Understanding the Connection Between Cognitive Tool Use and Cognitive Processes as used by Sixth Graders in a Problem-Based Hypermedia Learning Environment

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Abstract

The purpose of this study was to examine the connection between sixth graders' cognitive tool use and the cognitive processes they engage in as they solve a complex problem in a hypermedia learning environment. The three research questions were: (1) Which cognitive tools are used for which cognitive processes?, (2) Is there a relationship between the extent of students' engagement in cognitive processing and their cognitive tool use?, and (3) Are there any differences in cognitive tool use and performance scores between students who are engaged in different patterns of cognitive processing? The findings showed that different cognitive tools were used for different cognitive processes, and the degree of engagement in cognitive processing was positively related to the frequency of tool use. These results indicate that there is a connection between cognitive tool use and cognitive processing. In addition, tool use patterns reflected different characteristics of the learners (information processing versus metacognition oriented). Students who were more metacognitively oriented were more consistent in their tool selection, while students who were more information processing oriented were more action oriented in performing the tasks. However, there was no difference in the diversity of tool use or the performance scores between the two groups of students.

(Keywords: cognitive tools, cognitive processes, tool use pattern, hypermedia technology, problem-solving)

Preparing students to be good problem-solvers, critical thinkers, and lifelong learners has become a critically important educational goal in this twenty-first century (Bransford, Brown, & Cocking, 2000). Much effort has been put into creating technology-enhanced, student-centered learning environments to help students develop higher-order thinking skills (Land & Hannafin, 2000). Because student-centered environments are typically problem-based, open-ended, and complex, different forms of scaffolding are needed for students and teachers to succeed in such environments. One form of support involves the use of technology as cognitive tools. We are interested in examining the use of cognitive tools by students as they are engaged in solving a complex problem in a hypermedia learning environment. Our previous research investigated students' tool use patterns (Liu & Bera, 2004). The present study continues our inquiry by examining the connection between students' tool use and the cognitive activities they engage in. Our intention was to find out how technology tools can be used as a form of scaffolding to assist students in their problem-solving.

Research Framework

Cognitive Tools as a Form of Scaffolding

Cognitive tools are instruments that can enhance the cognitive powers of learners during their thinking, problem-solving, and learning (Jonassen & Reeves, 1996; Pea, 1985; Salomon, Perkins, & Globerson, 1991). Jonassen (1996) defined cognitive tools as "computer-based tools and learning environments that have been adapted or developed to function as intellectual partners with the learner in order to engage and facilitate critical thinking and higher-order learning" (p. 9). According to Kozma (1987), cognitive tools should be of particular use in assisting learners in accomplishing complex cognitive tasks. Lajoie (1993) identified four types of cognitive tools according to the functions they serve. These included tools that: (a) support cognitive and metacognitive processes, (b) share cognitive load by providing support for lower level cognitive skills so that resources are left for higher order thinking skills, (c) allow learners to engage in cognitive activities that would be out of their reach otherwise, and (d) allow learners to generate and test hypotheses in the context of problem-solving.

Harper, Hedberg, Corderoy, and Wright (2000) described cognitive tools included in a multimedia program, Exploring the Nardoo. In this program, high school students were provided with such tools as a personal digital assistant, nine genre templates, and three simulators for problem-solving, communicating, and preparing multimedia reports while studying ecology. They believed that cognitive tools in the form of simulations could provide learners with the opportunity to explore and test ideas without risks. Corderoy, Harper, and Hedberg (2003) examined the effect of the three built-in simulators in Exploring the Nardoo on learning outcomes. They found that although using the simulators resulted in significantly improved acquisition of factual knowledge for both the control and experimental groups, the experimental group that had access to the built-in simulations showed a significantly greater increase in factual knowledge scores than the control group. Results also suggested that the simulations facilitated a deeper understanding of the processes and relationships between causal factors for the students in the experimental group. The authors concluded that these cognitive tools had the potential to provide learners with a greatly enriched learning experience by facilitating the review of their existing knowledge and construction of new knowledge.

Lajoie (1993) described research using Bio-World, a program that supports scientific reasoning about diseases. In Bio-World, the argumentation process is enhanced by tools that allow students to form diagnostic hypotheses and collect evidence to confirm or disconfirm their diagnoses. Results from a pilot study showed that there was a significant difference in confidence ratings between the first and the last diagnosis that high school students entered. Students' confidence level in their diagnoses increased as they used the program.

Building cognitive tools into an environment, however, does not ensure that learners will use them when they are needed and in the way they are intended to be used. Oliver and Hannafin (2000) investigated middle school students' use of cognitive tools to help them collect, organize, annotate, and evaluate complex information during a scientific inquiry. They proposed that using these tools to manipulate hypermedia resources in a manner consistent with higher-order thinking (e.g., organizing, integrating, evaluating) would help students solve complex, open-ended problems. However, results revealed that the tools mostly supported lower-level information gathering and thinking rather than facilitating higher-order reasoning for which they were designed. The students failed to use the tools to their full potential. Their study suggests that tools may not be effective at providing guidance if the students are not aware of when and how they should use them. More research is needed to examine the connection between tool use and the cognitive activities students engage in and to investigate what tools are used for what processes.

Cognitive Tools to Assist Problem-Solving

One important benefit of using cognitive tools is that they can assist students in developing problem-solving skills (Jonassen & Reeves, 1996; Pea, 1985; Salomon, Perkins, & Globerson, 1991). Problem-solving is cognitive processing aimed at accomplishing certain goals when the solution is unknown (Mayer & Wittrock, 1996). It involves different cognitive processes. A revised version of Bloom's taxonomy defined six categories of cognitive processes: remembering, understanding, applying, analyzing, evaluating, and creating (Anderson et al., 2001). Bransford and Stein (1984) identified five components of an IDEAL problem-solver: the ability to identify the problem, define the problem, explore possible strategies, act on these strategies, and look at the effects.

According to Jonassen (2000), the ability to solve problems "is a function of the nature of the problem, the way that the problem is represented to the solver, and a host of individual differences that mediate the process" (p. 69). Problem representation is key to successful problem-solving. In studying how computers can assist problem-solving, Tennyson and Breuer (2002) suggested using computer-based complex-dynamic simulations to improve problem-solving. Jonassen (2003) suggested, "What makes experienced problem-solvers more effective is their richer, more coherent, and interconnected representations of problems" (p. 365). He suggested using cognitive tools for externalizing problems. According to Zhang and Norman's theory of distributed representations (1994), performing a cognitive task distributed representations across the internal mind and the external environment. External representations are not simply inputs and stimuli to the internal mind, but indispensable to the representational system of any distributed cognitive task (Zhang, 1997). In examining students' tool use patterns in a hypermedia environment in which cognitive tools were provided as a form of external representations, Liu and Bera (2004) found some empirical evidence to support this notion that external representations can guide, constrain, and determine certain cognitive behaviors. The findings showed that cognitive tools assisted the students in performing complex open-ended problem-solving tasks more like experts.

Purpose of This Study

The purpose of our research was to investigate whether cognitive tools can scaffold learners' problem-solving processes; and if so, in what way? The context for our investigation was Alien Rescue, a hypermedia problem-based learning (PBL) environment in astronomy for sixth graders. Alien Rescue engages sixth grade students in scientific investigations aimed at finding solutions to complex and meaningful problems. To assist the students, 13 cognitive tools are provided to scaffold their problem-solving. In a previous study (Liu & Bera, 2004), we used students' log data to examine their tool use patterns while navigating the environment to see which tools were used and at what stages of the problem-solving process. The results showed that the use of different types of tools was associated with different stages of problem-solving, and the students increasingly used multiple tools in the later stages of their problem-solving process. The findings indicated that tools performing different functions enabled students to coordinate multiple cognitive skills and, therefore, facilitated their information processing.

Although the log data provided an objective and unobtrusive way to examine students' actual use of tools, we can only infer about the thinking processes students engaged in while selecting the tools. To be able to solve a problem successfully, one not only needs adequate domain knowledge, but also an understanding of when and how to use the knowledge (Mayer, 1998). Research is needed to investigate more explicitly the connection between students' tool use and their cognitive processes. The present study was, therefore, guided by the following three research questions:

1. Which cognitive tools are used for which cognitive processes?
2. Is there a relationship between the extent of engagement in cognitive processing by the students and their cognitive tool use?
3. Are there any differences in cognitive tool use and performance scores between students who are engaged in different patterns of cognitive processing?

Method

Sample

Participants were 161 sixth graders from two middle schools in a mid-sized southwestern city. These students were from the same school district and shared similar demographics: About 15% were Hispanic, 6% were African-American, 73% were Caucasian, and 5% were from other ethnic backgrounds. The teachers reported that most students were comfortable with computers and had used computer programs such as games and word processing programs prior to this study. Three sixth grade science teachers were involved in this study.

The Learning Environment: Alien Rescue

As in our previous study, Alien Rescue, a CD-based hypermedia PBL environment for sixth graders, was used. The design of this program was guided by current theories and research on PBL (Liu, Williams, & Pedersen, 2002). Alien Rescue begins with a video scenario describing a complex problem for students to solve: Six species of aliens, different in their characteristics, have arrived in Earth's orbit due to the explosion of their home planets. The aliens need new homes within our solar system that can support their life forms. The students, acting as scientists, are asked to determine the most suitable relocation site for each alien species. Depending on the unique characteristics of each alien species and properties of each planet, some relocation sites are more appropriate, and some have obvious drawbacks. The program was intentionally developed in such a way that there is more than one good choice for each alien species. Students must provide reasons for their choices. The assessment of students' solutions is determined both by the appropriateness of the choices and the rationales to justify them. Such a design consideration departs from other educational programs in which there is only one correct answer to a problem and encourages sixth graders to actively interact with their peers and the tools provided in the program. In Alien Rescue, learning is driven by students' efforts to develop a solution. To solve the central problem, students must engage in a variety of problem-solving activities. They need to research the aliens' needs as well as the planets and moons in our solar system to find possible homes. Students must also engage in planning and decision-making as they determine how to use the resources of the solar system effectively.

Thirteen cognitive tools are provided in the program to scaffold students' problem-solving. These tools can be classified into Lajoie's (1993) four conceptual categories as tools that (a) support cognitive processes, (b) share cognitive load, (c) support cognitive activities that would be out of reach otherwise, and (d) allow hypothesis generation and testing. Table 1 provides a description of each tool under each category.

------Insert Table 1 here------

The four databases provided in Alien Rescue are examples of tools that *share cognitive load*. These are carefully constructed and well-organized knowledge databases enhanced through graphics, animations, and 3-D videos. If a student wants to know what a species looks like, where it lives, the atmosphere or gravity on a planet, or about past NASA missions, he or she can find such information in the alien database, solar database, or mission database. If a student comes across a scientific concept that he or she is unfamiliar with, it can be looked up in the concepts database, where various science topics are visually illustrated. Such tools help reduce the memory burden for the students and put the multimedia-enriched information at their fingertips.

The expert modeling tool is an example of a tool that *supports cognitive processes*. The expert, presented in video format, is available at four critical areas within the program to model his thinking process in solving the central problem. The probe builder and launcher rooms are two tools that *support cognitive activities that would be out of reach otherwise*. They allow students to equip probes with various scientific instruments, such as mass spectrometers, thermometers, and infrared cameras. Each of these instruments can provide the students valuable information about the worlds in which they are interested. The launcher room allows the students to launch their probes to an intended planet or moon. Finally, the control room and solution form are examples of tools that *allow hypothesis testing*. In the control room, students study the data coming back from probes to test their hypotheses and then write up their solutions using the solution form.

Using the tools in categories A and B, students locate helpful resources, search and research existing knowledge databases, select relevant information, and make effective comparisons and decisions. With the tools in categories C and D, students collect new data, interpret and organize data, build the rationales for their decisions and present their solution plans. Although students have access to all the tools and information needed to develop a solution plan, the program is structured in such a way as not to suggest solutions. Students are encouraged to explore the environment and select appropriate tools as they determine for themselves the information they need and the process they will use to develop a solution plan. Screen shots of some tools are provided in Figure 1.

------Insert Figure 1 here------

Cognitive Processes Needed for Problem-Solving With Alien Rescue

To understand the cognitive activities the sixth graders engaged in and which tools they used to assist them in performing these cognitive tasks, a task analysis was conducted. Three advanced doctoral students attempted to solve the problem in Alien Rescue as sixth graders do. Two of them majored in human cognition and were instructors of an undergraduate course teaching learning strategies; one was an advanced doctoral student majoring in instructional technology. Compared to sixth graders, these doctoral students should have possessed better problem-solving skills and been more aware of when and how they used strategies. Each of the three students recorded her thinking processes and the steps taken to solve the problem while using Alien Rescue. The processes these doctoral students used were then compiled. A list of similar processes used by all three students was identified. From this list, the twenty most representative processes (those listed with the highest frequency) were selected for inclusion in a *Cognitive Task Questionnaire*.

These 20 items represented the key cognitive activities one would most likely undertake in problem-solving with Alien Rescue. For example, one item states, "When using Alien Rescue, I first thought about the problem I needed to solve and figured out what I needed to do." Another item states, "When designing probes, I first decided what I wanted to find out and then chose instruments that would help me get that information." These 20 items address all six (and especially the last five) types of cognitive processes as indicated in the revised version of Bloom's taxonomy (Anderson et al., 2001) and the five components of an IDEAL problem-solver (Bransford & Stein, 1984). The items were classified into four conceptual categories of cognitive processing by a panel of two experts in human cognition who were familiar with problem-solving in Alien Rescue. The four conceptual categories of cognitive processes, detailed in Table 2, included: (a) understanding the problem, (b) identifying, gathering, and organizing information, (c) integrating information, and (d) evaluating the process and outcome. Each category builds upon each other in that one must first understand the problem before they can identify important information; and they must identify important information before they can integrate that information. A successful problem-solver will employ all processes in these categories when solving a problem, and will need to have the knowledge of a variety of strategies and how to use each strategy. Furthermore, they will apply these strategies and learn from the results of each application. Our categories of cognitive processes are consistent with Bloom's taxonomy and the IDEAL model.

------Insert Table 2 here------

Instruments

Cognitive Task Questionnaire. A *Cognitive Task Questionnaire* was created based upon the 20 key cognitive processes identified as discussed above. The wording and format of the questionnaire were reviewed by the classroom teachers for clarity and appropriateness, and revised accordingly. The degree of psychological engagement in various cognitive processes varies from student to student. Therefore, for each of the 20 activities in the questionnaire, students first were asked to rate, using a Likert scale, the extent to which they engaged in each cognitive process, with 1 representing "not at all" and 5 representing "all the time." The higher the number, the more involved the student indicated she was in a particular cognitive process. To understand the connection between the extent students are involved in the cognitive processes and the use of cognitive tools for each of the 20 statements, students then were asked to indicate which of the 13 tools they used while performing that cognitive activity. They were asked to mark all the tools they used for each activity (see Appendix for the formatting of the questionnaire).

Science knowledge test. A 25-item, multiple-choice test (r=.73) was used to measure students' understanding of the science concepts introduced in Alien Rescue. This test was based on a version developed in a pilot study (Williams, 1999) and was revised numerous times according to teachers' suggestions and pilot testing results. It had been used in previous studies using similar samples (Bera & Liu, in press; Liu, 2004). We compared students' performance by different groups as well as from pre to post. Since no direct teaching was involved in this study (see *Procedure* for more information), a gain in the performance score on the posttest would indicate that the student acquired a good understanding of these scientific concepts through her own self-directed learning, classroom discussions, and/or the peer interaction that occurred while using Alien Rescue.

Procedure

Students used Alien Rescue daily for three weeks in their 45-minute science classes. Each student had his or her own computer for use. All three teachers participated in a training workshop before implementing Alien Rescue. During the workshop, the philosophy and attributes of student-centered learning environments were discussed in depth. In particular, the role of the teacher as a facilitator was highlighted. These teachers were selected for participation in this study because classroom observations indicated that their teaching practices were consistent with the pedagogy encouraged by Alien Rescue (e.g., that the teacher's primary role is that of a facilitator). No direct teaching (e.g., telling students what to do without encouraging thinking, giving answers whenever students raise a question, teaching directly to the performance measures) was noted in these classrooms. Instead, these teachers encouraged the sixth graders to be independent, help each other, and pursue their own learning. Each teacher had her own way of facilitating Alien Rescue. One relied heavily on mini-classroom discussions at the beginning and end of each class session, while another focused mainly on individual interactions with the students. Both of these science teachers had used Alien Rescue in the past few years and were experienced in using the program. The third teacher had not used the program previously. She followed the example of an experienced teacher and used class discussions to facilitate.

The science knowledge test was given before and after the completion of Alien Rescue. Students completed the *Cognitive Task Questionnaire* right after they finished the program.

Results

Tool Use and Cognitive Processes

To answer our first research question, *Which cognitive tools are used for which cognitive processes?*, we examined the association between four categories of cognitive tool use and four categories of cognitive processes. Chi Square analysis was performed between the frequencies of cognitive tool use and cognitive processes to understand which tools were used for which processes.

The Chi Square analysis showed a statistically significant association between the four categories of tools and the four categories of cognitive processes: $X^2 = 517.67$, df=9, $p < .01$ (see Table 3). Inspection of the observed minus expected values in the table indicates that three sets of relationships most likely contributed to this significant result:

1. Stronger associations between the category "tools that support cognitive load" and all four cognitive process categories. Students reported higher than expected frequency of tool use in this tool category for the following cognitive processes: “understanding the problem,” “integrating information,” and “evaluating the process and outcome.” Students reported lower than expected frequency of tool use in this tool category for the cognitive process of “identifying, gathering, and organizing important information.”

2. Stronger associations between the category "tools that support activities otherwise not possible" and all four cognitive process categories. Students reported higher than expected frequency of tool use in this tool category for the cognitive process of “identifying, gathering, and organizing.” Students reported lower than expected frequency of tool use in this tool

category for the following cognitive processes: “understanding,” “integrating,” and “evaluating.” It is interesting to note that these two sets of relationships were in reverse directions.

3. Stronger associations between the category "tools that support hypothesis testing" and two of the four cognitive process categories. Students reported lower than expected frequency of tool use in this tool category for the cognitive process of “understanding” and higher than expected frequency of tool use in this tool category for the cognitive process of “integrating.”

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Extent of Engagement in Cognitive Processing and Tool Use

To answer our second research question, *Is there a relationship between the extent of engagement in cognitive processing by the students and their cognitive tool use?*, correlation analyses were performed between students' reported engagement level and their reported tool use across the 20 different cognitive processes.

The correlation analyses showed that for six of the 20 cognitive processing statements, a statistically significant moderate positive relationship existed between the reported degree of engagement and the reported frequency of tool use in all four categories (see Table 4). That is, for these six cognitive processes, the more engagement students reported, the more tools they reported using. Interestingly, five of these processing statements were in the category of “evaluating.” For most of the rest of the processes, a statistically significant moderate positive relationship was also found between the reported degree of engagement in cognitive processing and the reported frequency of tool use in at least one tool category (see Table 4).

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Different Patterns of Cognitive Processing and Students’ Tool Use and Performance Scores

To answer our third research question, *Are there any differences in cognitive tool use and performance scores between students who engage in different patterns of cognitive processing?*, an exploratory factor analysis was conducted using the responses from the *Cognitive Task Questionnaire* to investigate the underlying dimensions. For the factor analysis, intercorrelations among the students were computed across the 20 items of the *Cognitive Task Questionnaire*. To derive the factors, we applied maximum likelihood factor analysis followed by a varimax rotation. Because this was an exploratory factor analysis, and for purposes of parsimony, any item that failed to load significantly on any factor was removed. To determine the optimal number of factors, we used a scree test (Stevens, 1997). For this sample, a two-factor solution accounted for nearly half (49%) of the variance, a relatively high percentage. One factor was characterized by items referring to activities primarily information processing in nature, and the other factor was characterized by items referring to activities primarily metacognitive in nature (see Table 5). Given these two factors, labeled informational and metacognitive, we then assigned the students to one of the two categories using their individual factor scores. Given the nature of the tasks students were engaged in, informational students tended to report being more *action oriented* (i.e., information processing oriented) problem-solvers, while metacognitive students tended to report being more *metacognitively oriented* (i.e., thoughtful) problem-solvers. Two ANOVAs then were run using this student grouping as the independent variable and tool use and performance scores as dependent variables respectively.

------Insert Table 5 here------

Tool use. Students' tool use was defined along three dimensions: diversity of tool use, consistency of tool use, and activeness of tool use. A one-way MANOVA was performed with groups of students (informational or metacognitive) as the independent variable and diversity, consistency, and activeness of tool use as the dependent variables.

The "*diversity* of tool use index" indicated the extent to which students used a variety of tools. This score could range from 1 to 13, representing how many different tools the students reported using. If a student reported using an individual tool more than once, they would receive 1 point for that tool. A student who reported using all 13 tools more than once would get 13 points, indicating that they had used a wide variety of tools.

The "*consistency* index" reflected whether students used a particular tool across all 20 cognitive processes. Students had to report using a tool for10 or more cognitive processes (i.e., 50% or more), out of the 20 possible processes, for its use to be considered consistent. This score could range from 1 to 13, representing the number of different tools a student reported using consistently. If a student reported using a single tool for more than 10 cognitive processes, they would receive one point for that tool. A student who reported using all 13 tools 10 or more times would get a score of 13 points, indicating that they used all the tools all the time.

The "index of *activeness*" indicated the extent to which students reported high engagement in a cognitive process. That is, for how many of the cognitive processing statements did a student indicate that they engaged in it "all of the time" by marking a "5" on the Likert scale? This score could range from 0 to 20. If a student reported a "5" on the Likert scale for all 20 processing statements, she would receive a score of 20, indicating a high level of engagement in the cognitive processes.

The MANOVA analysis indicated a significant multivariate difference in the diversity, consistency, and activeness index scores based on student grouping (informational or metacognitive) ($F(3,157) = 10.16$, $p < .01$). Univariate analyses revealed no significant difference in the diversity of tool use by the two groups of students (F = .072, p=.79; $M_{\text{information-oriented}}$ =10.46, SD=1.90, $M_{\text{metacognitive-oriented}}$=10.56, SD=2.59). However, there was a significant difference in the consistency of tool use (F = 6.14, p<.01; $M_{\text{information-oriented}}$ =1.83, SD=1.93, $M_{\text{metacognitive-oriented}}$=2.79, SD=2.96) and in the activeness of tool use (F = 19.37, p<.01; $M_{\text{information-oriented}}$ =6.12, SD=2.95, $M_{\text{metacognitive-oriented}}$=3.92, SD=3.41) (see Figure 2). That is, the number of different types of tools used did not differ significantly between the two groups, but metacognitively oriented students reported using more tools in a consistent manner, and information processing oriented students reported a higher degree of engagement in the 20 different cognitive processes.

------Insert Figure 2 here------

Performance on the science knowledge test. An ANCOVA was conducted to see if the two groups performed differently in the science knowledge test. Grouping (informational or metacognitive) was the independent variable, and the science knowledge posttest score was the dependent variable with the pretest score as the covariate.

This analysis showed no significant result (F=3.069, p=.082), indicating that the two groups of students did not differ significantly in their scores on the science knowledge test: M_{total} =15.51; $M_{\text{information-oriented}}$ =16.28, SD=4.72, $M_{\text{metacognitive-oriented}}$ =14.65, SD=4.13. When we examined the students' performance from pretest to posttest, the t-test analysis showed that there was a significant gain in students' performance scores from pre to post: t=-24.49, p<.01 (n=318); M_{pre} =10.17, SD=3.61, M_{post} =16.05, SD=5.11. Because completing this science knowledge test was considered part of the students' grades whereas filling out the questionnaire was voluntary, many more responses were received and included in the analysis. This significant increase in the science test from pre to post showed that the sixth graders had acquired many scientific concepts introduced in Alien Rescue through using the program, class discussions, and/or peer interaction, even though no direct teaching was involved. Although Alien Rescue was shown to be efficacious in assisting students' learning, such a finding needs to be further verified by using a control group. Using a control group was not possible in this study because all students in the participating schools used Alien Rescue.

Discussion

Connection Between Cognitive Tool Use and Cognitive Processes

This study sought to understand the connection between the use of cognitive tools and the cognitive processes students engaged in as they solved a complex problem in a student-centered learning environment, Alien Rescue. The findings of the study showed that for different cognitive processes, different tools were used. The connection between tool use and processing was particularly marked between the category of "tools that support cognitive load" and all four process categories, between the category of "tools that support activities otherwise not possible" and all four process categories, and between the category of "tools that support hypothesis testing" and two process categories ("understanding" and "integrating").

It appears that tools supporting cognitive load were essential for the students as they engaged in the process of understanding the problem. Examples of tools in this category are four databases providing rich multimedia-based information resources. These tools supply important information for the students as they conceptualize the problem. Tool use patterns from our previous study indicated that students typically use these tools during the early stages of problem-solving as they search, research, understand, and define the problem (Liu & Bera, 2004).

The importance of these tools in assisting students' problem-solving also was reflected in teachers' perceptions of the tools. At the end of the study, we conducted interviews with the teachers on how they thought the tools helped students' problem-solving. When asked, "What tools helped the students to solve the problem?," one teacher indicated that the alien database, solar system database, concepts database, spectrograms, and periodic table were particularly helpful. All of these cognitive tools are in the category of tools supporting cognitive load.

It is worthwhile to note that there was also a strong association between using these tools and the cognitive processes of "integrating," and "evaluating." This finding supports other studies that showed that tools sharing cognitive load also were used in the final stage of problem-solving as students integrated, evaluated, and finalized their solution plans (Bera, & Liu, in press) and that multiple tools increasingly were used in combination toward the later stages of problem-solving (Liu & Bera, 2004). Such findings seem to suggest that students learn where to look for necessary information early in the problem-solving process. Then, later in this process they return to these "mental markers" to acquire, integrate, and extend their knowledge from the information provided. The strong association between using tools supporting cognitive load and all four cognitive processes not only supports previous research that showed that cognitive load reduction tools can support lower-level processing (Oliver & Hannafin, 2000), but also indicates that such tools are important in facilitating higher-level processes such as integration and evaluation. This finding adds a new dimension to our understanding of the role that tools supporting cognitive load can play in a learning environment.

The results indicated that more tools "supporting activities out of reach otherwise" were used for the cognitive process of "identifying, gathering and organizing." An explanation for this finding is that 80% of the processing statements in this category related to probe design and probe launching tools. These tools allow students to create their own probes, launch them, and study the data sent back. Performing such activities is not possible without the assistance of computer simulations. These tools offer an exciting opportunity for sixth graders to emulate the work of professional scientists. It makes sense to see a close connection between these tools and the processes they directly support. Tools supporting activities impossible otherwise were used less when students were engaged in other processes, such as understanding, integrating, and evaluating. The interesting reverse relationships between tools supporting cognitive load and all processes, and tools supporting activities out of reach otherwise and all processes seem to suggest the relative importance these tools have with respect to the different processes: In this study, the use of rich multimedia database tools was more closely related to the stages of understanding, integrating, and evaluating, while simulation tools such as the probe design and launcher were used more during the stage of information gathering,.

In addition, the results showed that tools "supporting hypothesis testing" were used more at later stages of problem-solving when students were integrating the information and less when they were trying to understand the problem. One may wonder why tools "supporting hypothesis testing" were not used more often during evaluating. An explanation may lie in the various process statements that form the evaluation category. Most of the statements in this category focus on thinking and reflecting, not on doing. Tools in the category of hypothesis testing are not truly needed for these processes. It is necessary to point out that the processes defined in the *Cognitive Task Questionnaire* are specific to problem-solving with Alien Rescue. Research indicates that cognitive processes can be task specific (Yang, 2002), and the skills required to solve different problems can differ (Jonassen, 2000).

The finding of a significant positive relationship between the degree of engagement and the frequency of tool use further supports the idea that the cognitive tools assisted the cognitive tasks the sixth graders were performing. The more engaged a student was, the more tools they used.

Our previous research (Liu & Bera, 2004) showed that cognitive tool use was associated with different stages of problem-solving. The findings from the present study showed that different types of tools were used for different types of processes; and connections were found between cognitive tool use and cognitive processes. Together, the results from this program of research provide some empirical evidence that hypermedia-based cognitive tools play an important role in assisting sixth graders' problem-solving.

Cognitive Tools as Only One Factor to Support Problem-Solving

The findings revealed no difference in the diversity of tool use between students engaged in different patterns of cognitive processing and no difference in their performance scores. It appears that different types of tools were needed and used by these sixth graders to gain science knowledge. Regardless of their patterns of cognitive processing, different tools played a role in helping the students learn.

Students, however, exhibited different characteristics in the consistency and activeness of their tool use. Students more metacognitively oriented were more consistent in their tool selection. Students more information processing oriented were more action oriented in performing the tasks. Metacognition involves both self-assessment and self-management. We hypothesize that metacognitive students are more deliberate and strategic in processing information. Perhaps they are more explicitly aware of the tools and their functions and spend more time thinking and reflecting on how the tools can support their processes. This would lead to very careful and consistent tool use. Information processing students, on the other hand, are more active in processing information and spend more time performing action-related tasks.

They may use more of a trial and error approach. This would lead to more tool use overall. This hypothesis needs to be further examined by additional research. The finding of this study reflects the different characteristics of these two types of learners and indicates that we need to consider other factors when investigating the role of cognitive tools.

In examining group patterns of cognitive tool use to determine if the patterns affect students' individual performance and experience of problem-solving, Bera and Liu (in press) found that various contextual factors (group processing, individuals' need for cognition, and experience) can mediate learning. Mayer (1998) discussed cognitive, metacognitive, and motivational aspects of problem-solving. According to him, to solve a problem successfully, one needs not only the skill (domain-specific knowledge relevant to the problem-solving task) and the metaskill (strategies for how to use the domain-specific knowledge), but also the will (feelings and beliefs about one's interest and ability to solve the problems). In order to design better tools, it is important to investigate not only how the tools are used, but how different types of learners use the tools, especially when learner differences influence learning outcomes. The findings from the present study underscore that cognitive tools are one important variable that can influence learning. Other factors, however, may come into play. It is the interaction of these contextual factors and the manipulation of these factors that can create an optimal learning situation.

Summary

The findings of this study suggest that different cognitive tools are used for different cognitive processes, and students' degree of engagement in cognitive processing is positively related to the frequency of tool use. These results indicate that there is a connection between cognitive tool use and cognitive processing. In addition, tool use patterns reflected different characteristics of the learners (information processing versus metacognition oriented).

One limitation of this study is that we relied primarily on students' self-reported data. With self-reported data, it is possible that students only report what they think the teacher or their friends consider desirable and not their actual practices. However, this study extends our previous research using log data as an objective way to investigate students' cognitive tool use patterns. The two studies examined the role of cognitive tools in providing scaffolding to sixth graders during their problem-solving with Alien Rescue from two different perspectives. Together, these studies provide some evidence of how the students used the tools and for what cognitive processes. A logical next step is to combine reported data with log data to examine how well the reported data are reflected in the log data. By continuing to research various aspects of how tools support learning, we can better understand the role of cognitive tools in assisting problem-solving and perhaps make evidence-based recommendations for the design of more effective learning tools.

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