Principle-Based Design of Technology Use to Support Community Knowledge-Building

Abstract. The purpose of this study is to explore the effects of a principle-based design of technology use on a community's knowledge building dynamics. The pedagogical design at issue concerned students' use of three tools—a Vocabulary Analyzer, a Social Network Analysis Tool and a Semantic Analysis Tool—in Knowledge Forum® under the guidance of a set of knowledge building principles for their knowledge works. Design research, with the technology design as an intervention, was conducted to test the design effects. Data for this study mainly comes from knowledge building discourse generated by grade 5-6 students over a semester period in a Knowledge Forum database. Findings based on a mixed-methods design of quantitative and multi-level content analyses revealed principle-based design to be a promising approach to fostering reflective use of technology for sustained community knowledge advancement.

OVERVIEW

The students in the current study are engaged in knowledge building, in their interactions with each other, and in their work in a computer-supported knowledge-building environment enabled by the Knowledge Forum software. Knowledge building is a social process focused on the production and continual improvement of ideas of value to a community (Scardamalia & Bereiter, 2003), and defined by a set of knowledge-building principles which represent design challenges, ideals, and improvable objects in their own right (Scardamalia & Bereiter, in press). The theoretical framework of knowledge building underlies the design of Knowledge Forum, whose sustained improvement, in turn, further expands both individual and community's capacity for more advanced knowledge-building (Scardamalia, 2003; 2004).

Knowledge Forum represents a multimedia community knowledge space where participants contribute their ideas in the form of *notes*[1] to *views*, which are virtual spaces for collaborative inquiry and discourse among community members. In addition, participants are able to *co-author notes*, *build-on* and *annotate notes* of others, generate *problems* and add *keywords*, and create *rise-above notes* to summarize different *notes* with related ideas. Knowledge building activities (e.g., *reading*, *linking*, *editing*) are recorded automatically in the database, and can be summarized statistically by means of the Analytic Toolkit software (Burtis, 2002). Figure 1 shows examples of a *view* and a *note* created by the participants in this study.

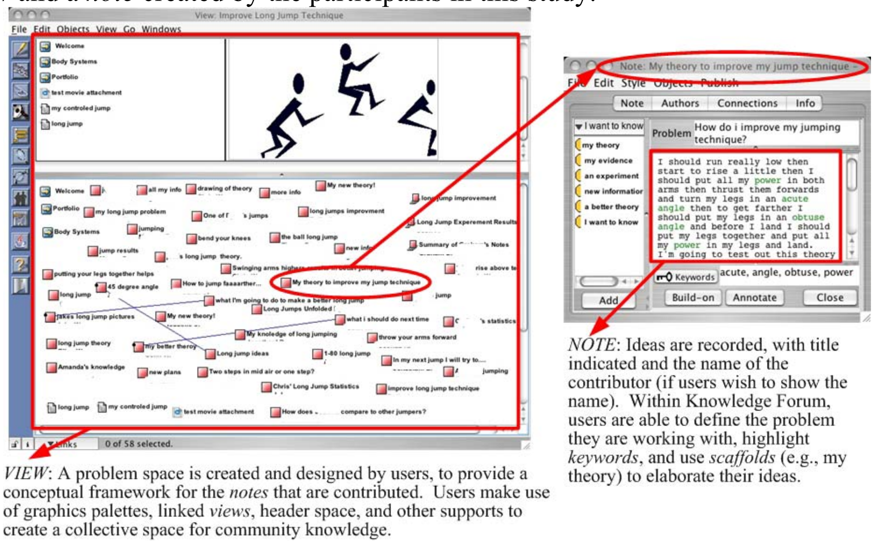

Figure 1. Examples of a *view* and a *note*

As an integral part of Knowledge Forum (version 4.6), the three lately developed technological tools include a Vocabulary Analyzer, a Social Network Analysis Tool and a Semantic Analysis Tool. Thy are part of the next generation of Analytic Toolkit. The Vocabulary Analyzer is designed to trace a member's vocabulary growth over time in the database. It also shows a member's vocabulary level as evaluated against a pre-defined dictionary. The Social Network Analysis Tool helps convey social dynamics of a community, for example, which members of the community are building on to the work of others, are not communicating with or are isolated from others and so forth. This tool also tells how many *notes* an individual *contributes* or *builds-on*, *links to*, or *references* to others' *notes*[2]. The Semantic Analysis Tool is designed to compare key terms extracted from different sets of *notes* and identify the overlapped terms with any benchmark users select, such as readings

[1] Throughout the paper, the *italic* terms are used to refer to the unique terminology in the Knowledge Forum.
[2] These functions are now separated from the Social Network Analysis Tool and become part of a new Contribution Tool.

for a unit or curriculum guidelines, or to identify idea similarity as indicated by the number of shared key terms between members. Figures 2-4 show each tool.

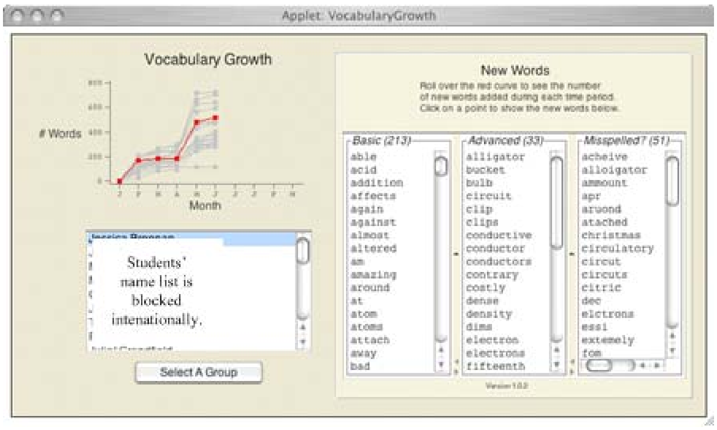

Figure 2. Vocabulary Analyzer: Illustrating the profile of one person's vocabulary growth

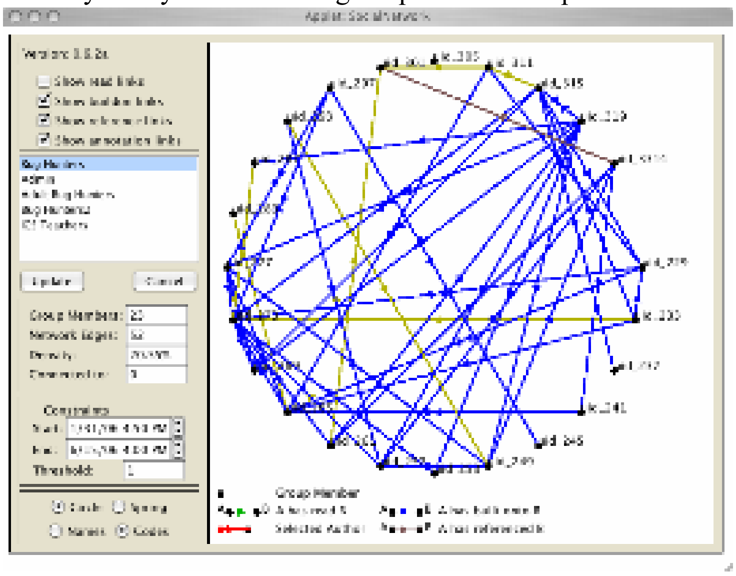

Figure 3. Social Network Analysis Tool: Illustrating social dynamics of a community

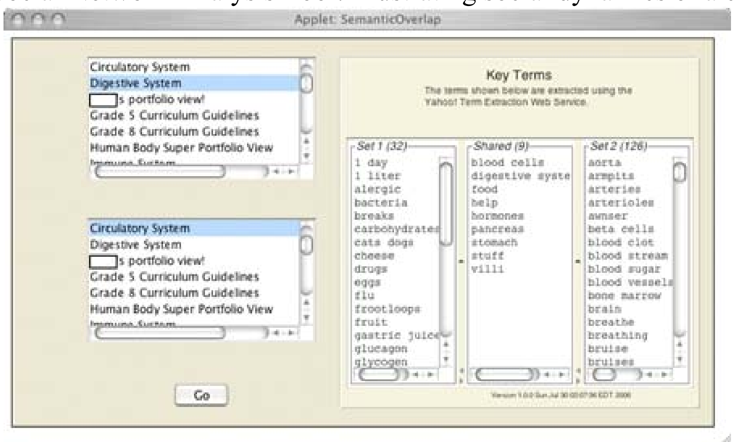

Figure 4. Semantic Tool: Illustrating shared ideas/key terms between two sets of *notes*

PRINCIPLE-BASED DESIGN

An important goal for developing these new tools is to continually improve the capacity of Knowledge Forum as a knowledge-building environment. How to actually implement them in a real context to most effectively support knowledge-building, however, remains an empirical question and a pedagogical design issue. For example, who should use the tools and how should they be used? Should they be used only by teachers? Or can they be used also by very young children? Should they be used only as pure assessment tools for summative evaluations? Or can they be used as knowledge-building tools for achieving an even higher goal of knowledge advancement? It is posited that with careful design, these tools can be used as knowledge-building tools even by very young children. The question is how? In the present study, a principle-based design approach was adopted to test the above assumption.

Design Principles

Marlene Scardamalia (2002) has elaborated 12 knowledge-building principles to guide the pedagogical use of Knowledge Forum technology. Of these 12 principles, the following four principles are especially salient and useful for guiding the use design of the three tools for knowledge building purpose:

Community Knowledge. This principle emphasizes the creation of community knowledge as the fundamental aim of knowledge building. As Scardamalia (2002) notes, contributions to shared, top-level goals of the community are prized and rewarded as much as individual achievements. Team members produce ideas of value to others and share responsibility for the overall advancement of knowledge in the community.

Symmetric Knowledge Advances. This principle underscores the reciprocal relationship between community knowledge advancement and personal knowledge growth. As expertise is distributed within community, symmetry in knowledge advancement results from knowledge exchange and from the fact that to give knowledge is to get knowledge. In other words, to advance community knowledge is to enhance personal knowledge.

Epistemic Agency. This principle highlights the importance of knowledge building process to be that participants set forth their ideas and negotiate a fit between personal ideas and ideas of others, using contrasts to spark and sustain knowledge advancement rather than depending on others to chart that course for them. They deal with problems of goals, motivation, evaluation, and long-range planning that are normally left to teachers or managers.

Concurrent and Embedded Assessment. The principle underlies the importance of viewing assessment as part of the effort to advance knowledge. Assessment should be used to identify problems concurrently as the work proceeds and should be embedded in the day-to-day workings of the community. Stated differently, assessment should be performed not only for the sake of increasing personal knowledge at an individual level, but for the benefit of community knowledge advancement at a collective level.

The main purpose of this study is to investigate whether a principle-based design of technology use has any effects on the knowledge building dynamics of a group of fifth-and-sixth-grade students. Specific research questions look into whether there are any the design effects on the following knowledge-building aspects in this particular community: (1) overall knowledge-building dynamics; (2) "what" knowledge is built; (3) "how" it is built; and (4) "why" it is built in a certain way. The four knowledge-building principles were used also as evaluative criteria to assess the findings.

METHOD

Context and Participants. The study was conducted in a science class at a school in downtown Toronto, Canada, and was conducted throughout the spring semester in 2006. The students under study were engaged in a course titled "integrated studies" and the theme to be explored was decided by the class as a whole to be "human body system." The aim of this course was to gain a deeper understanding, from an inter-disciplinary perspective, of the human body as a holistic system composed of many inter-related sub-systems.

The semester can be divided into two major initiatives: inquiry into the internal body as a system, e.g., studying how the brain, nerves, blood and cells work together (this phase covered the first nine weeks); and the physical body as a system, e.g. studying how the head, hands, legs, knees and feet coordinate to perform certain exercises such as a long jump (this phase extended from weeks 10-18). Through these two initiatives, students studied human body system from both a biological perspective and a physical perspective.

Participants were 22 fifth and sixth graders (10 girls and 12 boys) and were all experienced knowledge builders as they had been engaged in knowledge building for five or six years depending on their grade level. The teacher was also an experienced knowledge-building practitioner given his seven-year experience of knowledge-building practice in teaching.

Overall Research Framework and Procedures. This research is formative by nature as it is part of a greater effort of design research (Bereiter 2004; Cobb, Confrey, DiSessa, Lehrer, & Schauble, 2003; Collins, Joseph & Bielaczyc, 2004) aimed at sustained improvement of Knowledge Forum technology. Towards this end, this study employed a within-subject design, with the first inquiry phase (weeks 1 to 9) serving as a baseline and the second phase with three tools integrated into experimental designs.

In terms of the procedure, the three tools were introduced respectively between weeks 2-4 in phase 2, and they were introduced first by demonstrating their basic features to students. Then, students were guided to explore the tools. After that, the tools were open to free use and students were encouraged, but not required, to record their reflection around four scaffolding questions (designed as a guiding framework based on the four principles, see below) in their portfolio *views* in the database. Besides this, no specific instruction as to how to use the tools for knowledge building was given.

Pedagogical Design of Tool-Use. The purpose of employing a principle-based design is to create an overall guiding framework that would allow tools to be used creatively and opportunistically by students in advancing their knowledge whenever and wherever necessary. So, tools will not be used passively and routinely for pure assessment only such as the design of many computer-based or computer-assisted assessments, in which tools are commonly used to automatically produce assessment feedbacks for students (see, e.g., Conole & Warburton, 2005; Thelwall, 2000). One important feature devised in Knowledge Forum to support the overall guiding framework is the use of customizable scaffold. For example, a commonly used theory-building scaffold, designed to support sustained idea improvement, uses incomplete sentences such as "My theory is", "I need to understand" "This theory cannot explain" "A better theory is" to help students frame and improve their ideas. In a similar vein, to facilitate reflective and constructive use of tools for community knowledge building, the teacher and the authors together designed a new set of scaffolding, using the following questions: (1) What information from the tool did you find useful and how will this information affect your knowledge building? (2) What is your idea improvement this week? (3) What is your individual plan to advance knowledge in class next time? (4) How will you contribute knowledge to the class community?

Underlying the design of these four scaffolding questions are the four knowledge-building principles described earlier. First, the principle of "community knowledge", which highlights the creation of community knowledge as the fundamental aim of knowledge building, is embedded in question 4. Second, the principle of "symmetric knowledge advances", which underscores the reciprocal relationship between community knowledge advancement and personal knowledge growth, is reflected in the two contrasting questions 3 and 4. Third, the principle of "epistemic agency", which emphasizes the importance of knowledge building process to be that participants set forth their ideas and negotiate a fit between personal ideas and ideas of others, is especially characterized by questions 2-4. Finally, the principle of "current and embedded assessment", which underlies the importance of viewing assessment as part of the effort to advance knowledge, is initially prompted by question 1 (self-awareness) and then strengthened by the other three questions (self-evaluation).

As a whole, the theoretical design of the four questions is also highly supported by the concept of promoting metacognitive reflection. To elaborate, Brown, Bransford, Ferrara, and Campione (1983) refer metacognition as having two separate and yet related parts, which are knowledge and regulation of one's own cognition. The first part, knowledge of cognition, can be defined as one's being cognitively aware of what he or she was not previously aware of. Question 1 was designed to prompt the first part of metacognition. The second part, regulation of cognition, can be defined as one's executive control of regulating (e.g. evaluating, monitoring, and planning) his or her own knowledge work. Questions 2 to 4 were designed to foster the second part of metacognitive evaluation. Together, the design of these four questions was to support a design concept of "performing, reflecting, and re-performing" (Collins, 1996, p.10) and was intended to help students develop a reflective habit of mind (Black & Wiliam, 1998; Zessoules & Gardner, 1991) for sustained knowledge work. Appendix C shows the protocol criteria pre-designed for evaluating students' reflective responses to the above four questions.

Data Source and Analysis. Data mainly came from knowledge-building discourse among students in the Knowledge Forum database. The study employed an explanatory mixed-methods design (Creswell, 2005), which consists of analyzing quantitative data and then analyzing qualitative data to help elaborate on the quantitative results (Figure 5).

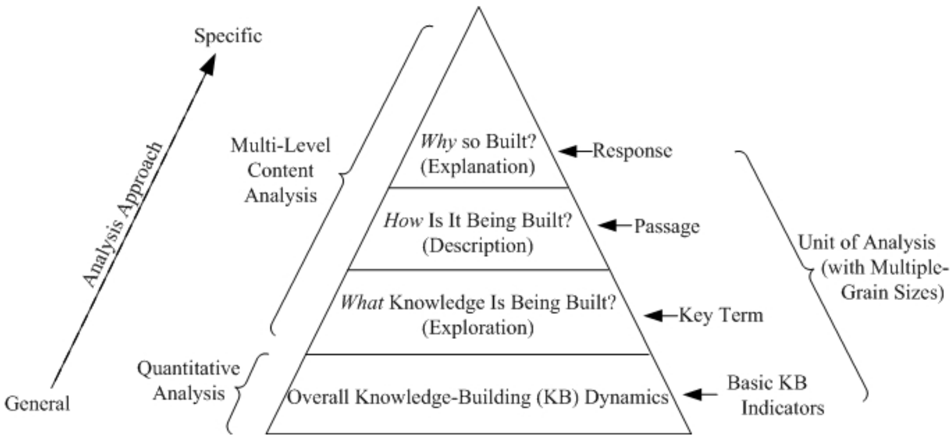

Figure 5. A mixed-methods design for analysis on knowledge-building dynamics

As Figure 5 shows, at a most general level, a quantitative analysis was employed to explore the overall knowledge-building dynamics recorded in the database by means of knowledge-building indicators pre-defined in the Analytic Toolkit software (Burtis, 2002).

At higher levels (see also Figure 5), a multi-level content analysis was then employed (Miles & Huberman, 1994, Chapters 5-6), to systematically address the questions of what knowledge is built (exploration), how it is built (description), and why it is so built (explanation) in a knowledge-building community. Previous studies in the field of computer supported collaborative learning using content analysis as method have revealed that a lack of coherence in terms of theoretical base and the choice for the unit of analysis (see de Wever, Schellens, Valcke, van Keer, in press, for a review). The purpose of using multi-level content analysis with multiple-grain sizes as unit of analysis is to increase the overall validity of analysis (Hogenraad, McKenzie & Peladeau, 2003).

To further elaborate, the first-order content analysis used key-terms extracted from students' *notes* as unit of analysis (Zolotkova & Teplovs, 2006) and was intended to explore what knowledge (as represented only by key terms) might be built in the community by means of knowledge representation. Key terms were automatically extracted and then compared by two researchers, both with science teaching background and extensive knowledge of the database content. The inter-rater agreement was 0.95, with differences resolved later by discussion.

As characterized by their power to represent important concepts or ideas, key terms have been widely used for subject-indexing (e.g., in books), for idea search (e.g., in academic papers or on Internet), and for knowledge representation (e.g., tag clouds, see Hassan-Montero & Herrero-Solana, 2006; semantic or propositional network, see Anderson, 2000; and knowledge or concept map, see O'Donnell, Dansereau, & Hall, 2002). Figure 6 exemplified how the key terms are used to represent content knowledge recorded in the database. In the left oval, the number of key terms (which is six) represents the breadth of key-term use in a student's (student A) personal knowledge space; and the frequency of appearance of these six key terms (which is nine times in total) represents the depth of key-term use by student A in his personal knowledge space. In the middle overlapped area, the number of key terms (which is four) represents the breadth of key-term use in the community knowledge space; and the frequency of appearance of these four key terms (which is 16 times in total) represents the depth of key-term use in the community knowledge space. In addition, in terms of how knowledge interacts between the personal and community knowledge spaces, student A' "knowledge contribution to the community" is represented by the percentage of his key terms contributed to the community knowledge space (four out of six, which is 66.7%). In contrast, "community contribution to individual member's personal knowledge" for student A is represented by the ratio of the frequency of key-term use in the community, over the frequency of key-term use by student A (16 times over 9 times, which is 1.78).

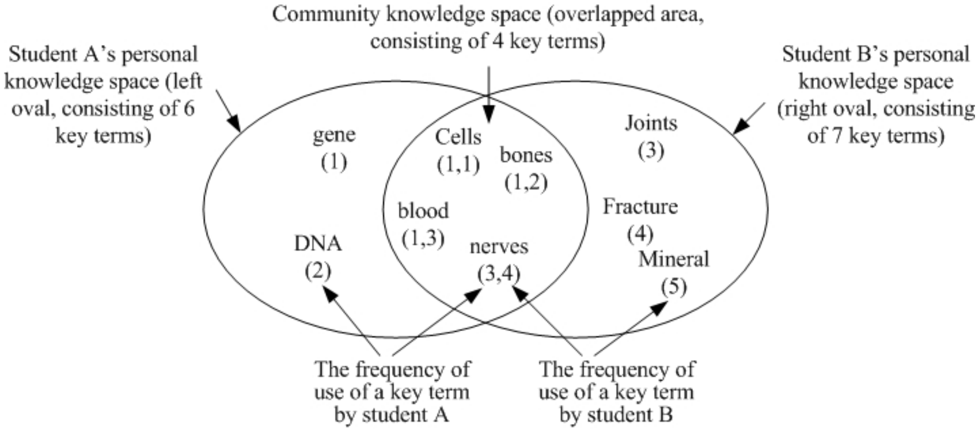

Figure 6. An example of using number of key terms
and frequency of key-term use to represent breadth and depth of knowledge

The second-order content analysis used passages parsed from students' *notes* as unit of analysis and focused on descriptive analysis of "how" knowledge is being worked on. For this analysis, an open-coding method of grounded theory (Strauss & Corbin, 1990, chapter 5) was adopted. Two researchers independently performed the coding procedure (inter-rater agreement=.84; differences resolved by discussion). Eight themes, emerged from the open coding, were then combined into three general parts of knowledge building process. Appendix B shows the number of passages coded in each category and related coding examples.

The third-order content analysis used students' whole responses to the scaffolding questions as unit of analysis and was intended to answer the question of "why" knowledge-building is pursued in a certain way. The evaluation criteria employed for analysis of each response were developed based on the method suggested by Rourke and Anderson (2004) which highlights the importance of developing a theoretically valid protocol (see Appendix C). In this particular analysis, Brown et el.'s (Brown, Bransford, Ferrara, & Campione, 1983) conceptual definition of metacognition served as this theoretical basis. Using the protocol, two researchers independently evaluated all responses and then put them into three pre-defined categories (yes, no, not applicable). Inter-rater agreement was calculated to be 0.91. Differences resolved also by discussion.

RESULTS

1. Overall Knowledge Building Dynamics

As a base line comparison, a t-test found that there was no significant difference between the two phases in terms of the total number of notes contributed (t=1.89, df=21, p>.05, with N=254, M=11.55, SD=4.39 in phase 1, and N=212, M=9.64, SD=3.92 in phase 2). In a more detailed manner (see Table 3), t-tests indicated that there were significantly more inquiry *problems* being generated and worked on in the first phase. Also, there were significantly more *notes* being *linked* and *built-on* in the first phase. On the contrary, there were more words (per-*note*) being generated by students in phase 2. Clearly, there were changes in the community's knowledge building dynamics between the two phases. It seems that the time and effort spent on using and reflecting with the tools have resulted in (1) less time being spent on *note-linking, building-on,* and *problem* generation, and (2) more time being spent on writing longer *notes*, in phase 2. This undoubtedly represented a sign of change, both in terms of the quantity and quality of knowledge building dynamics, from phase 1 to phase. The question is what is this change actually?

One possible explanation may be that there is a change from focus more on breadth of inquiry to focus more on depth of inquiry from phase 1 to phase 2. This is particularly indicated by a higher number of "problems worked on" in phase 1, suggesting much of the inquiry effort was spent in dealing with different issues and problems, and a higher number of words per note in phase 2, suggesting that students might be more reflective and elaborative in working on the same problems. However, without analyzing the actual content in the database, this explanation remains highly speculative.

Table 3. Overall knowledge building dynamics (N=22)

Basic Indicators	Phase 1	Phase 2	t values

	Mean	SD	Mean	SD	
Number of notes read	12%	7%	8%	4%	1.96
Number of *notes* edited	5.32	2.15	4.05	2.66	1.89
Percent of *notes* linked	25%	20%	10%	7%	3.33**
Percent of *notes* with keywords	13%	18%	6%	16%	1.98
Number of *problems* worked on	9.41	4.35	2.00	2.16	8.35***
Number of non *build-on notes*	7.32	2.50	6.64	3.30	0.82
Number of *build-on notes*	3.00	3.13	1.00	0.76	3.24**
Number of total words	574.77	227.20	699.82	300.26	-1.93
Number of words per *note*	51.03	17.73	72.61	15.83	-5.66***

** P<.01 *** P<.001

2. What Knowledge Was Being Built?

Community Knowledge. Table 4 shows a summary of results derived by comparing content knowledge (as represented by key-term use) between the two phases. As it shows, both the personal and community knowledge (as represented by frequency of key-term use) went deeper in phase 2. Judged by the principle of "community knowledge", the findings seem to suggest that the tool design had a positive impact on prompting students to pursue a depth-oriented knowledge building course. This finding basically confirms what was suggested in the "Overall Knowledge Building Dynamics."

Table 4. Knowledge representation between the two phases
as indicated by the number of key terms and the frequency of key-term use (N=22)

	Phase 1		Phase 2		
	M	SD	M	SD	t values
Personal Knowledge Representation					
Number of key terms (Breadth)	40.10	16.74	33.27	11.35	2.065
Frequency of key-term use (Depth)	78.41	38.74	100.14	40.11	-2.483*
Community Knowledge Representation					
Number of key terms (Breadth)	29.1	12.55	30.64	9.35	-0.617
Frequency of key-term use (Depth)	203.77	63.77	324.36	68.02	-7.686***

* p<.05 ***p<.001

Symmetric Knowledge Advances. To further explore how personal and community knowledge interact with and contribute to each other, additional two analyses were conducted. First, Pearson's correlation coefficients were applied to investigating how key terms were used between personal and community knowledge spaces. Table 5 summarizes all possible correlations. The high correlation coefficients ranging from 0.79 to 0.99 seemed to suggest a high degree of interaction between personal and community knowledge in both phases. The question is whether there is a difference between the two phases.

Table 5. Pearson's correlation coefficients between personal and community knowledge

	Personal Knowledge Representation			
	In Phase 1		In Phase 2	
	Number of key terms (Breadth)	Frequency of key-term use (Depth)	Number of key terms (Breadth)	Frequency of key-term use (Depth)
Community knowledge Representation				
In Phase 1				
Number of key terms (Breadth)	0.89***	0.88***	0.44*	0.42
Frequency of key-term use (Depth)	0.90***	0.79***	0.38	0.32
In Phase 2				
Number of key terms (Breadth)	0.48*	0.56**	0.99***	0.84***
Frequency of key-term use (Depth)	0.43*	0.53*	0.88***	0.81***

*p<.05 **P<.01 ***P<.001

To answer this question, another analysis of how individuals contribute their knowledge to the community and how community members in return help individuals deepen their knowledge were conducted. As shown in Table 6, there seemed to be a stronger knowledge interaction between personal and community knowledge in phase 2. Judged by the principle of "symmetric knowledge advances," the findings seemed to suggest that pursuing a higher goal of community knowledge not only benefited the community as a whole but also help members as knowledge contributors deepen their own personal knowledge.

Table 6. Comparison between the two phases in terms of symmetric knowledge advances (N=22)

	Phase 1		Phase 2		
Symmetric Knowledge Advances	M	SD	M	SD	t values
Personal contribution to the breadth of community knowledge	73.2%	12.5%	93.3%	6.0%	-6.207***
Community contribution to the depth of personal knowledge	2.97	1.05	3.68	1.41	-1.976*

* p<.10 ***p<.001

Admittedly, using key terms to represent knowledge has its limitations. One potential limitation may be related to its deficiency in capturing process-related community knowledge. Ryle (1949) argues that "know-that" and "know-how" are two essential kinds of knowledge. In various form, they are also referred to as declarative and procedural knowledge (Anderson, 2000). Corresponding to the concept of community knowledge, know-that may refer to the key ideas, concepts or problems collectively inquired in a community. Know-how may refer to the process knowledge that helps fulfill a deeper understanding of these ideas, concepts or problems. Arguably, as long as ideas or concepts are recorded in a community database, key terms are a reliable tool in capturing them and using them to assess the scope and depth of collective inquiry in a community via total number of key terms and frequency of their use. However, they may not be useful in assessing process-related community knowledge, e.g., how a certain key concept is actually pursued in depth over time. To supplement this deficiency, a second-order, and more in-depth, content analysis was conducted.

3. How Was Knowledge Being Built?

Epistemic Agency. This particular content analysis explored how students assume a higher level of responsibility in working with knowledge. As a baseline comparison, it was found there was no significant difference between the two phases in terms of students' overall knowledge building process, as indicated by the total number of passages coded (t=.662, df=21, P>.05; with M=13.55, SD=6.221 in phase 1, and M=111.64, SD=4.63 in phase 2). Supporting data from class observation basically confirmed that students were all very motivated and diligent in pursuit of knowledge work in both phases.

However, a further repeated measures analysis indicated that there is an overall significant difference between the two phases in terms the three detail parts of knowledge building process—self-initiated inquiry, self-directed improvement, and self-assessment (Wilk's $\lambda = 0.22$, F=22.51, p = .000, η^2=.78). Specifically, it was found that there were significant differences in self-initiated inquiry and in self-assessment. In terms of self-initiated inquiry, it was found that there were significantly more problems and hypotheses generated in phase 1 (F(1,21)=34.13, P=.000; M=13.55, η^2=.62) than in phase 2 (M=11.64). In terms of self-assessment, it was found that there were significantly more frequent assessment activities occurred in phase 2 (F(1,21)=17.60, p=.000; M=5.00, η^2=.46) than in phase 1 (M=1.232). One thing to note is that the tools can be used to analyze any activities occurred previously in the database. As a result, tool support has not only enabled students to reflect on their inquiry in phase 2 but also extended their capacity to reflect farther back on their inquiry in phase 1. The data have suggested that such reflection was apparently not possible without the tool support. For example, after using the Social Network Analysis tool, a student wrote the following in one of his notes, "I have figured out that in the old view people have read each others notes more times but I haven't connected with one person as many times as the new view."

Together, as the results suggested, the tool-use design seems to have changed the dynamics of knowledge building process in class from problem-generation (breadth of inquiry) to more self-assessment of advances with the problems generated (depth of inquiry). Table 7 shows the statistic results among the three detailed parts of knowledge-building process. These results basically corroborated what was found above about the increasing depth of community knowledge in phase 2. In fact, not only the students showed an increased capacity in self-reflection but the supporting interview data also showed that the teacher believed students' collective inquiry went progressively deeper. This evidence was further supported by the teacher's receiving an award, recognizing his "most creative use of technology to enhance teaching and learning in the classroom" in phase 2 (Messina & Peebles, 2007).

Table 7. Comparison between the two phases by using repeated measures regarding knowledge-building process (N=22)

Knowledge-building process	Phase 1		Phase 2		F	
	Mean	SD	Mean	SD	Values	Eta Square
Self-initiated inquiry	8.09	4.01	3.09	2.22	4.713***	0.62
Self-directed improvement	4.23	2.49	3.55	2.13	1.024	0.00
Self-assessment	1.23	1.66	5.00	3.10	-4.763***	0.46

***p<.001

4. Why Was Knowledge Built in a Certain Way?

Concurrent and Embedded Assessment. The third-order content analysis investigated the causal relationship between the changing nature of the knowledge-building dynamics in phase 2 and students' reflection with tool-use by analyzing students' reflective responses to the four scaffolding questions. Overall, the total number of reflection as recorded in students' *notes* was 143 times (M=6.5; SD=2.81). Supporting data from class observation of tool use, however, indicated that students did not always record their thoughts after using the tools. The analyses here were based only on the recorded data. Table 8 shows the descriptive statistics, with supporting examples, using a pre-determined protocol (Appendix C) as evaluative criteria.

First, it was found 92.3% of responses clearly demonstrated students' awareness that tools have made possible of useful feedbacks to them. For example, students mentioned that they (1) became aware of the level of their use of advanced vocabulary (Example 1), (2) became aware of whom they usually collaborate with and how often (Example 2), and (3) became aware of how the key terms used in their *notes* overlapped with those of others' and those covered (or not covered) by the curriculum guideline (Examples 3-4). Together, the data showed that there was a strong sense of community awareness that was made possible especially by use of the Social Network Analysis Tool and the Semantic Analysis Tool (Examples 2-3). Second, it was found 90.7% of responses clearly demonstrated that students were able to constructively evaluate their knowledge work for further idea improvement (Example 5). Moreover, some of these responses even demonstrated that students were able to monitor other students' knowledge progress by contrasting each other's ideas (Example 6). Third, it was found 98.3% of responses clearly demonstrated that students were able to lay out feasible plans and carried them out subsequently to advance their personal knowledge relevant to their inquiry topic of long jump (Examples 7-9). Finally, it was found that 96.6% of responses clearly demonstrated that students were able to lay out feasible plans and carry them out for the purpose of advancing community knowledge (Examples 10-11).

Together, the results seem to suggest an effective implementation of the knowledge-building principle—concurrent and embedded assessment—in phase 2. As an illustration, a student's *rise-above note* that summarized the process of his idea improvement along the course of knowledge building was presented below to show how concurrent assessment was embedded within students' knowledge work:

> "My original theory wasn't very successful. For my normal jump [as compared with the experimental jump] I got 2.20 m and for when I used running in the air my results were 1.48 m. So don't run in the air... but it might only be for me so you could try it…so I am going to try something the opposite of that. I am going to try not moving in the air. Also I am going to keep my legs tucked in too (but at the end stick them out so I will go higher. I think that is going to work because I will go high and you want to go high because then you won't touch the ground sooner."

The findings in this section are in agreement with the findings already described above. Namely, the tool-use design was effective in fostering more reflective and deeper inquiry in the community.

Table 8. Percentage of reflective responses demonstrating effective reflection with tool use for knowledge-building (N=146)

Category	Supporting Examples
Awareness (26, 92.3%)*	1) The vocabulary [tool]…is good because you can see what you have typed that is advanced and misspelled! 2) I really like the network tool. i really enjoy finding out who i have connected with or talked to and who i should talk to more, to find out their theories. 3) …the [Semantic] tool can be helpful if you what to know how many words that you and some one else shared. 4) What I learned from the [Semantic] tool is that I have written some really sophisticated words but the curriculum doesn't have it.
Evaluating/ Monitoring (43, 90.7%)	5) I figured out that putting your legs forward and swinging your body over your legs help a lot. 6) My idea for improvement early this week was: PUSH KNEES TO 45 DEGREE ANGLE. I tested it out and it really didn't work, although with M.C., who's long jump I have studied many times, it worked perfectly.
Planning on enhancing personal knowledge (39, 98.35%)	7) I am going to get more interested other people's theory. 8) [S]ince my [previous] idea worked i will swing my arms up next time and tuck [myself] into a ball in the air. 9) My new plans are to try to get more height. And when i did my jump i will try to keep my legs together for the whole jump. Cause on my jump i put my legs together for just the end. And not the whole jump so i don't know if it is better or not.
Planning on contributing to community knowledge (30, 96.6%)	10) My plan to give knowledge to the class is first i'm going to look at my data from my third jump. Then i'm going to write about it in Knowledge Form so peolpe won't have to try it again because I tried it. 11) I will share this information by showing how far i got when i swung my arms up and then i will show how far i got when i tucked into a ball and swung my arms.

*Note: The number and percentage in the parentheses ( ) refer respectively to "the total number of reflective response in a given reflection category" and "percentage of responses demonstrating effective reflection with tool use for knowledge-building" as evaluated by the pre-determined protocol (Appendix C). Of all reflective responses, five of them were excluded from analysis as they were categorized as "Not Applicable."

CONCLUSION

Based on the findings, the following conclusions are obtained. First, principle-based tool-use design can be extremely helpful in fostering more reflective use of technology for building community knowledge. Second, not all kinds of reflection will lead to community knowledge advancement. To support knowledge building, technology will need to be designed not only to foster reflection as an individual act, but designed to be able to extend individual reflection to a higher level where one can even reflect on other members' ideas and help improve them accordingly for the benefit of community. Thirdly, technology can be used just as assessment tools or used more effectively as knowledge-building tools. Clearly, technology designed as assessment tools can only be useful in helping individual students or teachers evaluate knowledge that an individual learner possessed. But if a community is to pursue a higher goal of sustained knowledge advancement, technology must be transformed into knowledge-building tools for a higher level use.

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Appendix A. Key terms contributed in each phase and their frequency of use

Key terms and their frequency of use
Phase 1: adult (1), alcohol (5), allergic (7), allergy (3), animal (4), ankle (3), antibodies (14), aorta (2), arm (8), armpit (1), arteries (4), arthritis (6), atrium (1), Avian flu (1), axis (1), babies (2), baby (5), bacteria (3), ball (2), ball and socket joint (2), B-cell (5), bend (1), benign tumor (1), beta cell (1), bird (2), birth (2), bleed (1), blood (54), blood cell (25), blood circulation (1), blood stream (1), blood sugar (11), blood transfusion (2), blood vessel (6), bodies (2), body (50), bone (74), booger (2), brain (49), brain imaging (3), brain tissue (1), brain tumor (3), break (6), break down (3), breast bone (1), breath (10), breathe (5), brittle (2), Broca's area (1), broke (3), brother (1), bruise (7), bug (1), calcium (4), cancer (2), canine (1), carbohydrate (2), carbon dioxide (12), cartilage (6), cast (2), cat (1), cell (54), central control (1), chalk dust (1), chamber (3), chimpanzee (1), chromosome (4), circulate (1), clog (2), cloning (2), cold (6), collar (1), collar bone (9), coma (1), compact bone (1), conjoined twins (1), connection (2), contagious (1), contagious disease (2), cool down (1), cord (2), core of red marrow (5), cough (2), crack (2), crash (1), crush (2), current (3), cut (11), DNA (6), damage (2), damaged cell (1), dangerous (1), death (1), defense (3), diabetes (8), dial (1), diaphragm (2), die (9), digest (7), digestive system (1), disabilities (1), disease (23), dislocate (1), disorders (3), division (1), dizziness (1), dizzy (1), doctor (3), dog (1), down syndrome (9), dream (3), drink (9), dust (1), ear (7), ear bone (1), ear wax (1), eat (5), Egypt (1), elbow (1), electric (1), electrical signal (1), ellipsoidal (2), ellipsoidal joint (1), embryo (4), embryonic stem cell (3), enemy (1), energy (2), enzymes (1), erythrocytes (2), evolve (2), exercise (2), facial (3), faint (1), fat (4), fatigue (1), fats (1), feather (1), feel (21), fetus (1), fever (2), fibula (1), fight (2), fight disease (2), filter (1), flat bone (2), floppy (1), flow (3), flow of blood (1), fluid (4), food (15), foot (5), foreign particle (1), formulation (1), fracture (11), frontal lobe (1), gas (1), gastric juice (1), gene (5), genetic (2), genetic code (1), germ (17), gland (1), glucagon (2), glucose (1), glycogen (1), gold (1), gorilla (1), grandparent (1), gravitation (1), grow (11), growl (2), hair (3), hammer (1), hand (3), head (11), headache (3), heal (7), hear (24), hearing loss (1), heart (19), heat (1), hemoglobin (4), hereditary (3), hinge (1), hinge joint (3), homing device (1), honeycomb (1), hormone (8), hot (3), human (15), humorous (1), hungry (5), ice (2), illness (5), immune system (11), immunity (1), infection (1), inject (2), injure (1), injury (2), insulin (10), intestine (6), invader (1), irregular bone (1), itch (1), jaw (1), joint (19), juice (1), jump (1), kidney bean (1), kill (2), kiss (4), knee (8), knee cap (1), knuckle (4), language area (1), learn (4), leg (10), life threatening (1), ligament (1), liquid (4), lisp (3), live (18), liver (13), liver disease (6), living tissue (1), long bone (4), lower neck (1), lump (2), lung (6), lymph (23), lymph gland (2), lymph node (8), lymphatic system (2), lymphocyte (4), lysosome (10), macrophage (15), malignant tumor (1), marrow (5), medicine (3), membrane (2), memories (2), memory task (2), men (5), message (10), milk (2), mind (2), mineral (2), mitochondria (2), molar (1), monkey (4), mononucleosis (3), mosquito bite (1), mother (1), motor strip (1), mouth (7), mucous (1), mucus (1), multiply (1), muscle (8), neck (3), needle (1), nerve (37), neuron (1), neutron (2), Nile (1), non-disjunction (1), nose (4), nucleus (10), numb (3), number (2), nut (3), nutrient (2), old age (1), orangutan (1), organ (5), oval cup (1), overweight (1), oxygen (12), pain (7), pancreas (6), paralysis (1), paralyze (2), parent (6), passage (1), patella (1), pathogen (5), people (14), periosteum (2), pesticide (1), petechiae (1), phagocyte (3), pine (1), pivot (2), pivot join (1), plane joint (2), plant (1), platelet (1), pollen (1), power (3), predator (1), pregnancy (1), pulmonary (1), pump (9), purpura (1), radius (1), rat (4), reaction time (1), recognition (1), red marrow (8), refill (1), reflex (7), regional blood flow (1), remember (5), reproduce (2), reproducing (1), rib (5), root (1), rub (2), saddle joint (1), saliva (2), salt (2), scientist (2), scull (1), see (8), sense (8), separate (1), separation (1), shinbone (1), ship (1), short bone (1), short term (1), shorten (1), shoulder (5), Siamese (3), sick (7), side affect (1), signal (14), sister (1), skeletal system (1), skeleton (1), skin (13), skull (3), sleep (2), sliding (1), small intestine (3), smell (1), sneeze (3), sneezing (1), socket joint (1), sooth (1), speed (3), spinal cord (1), spine (5), split (1), spongy bone (3), spread (5), steel (2), sternum (1), stomach (16), straight (1), strength (2), stress (11), sugar (1), sun flower (1), sunscreen (1), sweat (7), swollen (9), Sylvian fissure (1), taste (1), T-cell (3), teeth (5), temperature (1), tendon (1), thigh bone (1), throw up (1), thumb (1), thymus (1), tickle (1), tired (6), tissue (1), toe (2), tongue (2), touch (4), transmit (1), triplet (2), trunk (1), tube (1), tumor (8),

twin (5), ulna (1), uncontrolled (1), universal joint (1), upright (3), vein (6), ventricle (1), villi (4), viral (1), virus (22), voluntary action (1), vomit (1), walk (5), wall (1), waste (1), water (17), weak (3), weight (4), Wernicke's area (1), white cell (2), wind (1), woman (1), womb (2), women (5), working memory (1).

Phase 2: act (2), acute angle (13), air (31), analyze (5), angle (25), arm (61), athlete (1), attachment (4), average (1), backward (10), backwards (9), ball (14), bend (9), body (13), centimeter (20), chain (3), circle (7), cold (1), come down (2), connect (16), control (2), control jump (5), controlled jump (3), crouch (6), curl (2), cycle (9), degree (20), diagonal (6), direction (3), distance (12), experiment (17), fall (3), far (87), farther (61), fast (17), fault (1), feet (17), flow (5), foot (11), form (9), forward (36), forwards (3), friction (1), function (2), further (21), go down (3), goal (2), ground (14), gymnastics (1), head (4), height (16), high (42), higher (23), highest (4), hip (6), hot (1), human body (13), improve (46), improvement (16), improving (6), information (23), invention (1), joints (3), jump (352), jumper (6), kinetic energy (1), knee (23), land (24), lean (3), lean forward (4), leap (4), left (2), leg (77), length (9), life (1), line (13), linear (1), live (1), long (141), long jump (8), longer (10), longest (4), low (7), math (1), maximum (1), maximum height (1), measure (11), measuring (6), meter (17), mid air (7), momentum (5), move (11), movement (2), movies (2), moving (4), muscle (1), natural (1), need (29), normal jump (9), observation (2), obtuse angle (3), Olympics (1), opposite (2), order (3), pass (2), pattern (1), plan (15), position (4), power (6), practice (3), pressure (1), process (5), professional (1), progress (1), pull (2), pump (2), push (9), ramp (1), reach (6), record (1), recycle (1), recycling (3), regular jump (2), relay (1), result (18), run (43), seconds (21), see (39), shift (4), short (5), shorter (5), shoulder (5), sit (2), slow (2), sophisticated (2), source (5), speed (11), spin (1), split (1), sport (1), sprawl (1), start line (3), starting (1), starting line (4), statistics (3), step (7), stop (2), straight (2), strategy (4), stretch (2), stride (20), swing (37), swung (6), system (115), take off (9), tall (1), technique (11), technology (4), test (9), theory jump (3), throw (10), thrust (1), time (57), travel (4), traveling (2), trunk (1), try out (1), tuck (16), vary (1), video (15), water (9), wave (2), waved (1), waving (3), weight (5), wind (5).

Note: (1) Terms are listed by alphabetical order; the number inside the parentheses ( ) is the frequency of use of each key term; (2) The focus of analysis in phase 2 was on key terms related to physical, (as well as spatial, mathematic, and measurement) concept. Therefore, many other key terms found related to the previously inquired topics such as internal human body system (as resulted from discourse continued from phase 1) and government system and electricity system (as resulted from discourse continued from previous semesters) were not included here.

Appendix B: Coding schemes for knowledge-building process and examples

Main categories	Themes (and number of passages)	Examples
Self-initiated inquiry	Question-generating (89)	How do cells move? I know that it move through the flow of blood but how does it turn when the blood is not turning? Do cells have some sort of way to steer their way through the blood?
	Hypothesizing/ theorizing (134)	My theory is putting our legs together helps because with your leg you can stretch further and you will have a better jump because when you are at the end you will put your leg at a better jump position with your legs together.
Self-directed improvement	Finding references/solutions/ answers (91)	In the reading my group did we found out that a lymph node is really the size of a single kidney bean. We also found out that you can feel [it] in your lower neck.
	Experimenting or providing/gathering evidence (29)	My evidence: We watched a video that explained that the skin was the first line of defense against viruses by not letting them in. Viruses can get in through your mouth, nose, an open cut on your skin, your eyes, and by a mosquito bite.
	Planning/monitoring learning process (73)	My plan is going to reflect on what my data turns out to be. If my technique worked I'll try to long jump like that next time, if not I won't ever do that again.
Self-assessment	Reflecting on what I have learned (56)	I learned that the pancreas is on the spine. And it help you digest fat, proteins & carbohydrates. The pancreas is behind the stomch. Also the pancreas sends hormones and lucagons. The lucagons breakdown glycogen.
	Reflecting on what I do not know or still need to know (30)	I want to know if your cells are so well protected by your cell membrane deciding whether or not to let things in how do diseases get through to infect your cells?
	Reflecting on how to know better (44)	I learnt that I have connected to fewer people, in the human body database then the previous one. Maybe I should write a few more notes or build on to a few more people instead of just writing notes.

Appendix C. Protocol criteria for evaluating students' reflective responses to the four scaffolding questions after tool use

Reflective practice	Evaluation Criteria
Awareness (Q1)	Check 'Yes', if a response demonstrates awareness of useful feedbacks made possible by any of the three tools (i.e. Vocabulary Analyzer, Social Network Analysis tool, and Semantic tool). Check 'No', if none of any awareness of useful feedbacks from the tools is mentioned in a response. Check 'N/A' if none of above applies.
Evaluating/ Monitoring (Q2)	Check 'Yes', if a response demonstrates that a student was able to constructively evaluate his or her knowledge work for further improvement. Check 'No', if no evidence of any idea improvement of long jump is mentioned in the response. Check 'N/A' if none of above applies.
Planning for advancing personal knowledge (Q3)	Check 'Yes' if a response shows that a feasible plan is laid out and subsequently carried out to advance one's personal knowledge relevant to the topic of inquiry, i.e., long jump, (by comparing with one's subsequent implementation as reflected in the supporting data from video recordings of individual long jump activities and from notes written in the database). Check 'No', if a response shows that no plan is laid out, that a plan is laid out but is not workable, or that a plan is workable but is not carried out accordingly. Check 'N/A' if none of above applies.
Planning for advancing community knowledge (Q4)	Check 'yes', if a response shows that a student does lay out a feasible plan and carry it out for the purpose of community knowledge advancement (by comparing with his or her own actual implementation as recorded later on in the database). Check 'No', if a response shows that no plan is laid out, that a plan is laid out but is not workable, or that a plan is workable but is not carried out accordingly. Check 'N/A' if none of above applies.