is consistent with the literature on metacognition (e.g., Hacker, Dunlosky, & Graesser, 1998). There are other motivational effects when students are asked to identify exemplary notes written by themselves and their classmates. One can see the possible effects on other students when their notes are identified as exemplary. Furthermore, the teacher does not have to be concerned with responding to many individual notes, rather the teacher can study the portfolio notes to see how the discussion has developed and how it can be improved. Peer and self-assessment are quite commonplace, and some examples exist in technology studies (e.g., ThinkerTools, Scientific and Mathematical Arenas for Refining Thinking Classrooms). To our knowledge, there are few attempts asking students to assess their own and community learning in their computer discourse. We propose that asking students to assess their own work would maximize agency and bring about deeper inquiry and collaborative work.

*Assessment Principle 4: Establish Criteria for Peer
and Self-Assessment*

It is not enough to ask students to examine their own contributions. In Study 2, the students were not given criteria for the first set of portfolios (Excerpt 3),

and they tended to identify notes with good answers as exemplary notes. Although recognizing good content in computer notes is useful, if the goal is to help students recognize and engage in knowledge building, we have to make explicit to them what knowledge building involves. When the students were provided the knowledge building principles, they focused more on the knowledge building process. As we saw, these principles scaffolded the online discourse to some extent—they instructed students on how to contribute to the discourse.

Although providing students with explicit criteria is becoming more common in classroom settings, we need to go further in CSCL classrooms. To capture the social and collective nature of learning, we used a set of knowledge building principles that span individual as well as distributed aspects of knowledge construction. With the help of the principles, students recognized that learning is more than an individual phenomenon; it is a collective phenomenon in which students build on other students' ideas to sustain idea improvement. Our studies focused on knowledge building, but different sets of criteria can be used for depicting collaboration depending on the conceptual perspective. The principle is that if we want students to engage in deeper and sustained collaborative inquiry, we need to provide them with criteria and examples as scaffolds illustrative of productive collaborative inquiry.

Assessment Principle 5: Design Reflective Assessment Tasks

Assessment tasks need to be designed for probing deep aspects of learning and collaboration. Contrary to the use of technology for efficient delivery and web-based testing of discrete content in computer-based instruction in higher education (Reeve, 2000), we argue that technology-based assessment tasks should be designed to serve the roles of scaffolding deep inquiry. In this study, we used the electronic portfolios in which students identified exemplary clusters of notes illustrating knowledge building episodes. As discussed earlier, the portfolio integrated and examined both content and process: The students had to focus on note content in the selections, but they also needed to reflect on their understanding of the knowledge building process. Furthermore, as we learned from Study 1, it is important to design tasks that do not undermine sustained inquiry and reflection. It is common for computer forums to organize student discussion around topics or readings. Student inquiry will be limited as they move from topic to topic each week; there is a need to provide students with authentic problems integrating issues across topics and let problems emerge from the inquiry.

Technology can provide many opportunities promoting deeper aspects of collaboration. However, if the students are asked to collaborate as communities on forums but are assessed on superficial content knowledge, it would not be sur-

prising that students have difficulty participating or engaging in deep discussion. We have proposed the use of knowledge building portfolios, but various kinds of cognitive assessments such as summary and collaborative notes tracking high points and synthesizing different ideas in the computer database can be used as well.

Further Research and Implications

We discuss several aspects of the studies for further clarification and point out possible lines of further research. First, it may be argued that if the study is about assessment of knowledge building measured by portfolios, we need to examine whether students have improved on their portfolio scores. In this respect, it is worth pointing out that the portfolios synthesize a considerable amount of online discourse. This means that they cannot be created very frequently—it takes time to let the discourse develop. In addition, the knowledge building principles themselves captured evolution, for example, progressive problem solving chronicled the histories of problems, as high points did this for students' personal learning. In ongoing work, we are examining students' portfolios over 2 years. In Study 2 of this paper, where two portfolios were assigned, we did demonstrate that the quality of portfolios improved, suggesting that the knowledge building portfolio was effective in bringing about deeper collaboration.

A second area of concern pertains to the distinction between content and process. Questions may be raised about the goals of the study. Are we investigating learning the literature on knowledge building, learning earth science, learning organic chemistry, or learning how to build knowledge? In these studies, we sought to examine the assessment of collective learning and the nature of knowledge building as a collaborative process. Thus, it would be useful to examine knowledge building in different domains and contexts. As the study evolved, we sought to examine the pedagogical effects of portfolios on students' subject matter understanding. Therefore, we assessed students' conceptual understanding of geography and biochemistry using paper and pencil tests (Studies 2 & 3). We designed knowledge building portfolios for identifying knowledge building processes and for examining its roles in promoting domain understanding. Finally, it would be useful to note that collective knowledge building goes beyond process or skills; knowledge building involves both content and skills as it depicts collective knowledge advances.

Other questions may be raised about the set of knowledge building principles we used. Although they seemed somewhat overlapping, each is designed to capture a specific aspect of knowledge building. The set we used was not the same as that formulated by Scardamalia (2002). As we explained earlier, we needed an intuitive and small enough set that could be integrated with instruction to form the basis of course assessments. We examined students assessing their own

collaboration, and a smaller set is more appropriate. However, the principles we used still captured the key ideas of knowledge building (Scardamalia & Bereiter, 2006).

Questions may also be posed whether the portfolio scores reflect collective knowledge advances. The portfolio scores were assigned to individual students based on their understanding of knowledge building process. However, students had to identify clusters of notes to explain how personal and communal ideas evolved. Our interest was to use the portfolio to capture collective knowledge growth and to foster collaboration and understanding. Nevertheless, it is useful to note that the portfolio scores were not collective scores; they were individual scores that encompassed aspects of collective understanding. We made some advances in capturing collective aspects of knowledge building through portfolios, but further work needs to be conducted examining the relations between individual and collective aspects of knowledge growth.

It is important to be cautious in interpreting the positive effects obtained for conceptual understanding in Studies 2 and 3. It is now widely recognized that many intertwining factors operate that affect student understanding in CSCL settings. The gains in conceptual understanding could be related to many factors, and we have not delineated the effects of the knowledge building principles and portfolios from Knowledge Forum or other classroom effects. In recent research, we compared different design conditions and obtained some findings suggesting the specific roles of the principles (Lee, Chan, & van Aalst, 2006). Further work is needed to investigate how portfolio can foster students' knowledge building practices.

In summary, this article has provided an example showing the design of student-directed assessments that addressed the problem of assessing collective learning in CSCL. Our studies have probed the conceptual aspects of knowledge building and shown the pedagogical effects of the designs as a tool for fostering collaborative inquiry and conceptual understanding. The knowledge building portfolio is a collective accomplishment that tracks the collaborative knowledge building process in the community; it is also a tool that helps to scaffold collaboration. We also identified certain guidelines for designing assessments that foster collaborative inquiry in asynchronous networked environments. First, assessments should be formative; they should be designed as learning events that foster collaboration in CSCL settings. Second, assessments should be conducted in ways that provide agency to students including peer and self-assessments with criteria and principles to scaffold learning and collaboration. Third, there is a need to assess both individual and collective aspects of learning. We have developed a portfolio approach for characterizing and fostering collaborative knowledge building. Asking students to examine their own collaborative process and identifying high points in the community can help teachers track student progress as well as foster individual and collective knowledge advances.

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