The Effect of Web-Based Question Prompts on Scaffolding Knowledge Integration and Ill-Structured Problem Solving

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Abstract

This study examined the effects of question prompts, knowledge integration prompts, and problem solving prompts, embedded in a Web-based learning environment in scaffolding preservice teachers' conceptual understanding and problem solving in an ill-structured domain. A mixed-method study was employed to investigate the outcomes of students' conceptual knowledge and ill-structured problem solving. The quantitative results indicated that students who received knowledge integration prompts had significantly higher scores in overall problem solving performance, but the same was not true for prompts focused on conceptual knowledge. Further, the qualitative findings revealed the positive effects of knowledge integration prompts in facilitating students to make intentional efforts to identify and explain major concepts and their relationships that are necessary for solving the ill-structured problem. This study has implications for designing curricula in ill-defined domains that seek to integrate and promote the application of educational principles to real-world problems. (Keywords: knowledge integration, ill-structured problem solving, scaffolding.)

INTRODUCTION

An important characteristic of experts is their extensive, well-organized knowledge in their disciplines, which allows them to flexibly and efficiently retrieve relevant knowledge (Bransford, Brown, & Cocking, 2000). Experts also have cognitive frameworks that support problem analysis and guide retrieval and application of past experiences to solve new problems (Beck, McKeown, & Grommell, 1989; Ericsson & Staszewski, 1989; Glaser & Chi, 1988; Hasselbring, Goin, & Bransford, 1987; Simon, 1980). However, novices do not possess such integrative knowledge frameworks, which leads to a tendency toward oversimplifying the complexity of the new knowledge, generating vague relationships between prior and new knowledge, and processing information superficially and mindlessly (Feltovich, Spiro, Coulson, & Feltovich, 1996; Pressley et al., 1992). Yet in previous research, novices' deficiencies in problem solving have been attributed to limitations in both domain and metacognitive knowledge (Brown, 1987).

Many researchers have emphasized that knowledge integration is an important process in students' science learning because it engages students to monitor, actively reflect, evaluate, and modify their own knowledge (e.g., Davis & Linn, 2000; Linn & Hsi, 2000). Due to the lack of recent empirical

studies focused on ill-structured problem solving in social science domains, it is critical for the researchers to build a theoretical framework on the earlier literature from cognitive science perspectives. From the few investigations on the effectiveness of knowledge integration from previous research in supporting conceptual knowledge and ill-structured problem solving in the social sciences, we believed that scaffolding strategies targeted at knowledge integration and problem solving could support students' cognitive and metacognitive skills. In this study, we specifically examined the effects of two types of question prompts, namely knowledge integration prompts and problem solving prompts, to scaffold students' conceptual knowledge and problem solving processes in an ill-defined domain. The curriculum context used for this study was educational measurement because it represented authentic and real-world problems in the practice and research of education. A Web-based learning environment was created that provided the information students needed within the discipline as well as learning scenarios to engage them in authentic problem solving activities and guide their learning process through scaffolding (Hannafin, Land, & Oliver, 1999; Jonassen, 1999).

THEORETICAL FRAMEWORK

Knowledge Integration

Learning is an active process by which students construct their own knowledge in light of their existing knowledge and through a process of generation, integration, and transformation of their experiential world (Gao, Baylor, & Shen, 2005). Unfortunately, students often hold multiple conflicting views before learning new information and create their repertoire of views without reflecting on their existing knowledge. Students' existing knowledge serves as an interpretative framework for knowledge integration because new knowledge is filtered through existing knowledge. Consequently, students' existing knowledge plays an important role in understanding new information. Understanding also goes hand-in-hand with the construction of an integrated conceptual framework (Hewitt, 2002). For this reason, promoting an integrated conceptual framework that furthers understanding should be explicitly taught.

Thus, Linn and her colleagues (2000) sought to design an instructional aid that promoted a more integrated student understanding of complex science concepts and processes. The Web-based Inquiry Science Environment (WISE) is one of the curriculum projects they created to help students develop more cohesive, coherent, and thoughtful accounts of scientific phenomena (Linn, Clark, & Slotta, 2003). WISE was guided by an instructional framework called scaffolded knowledge integration framework (SKI), derived from substantive and extensive research such as that on cognitive apprenticeships (Collins, Brown, & Newman, 1989). Significantly, a scaffolded knowledge integration framework requires students to reflect on their deliberately developed repertoire of models for complex phenomena, and to work toward expanding, refining, reconciling, and linking these models (Bell, 2002; Linn, 1995). In an intervention study, Davis and Linn (2000) found that students who were encouraged to monitor their learning progress and identify new

connections among ideas showed greater integrated understanding of the science phenomena compared to students who only devoted their attention to the inquiry process. Apparently, students who only focus on inquiry without a theoretical base are less likely to develop a robust conceptual understanding than students who compared ideas, distinguished cases, identified the links and connections among notions, sought evidence to resolve uncertainty, and sorted out valid relationships, thus improving their knowledge integration (Davis & Linn, 2000).

Likewise, Scardamalia and Bereiter (2003) indicated that we need to prepare for student learning as knowledge building. In a computer-based learning environment called Computer-Supported Intentional Learning Environments (CSILE), students were encouraged to clarify problem statements, develop theories, state difficulties in understanding certain issues, and summarize what they have learned; thus, students actively build their own knowledge bases (Scardamalia & Bereiter, 1996). Associations developed exclusively within the context of new material were less effective for knowledge building than those developed between new material and prior understanding. They concluded that instruction should support students' knowledge to be integrated, as opposed to disjointed and static.

As indicated, the features of a scaffolded knowledge integration instructional framework recognize students' weaknesses by critically examining their own thoughts and the evidence bearing on them in both their informal thinking about everyday topics and their thinking within formal academic studies (Linn, 2005). The framework has been examined and implemented in science inquiry learning contexts, in which students were constantly asked to reflect to help them monitor thoughts and construct a coherent and robust conceptual understanding (Linn & Hsi, 2000), which is also called metacognition.

Ill-Structured Problem Solving

In contrast to well-structured problems commonly encountered in educational settings, ill-structured problems are the kinds of problems that students face routinely in everyday life (Jonassen, 2002). Ill-structured problems have vague and less-defined goals and unstated constraint information (Voss, Wolfe, Lawrence, & Eagle, 1991). These problems have no right or wrong concepts, rules, and principles for arriving at the solution and possess multiple solutions or may not have any definite solution at all (Butler & Thomas, 1999). As a result, experts and novices also approach these problems differently (Bransford, Brown, & Cocking, 2000). The components and processes in experts and novices' ill-structured problem solving are discussed below.

The primary predictor of successful problem solving is domain knowledge (Murphy & Alexander, 2002). How much solvers know about a domain is important to understanding the problem and generating solutions. However, ill-structured problems cannot be solved simply by finding the information and following a constrained set of rules. In fact, that domain knowledge must be well-integrated in order to support ill-structured problem solving. Such "integratedness" also is described as structural knowledge. Structural knowledge is the knowledge of integrating domain knowledge into useful procedural

knowledge for solving domain problems (Jonassen, Beissner, & Yacci, 1993). In a study conducted in the Soviet Union, Voss and his associates (1986) found that the domain knowledge possessed by novices seemed to consist of bits and pieces of information that were not integrated and that ultimately impaired their problem solving processes. A series of additional investigations on expert and novice problem solving also indicated that experts were better problem solvers because their representations acquire more integrated domain knowledge of the problem and that helps them to construct a meaningful internal representation that can be manipulated (Wineburg, 1998). In brief, domain knowledge is not enough to solve ill-structured problems; it must be integrated as structural knowledge to enable problem representation and solve ill-structured problems.

In addition to representational and selection complexities, ill-structured problems have no clear solutions and demand that problem solvers consider alternative goals as well as handle competing goals. This requires problem solvers to control and monitor the selection and execution of a solution process. In other words, they have to use metacognitive skills such as self-awareness of cognitive knowledge and self-regulation of cognitive processes and strategies during problem solving (Brown, 1987). King (1991) examined the effectiveness of self-questioning as a metacognitive strategy on students' reading comprehension. She found that self-questioning promotes internal dialogue for systematically analyzing problem information and regulating execution of cognitive strategies (King, 1991). Likewise, Delclos and Harrington (1991) found that students who monitored their own problem solving processes tended to use more metacognitive strategies for completing the task. In sum, successful problem solvers use self-questioning and monitoring to gain access to and guide execution of strategies and to regulate use of strategies and problem solving performance (Lin, 2001). Although well-structured and ill-structured problems share similarities in some respects, ill-structured problems often require solvers to go beyond what is represented in the problem statement and consider alternatives using more metacognitive skills. Ge and Land (2004) synthesized past studies and created a model for ill-structured problem solving, including four processes: (a) representing problem(s), (b) generating and selecting solutions, (c) making justifications, and (d) monitoring and evaluating goals and solutions.

Question Prompts as Scaffolding Strategies

Merely presenting information generally will not cause students to develop accurate and integrative knowledge that fosters the understanding of pragmatic principle(s) and dynamic stances towards new knowledge. Therefore, intentional instructional supports should be made to elicit such knowledge building processes (Scardamalia & Bereiter, 1994). Students need to be prompted to think about new material in such a way that they transform the material, thus constructing new knowledge. Question prompts as instructional supports have been found to effectively promote students' knowledge integration. For instance, the studies of King and Rosenshine (1993), King

(1994), and Davis and Linn (2000) used prompts to engage students in knowledge integration that furthered their knowledge acquisition. In a similar manner, merely asking students to solve problems without providing necessary instructional supports appears to decrease the possibility of accomplishing the ill-structured problem solving process. Ge and Land (2003) investigated the use of question prompts in facilitating students' ill-structured problem solving and found that students who were prompted by questions made increased deliberate efforts to identify and seek relevant information in the problem.

Different question prompts may serve different needs and purposes for students. Recently, researchers have started to investigate in depth different types of questions that promote students' cognition and metacognition. For example, Davis (2003) examined science students' reflection productivity through what she labeled as "generic" and "directed" prompts. "Generic" prompts entailed having students to simply stop and think, whereas directed prompts were more elaborate, providing students with hints or directions for reflective thinking. She found that the "generic" prompts promoted more productive reflective thinking than did the "directed" prompts. Therefore, prompt types make a difference. While researchers in science contexts have begun to pay attention to different types of question prompts, it also is important to focus attention on the research in social science contexts.

Despite the justification for the use of question prompts to facilitate knowledge integration in science learning, the relationship between different types of questioning strategies and social science has not been sufficiently studied. Davis and Linn (2000) studied the effects of guided questions on metacognitive skills, knowledge integration, and problem solving. However, in Davis and Linn's (2000) study, the problems were situated in science and the subjects were eighth graders. Ge and Land (2003) provided a list of questions that were mapped to ill-structured problem solving processes to guide undergraduate students in completing ill-structured problem solving tasks in information science and technology. Although Ge and Land (2003) found that question prompts had positive effect on students' ill-structured problem solving, their study did not examine the students' prior knowledge aside from self-reports on prior problem solving experience across different conditions. The students' self-reports might be a questionable measurement of what students knew. Further, Ge, Chen, and Davis (2005) called for future research to compare the effects of different question prompts on students' conceptual knowledge and ill-structured problem solving.

PURPOSE OF THE STUDY

The purpose of this study was to investigate the effects of (a) knowledge integration prompts, (b) problem solving prompts, and (c) both knowledge integration and problem solving prompts on scaffolding students' conceptual knowledge and problem solving processes in an ill-structured task. The problem solving outcomes and processes investigated were (a) problem representation, (b) developing and evaluating solutions, and (c) monitoring and justifying a plan of action (Ge & Land, 2004).

The knowledge integration prompts in this study referred to a set of questions that prompted students to connect ideas, compare ideas, seek uncertainty evidence, transfer ideas, and summarize valid relationships. They also were intended to direct students' attention to explain and understand how, why, and what. The problem solving prompts in this study were a set of questions with specific procedures for problem solving.

The study examined the following questions:

1. Does the use of knowledge integration prompts only, problem solving prompts only, or the combination of knowledge integration and problem solving prompts have an effect on students' knowledge acquisition and problem solving outcomes in the domain of educational measurement in the Web-based learning environment?
2. How does the use of different question prompts influence students' conceptual knowledge and ill-structured problem solving?

METHODOLOGY

A mixed-method study was employed to investigate two research questions. The use of quantitative and qualitative methods helped the researcher to examine the results from different data sources and expand the scope and breadth of the study. The experimental study, designed to answer research question 1, was conducted to measure students' conceptual knowledge and problem solving outcomes in an ill-structured task. The qualitative study consisting of analysis students' ill-structured problem solving reports and follow-up interviews added depth and anecdotal evidence to findings from quantitative measures.

Participants

Participants in the experimental design were 51 undergraduate students (32 female and 19 male) recruited from three class sections of an introductory course in the Department of Educational Psychology at a south central U.S. university. Of these, 15 also participated in the follow-up interview. Most of the students were sophomores and juniors. About 70% had taken at least one educational psychology class and 47% had not yet taken an educational measurement class.

THE EXPERIMENTAL STUDY

Design and Procedures

Four versions of Web-based learning environments were created. A database was developed so that participants' responses could be saved and retrieved. The 51 participants were assigned to one of four Web-based learning environment study conditions: a) knowledge integration (KI) (n=13), b) problem solving (PR) (n=14), c) the combination of knowledge prompts and problem solving prompts (KP) (n=13), and d) control condition (Control) (n=11). Following the pretest, the participants were directed to read a set of instructional passages about educational measurement, particularly reliability and validity, and then solve an ill-structured problem in the discipline. The participants in the KI

and KP conditions were provided with and required to respond to a series of knowledge integration prompts after the presentation of the instructional passages. Their completed responses would be submitted, saved to the database, and displayed later. The participants in the PS and Control conditions simply read through the instructional passages. During the ill-structured problem solving, only the participants in the PS and KP conditions were provided with and required to respond to a series of problem solving prompts after the presentation of the case study. Again, their completed responses were submitted, saved to the database, and displayed on the next screen, where the participants could copy and paste their prior responses to be organized and edited into final solution reports. The participants in the KI and KP conditions could also retrieve their responses from the knowledge integration prompts. After solving the problem, the participants completed a posttest before exiting the study.

Materials

Prompt Types. Knowledge integration prompts were adapted from King (1994) and Linn (1995) studies, which addressed critiquing, interpreting, and explaining key concepts. For example, "Explain why reliability and validity are important," and "Go beyond what was covered in the instructional passages, summarize the purpose and the meaning of reliability and validity." Problem solving prompts were generated to be parallel with the ill-structured problem solving processes proposed by Ge and Land (2004), for example, "What facts from this case suggest a problem?", "Why is it occurring?", and "What specific strategies do you want to suggest to the teacher to help him solve the problems that you have identified?"

Pre/Posttests. A 19-item test about reliability and validity in educational measurement was developed to assess students' conceptual knowledge of the instructional passages provided. The test was evaluated by the instructors of measurement and evaluation courses to validate that the items were adequately and appropriately represented. The test included three major items: terminology (seven items), comprehension (seven items), and application (five items) tests. The test had a split-half internal consistency .65 reliability coefficient.

Ill-Structured Problem. The problem was generated from a real-world educational measurement problem with embedded reliability and validity principles. A rubric was developed to assess students' problem solving outcomes on the ill-structured problem. Students' problem solving outcomes were scored numerically based on their performances on (a) problem representation, (b) developing and justifying solution(s), and (c) monitoring and evaluating a plan of action. These coding schemes were chosen because they serve as indicators for the processes in solving ill-structured tasks (Ge & Land, 2004). Instructors from the educational psychology department and experts in ill-structured problem solving research also validated the rubric. Before grading, two raters reached a conceptual consensus on how to interpret the scoring rubrics through discussion and examples. Any discrepancies of assigned values were discussed among raters. Consequently, a high consensus was reached. A split-half internal consistency procedure was performed and found that the scoring rubric had .87 reliability coefficient.

Data Analyses

Quantitative data was analyzed first, followed by qualitative data. Multivariate analysis of variance (MANOVA) was conducted to examine the effects of different types of prompts on students' conceptual knowledge and ill-structured problem solving outcomes. MANOVA was used for this study because it allows researchers to include multiple dependent variables and evaluate whether the means on a set of dependent variables vary across levels of factors (Green & Salkind, 2003). Wilks's Lambda F (α = .05) was used in interpreting the multivariate test results. As shown by the results from the Levene's Test, the assumption of equal variance was met at the .05 alpha level, and thus met the MANOVA testing assumption that the residual errors follow a multivariate normal distribution in the population.

THE QUALITATIVE STUDY

Procedures and Materials

All 51 participants' problem solving reports were retrieved from the database by the first author. Different from the rubric that was developed to score quantitatively, the researcher coded each report individually in how participants defined and identified the concepts in their problem solving reports. Following the completion of the experimental study, participants were selected based on their willingness to take part in audiotaped interviews.

Data Analyses

The analysis process involved reading and jotting marginal notes on the transcripts, identifying emerging patterns into categories, and drawing conclusions. For example, the first author read through each student's problem solving report and highlighted the places where he or she identified key concepts and their relationships. Highlighted places were used to examine the participants' conceptual knowledge in the context of question prompts or no prompts. The next procedure was to organize and display the emerging patterns so that comparison could be made across different conditions. The analyses of problem solving reports and follow-up interviews added reliability to the findings along with member checks for validity and the use of multiple coders for inter-rater reliability (Bogdan & Biklin, 1998).

RESULTS

Quantitative Outcomes

To answer research question 1, "Does the use of knowledge integration prompts only, problem solving prompts only, or the combination of knowledge integration and problem solving prompts have an effect on students' conceptual knowledge and problem solving outcomes in the domain of educational measurement in the Web-based learning environment?," multivariate analysis of variance (MANOVA) was employed. The results of MANOVA on the effect of students' conceptual knowledge did not reveal significant differences among conditions, Wilks's Lambda (Λ) =.80, F (6, 92) =1.80, p>.05, η^2 =.11, observed power =.65. Table 1 shows means and standard deviations for the conceptual knowledge posttests by groups.

Table 1: Means and Standard Deviations for the Conceptual Knowledge by Question Prompt Types

	Condition	N	Mean	Std. Deviation
Pretest	KI	13	6.92	2.18
	PS	14	6.79	2.33
	KP	13	8.08	1.89
	Control	11	7.46	2.12
Posttest	KI	13	11.08	2.60
	PS	14	9.43	1.95
	KP	13	10.69	2.43
	Control	11	9.00	2.45

Note: The possible ranges of scores for pre/posttests are 0–19.

Table 2: Means and Standard Deviations of Dependent Variables by Treatment Group

	Treatment Group										
	Knowledge integration (KI)			Problem solving (PR)			Knowledge integration and problem solving (KP)			Control		
DVs	N	M	SD	N	M	SD	N	M	SD	N	M	SD
Problem representation	13	5.08	1.94	14	5.64	2.82	13	5.08	2.53	11	3.36	1.91
Developing solutions	13	4.57	2.50	14	4.07	1.90	13	4.50	2.93	11	1.64	1.69
Monitoring and evaluating a plan of action	13	4.85	1.99	14	3.00	1.92	13	2.63	2.64	11	1.18	1.25

Note: The possible ranges of scores for problem representation are 0–7; developing solutions are 0–6; monitoring and evaluating a plan of action are 0–6.

   Although there was no significant main effect on students' conceptual knowledge among groups, we found that there was a significant main effect on ill-structured problem solving, Wilk's Lambda (Λ) = .50, $F(9, 110)$ =4.0, p= .000. The multivariate η^2 based on Cohen (1988) was quite strong, .21, and observed power also was considerably high, .97. Further, a univariate test of between-subjects effects revealed significant effects in two of the three problem solving processes, i.e. developing and justifying solutions, $F(3, 47)$ =3.38, p=.026, η^2 = .18, observed power .73, and monitoring and evaluating a plan of action, $F(3, 47)$ =6.50, p=.001, η^2 = .29, observed power .96. Table 2 shows means and standard deviations for

the four conditions. The result indicated that the knowledge integration group had the highest mean scores on developing and justifying solution(s) (M=4.57, SD=2.50), and monitoring and evaluating a plan of action (M=4.85, SD=1.99) of all the groups. Follow-up post hoc comparison indicated significant differences between the KI and Control groups resided on developing/evaluating solutions and monitoring/evaluating a plan of action.

Qualitative Findings

The participants' problem solving performance in different conditions were examined qualitatively to supplement the quantitative findings. Below is a brief report of students' conceptual knowledge and ill-structured problem solving on the effects of different question prompts.

Analysis of the participants' ill-structured problem solving reports produced the following two findings. First, the participants who received knowledge integration prompts made intentional efforts to identify major concepts and their relationships that are necessary for solving the ill-structured problem. For example, "Validity refers to the appropriateness of the interpretation of the results of an assessment procedure for a given group of individuals, not to the procedure itself;" "the project was not valid as well when appropriateness of interpretation of assessment result…;"and "the purpose of reliability is to ensure that the tests that are given are consistent and do not vary in their form of results…" On the other hand, participants who did not receive knowledge integration prompts appeared to identify the concepts vaguely and ambiguously, and they also failed to draw clear connections and relationships among concepts. Examples from students' problem solving reports indicate that they used the concepts' reliability and validity interchangeably and showed misconceptions of what the concepts mean: "A reliable and valid rubric will yield more accurate content assessment;" "if there were a clear set of criteria there could be more reliability since …;" and "…you might want to compare students grades to another to check validity."

Second, the participants who received problem solving prompts appeared to make efforts to construct solutions and explicitly provide arguments for subsequent implementation. Those prompts also directed the participants' attention to seek alternative solutions they might have overlooked. For example, "Perhaps you can find another way to assess students, like have them sit in groups to work on things. However, make the projects individually based and grade each student individually upon completion of the project." And another student said, "I suggest the teacher give objectives to the students so they know exactly what they are being evaluated on and can work toward that goal." Comparing groups that received problem solving prompts with those that received knowledge integration prompts, the researcher found that problem solving prompts did not suffice to help the participants to retrieve constructed schema, which required participants to rely heavily on their limited working memory capacities to negotiate meanings.

Lastly, the follow-up interviews also were analyzed to provide in-depth insights. The participants who received knowledge integration prompts said that

those prompts helped them think about different aspects and the relationship of things. Those prompts also served as an "organizer" to understanding concepts and problem solving, and activated reflective thinking to draw attention to important elements, and also organized and transferred concepts as they applied in real-world situations. The participants who received only problem solving prompts mentioned that the problem seemed vague at first and, despite the prompts, they still had to spend time to pull the information together, relying more on their knowledge of the concepts than on problem solving process. One student mentioned, "I think they helped more in the problem-solving skill than the actual understanding of the concepts." The problem solving prompts seemed to help students focus on some of the important problems in the case studies, analyze the specific problem in-depth, and break down the problems into sub-problems.

DISCUSSION

Although the quantitative results did not show a significant difference between students who received knowledge integration prompts and those who did not with regard to conceptual knowledge, the qualitative results indicated that these students felt that they developed a better integrated understanding of educational measurement despite the challenges they faced learning this topic. When the students were prompted to proceed with the knowledge integration process, they abandoned single knowledge elements for multiple knowledge elements, so that new or stronger connections were fostered through engagement with this Web-based learning environment. By the end, these students were more likely to explain their reasoning with a well-integrated answer than with a less connected answer. Clearly, compared to instruction without scaffoldings, providing scaffoldings was more beneficial. In many cognitive situations with instructional goals such as learning a new unit of domain knowledge, knowledge integration prompts may be more useful than problem solving prompts when asking students to engage in connecting, summarizing, and reflecting. Problem solving prompts, on the other hand, focus students' attention only on the problem solving processes, and may not always correspond as well to students' understandings.

In the present study, problem solving prompts did not have a positive effect on solving the ill-structured problem. This finding contradicted Ge and Land's (2003) study, in which problem solving prompts did not have effects on students' ill-structured problem solving processes such as problem representation, developing and justifying solutions, and monitoring and evaluating a plan of action. In the qualitative analyses of students' problem solving reports and follow-up interviews, it was found that these prompts directed students to construct solutions and argumentations for subsequent implementation. However, the absence of integrative knowledge structures caused them to overlook a broader range of solutions.

The scaffoldings of both knowledge integration prompts and problem solving prompts did not have the increased positive results over the single scaffolding as we would expect. The knowledge integration prompts used in this study were

developed to help students identify weakness in their knowledge (Linn, 1995). The problem solving prompts were to guide students' attention to perform like experts in the problem solving processes (Ge & Land, 2004). However, other research shows that when students cannot interpret specific prompts, they may flounder or dismiss the purposes of all those prompts (Davis, 2003; Ge, Chen, & Davis, 2005). Further, when students are not in control of their learning, they may experience fatigue that could greatly impact the overall performance. The use of question prompts as scaffolding should be used with caution and consideration of students' prior knowledge and experiences. Excessive question prompts may cause a certain degree of cognitive overload, as seems indicated by the lower scores of participants with both knowledge integration and problem solving prompts. The design strategy of combining different types of prompts should be carefully evaluated in order to provide more explicit opportunities to help students apply concepts to real-world problems. A recent research endeavor looking at adaptive scaffolding by a human tutor provides new perspectives on how we can better diagnose student's level of understanding (Azevedo, Cromley, & Seibert, 2004; Azevedo, Cromley, Winters, Moos, & Greene, 2005).

IMPLICATIONS

The study has practical implications for Web-based instruction, where question prompts embedded in Web-based learning environments can challenge students' knowledge integration and support complex learning tasks. Web-based learning has considerable promise in the development and facilitation of students' understanding. This study yields several implications for designing such an environment to support the development of cognitive skills and models of understanding.

First, in order to support cognitive development effectively, a system is needed to facilitate intentional reflection and retention. Such a mechanism will raise students' awareness of the gaps and detect biases in their knowledge bases. Therefore, the Web-based cognitive modeling system should structure opportunities for intentional reflection.

Second, in order to engage students in meaningful learning, the system should provide real-world problems to help students reconcile the application of knowledge. Students often experience difficulty connecting educational theories with real-world problems; therefore, utilizing question prompts to act as a mediator for the instructor role will enable the linking system to activate students' knowledge application.

Last, but not least, it may be useful to provide feedback or features that structure opportunities for students to interact with experts and their peers. Distance learning is characterized by the separation between instructors and the students, whether by temporal or spatial distance. The cognitive advantage of incorporating a system that includes knowledge integration and problem solving prompts into distance education is that viewing materials from multiple perspectives can increase cognitive flexibility and interconnections as well as giving opportunities to share and become involved with the learning community.

RECOMMENDATIONS FOR FUTURE RESEARCH

This study urges further validation on the assessment of knowledge integration. Multiple assessment sources should help define and better represent knowledge integration. Possible multiple assessment sources should be investigated. Accordingly, it may be beneficial to examine and adapt methods used in other fields to understand knowledge integration better. For instance, a group of researchers used benchmarking as one of the techniques to assess the process of knowledge integration (Lee, Husic, Liu, & Hofstetter, 2006). A mixed initiative assessment that includes humans and computers has been widely discussed and implemented in real scaffolding classroom settings (e.g., Zimmerman, 2005). This dynamic assessment evaluates transitions in knowledge representations and performance while learners are in the process of solving problems, rather than after they have completed a problem, which is critical for providing valid interpretations of students' performance. A further investigation on the use of computers to assess and capture students' learning progress needs to be explored and discussed.

Another avenue for future research is how knowledge is integrated through the use of other scaffolding techniques, such as cooperative groups and expert modeling (Lajoie, 2005). Peer learning is assumed to promote sharing and the development of understanding. This study indicates that interaction and feedback loops may be useful in facilitating better knowledge integration. The Web-based learning environment developed for use in this study was specifically designed to promote knowledge integration and problem solving through different types of question prompts. From a design perspective, it would be useful to know whether other tools had a greater impact on students' knowledge integration than the question prompts (Chen & Ge, 2006). Knowing this might lead to more generalizable design principles for designing better knowledge integration environments. Research on this question would likely involve conducting interviews with students specifically regarding the use of tools, collecting pre-post analyses of knowledge integration, tracking students' progress (e.g., time logs of overall frequency of use as well as frequency of specific tool use), and increasing numbers of participants in the treatment and control groups to provide additional valuable information.

Contributors

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