Multi-Scaffolding Environment: An Analysis of Scaffolding and Its Impact on Cognitive Load and Problem-Solving Ability

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Abstract

A Multi-Scaffolding Environment (MSE) is a multimedia environment reliant on authentic scaffolding. We examine the impact of the availability of multiple scaffolds on learning and cognitive load within an MSE where learners are assigned a real-world task and given access to four support tools to help them complete the task. By examining an MSE in the area of geographic literacy, we explore the effectiveness of problem-based learning and whether multiple scaffolding is applicable to any content area. Quantitative and qualitative data indicate that a learner-controlled multi-scaffolding approach may be a valuable approach in problem-based learning contexts.

Multi-Scaffolding Learning Environment: An Analysis of Scaffolding and Its Impact on Cognitive Load and Problem-Solving Ability

The learner-centered approach of problem-based learning (PBL) that has been used within classrooms for over three decades is, according to Boud and Feletti (1997), “an approach to structuring the curriculum which involves confronting students with problems from practice which provide a stimulus for learning” (p. 1). As researchers have pointed out, however, the extent to which PBL actually serves as a stimulus for student learning, is sometimes limited by teachers not being comfortable with the PBL approach and thus not assuming an effective guiding role (Brush & Saye, 2001). This phenomenon has been noted in the teaching of several academic disciplines, including medicine (Mayo, Donnelly, & Schwartz, 1995), family and consumer sciences (Ward & Lee, 2002), and economics (Maxwell, Bellisimo, & Mergendoller, 2001).

Within the field of geography, PBL curricula have frequently been used to integrate geospatial technologies such as geographic information systems (GIS) to assist learners in meeting the National Geography standards. However, the integration of PBL curricula has been hindered by the lack of both technological and pedagogical knowledge on the part of teachers employing it (Doering, Hughes, & Huffman, 2003; Doering, Veletsianos, & Scharber, in press; Hughes, 2004, 2005). A geographic information system (GIS) is a geospatial technology that allows a user to store, retrieve, manipulate and display geographic data about any place in the world. Although it has been noted that GIS is the one technology that can assist students in meeting *all* of the National Geography Standards (Audet & Paris, 1995; Bednarz, 1999), the actual implementation of GIS within classrooms is far behind expected rates (Kerski, 1999), even at a time when the United States is highlighting the geographic illiteracy of students throughout the nation and geotechnology is being identified as one of the three fastest growing employment fields (Congressional Record References, 2005).

These recent developments have fast-forwarded the need for educators to effectively teach the National Geography Standards in K-12 social studies curricula utilizing geospatial technologies (Baker & Bednarz, 2003). Yet even with this strong desire, the results have not been promising and integration rates have barely increased. Bednarz and Audet (1999) have identified three main reasons that current approaches to teaching GIS in K-12 classrooms have not been effective: (a) the inadequate training of teachers in the use of GIS, (b) a lack of pedagogical teaching models, and (c) the failure of preservice teacher education programs to teach GIS in ways that are applicable to the K-12 classroom. These problems are also cited by Sanders, Kajs, and Crawford (2001) and continue to hinder the successful use of GIS in education.

Despite the growing calls for the use of GIS in geography instruction and interest on the part of teachers, research on the use of GIS in formal classrooms has been minimal (Baker & Bednarz, 2003), and the majority of the available empirical investigations relates to student attitudes, self-efficacy, and motivation (Baker & White, 2003; West, 2003) rather than to student achievement and effective teaching pedagogies. In the scant research that has addressed the efficacy of such teaching, a study of three online pedagogical models for integrating GIS in preservice teacher education courses (Doering, 2004) found that learning geography with geospatial technologies is best accomplished through the use of multiple scaffolds and guidance in structured problem solving as it provided students with guided practice along with expert assistance. The online guidance Doering refers to is similar to what Brush and Saye (2000) describe as teachers attending to numerous aspects of the learning environment. Similarly, Ertmer and Simons (2006) state that effectively implementing PBL requires “1) creating a culture of collaboration and interdependence, 2) adjusting to changing roles, and 3) scaffolding student learning and performance” (p. 42). Meeting this need for collaboration opportunities, flexibility within a learning environment, and scaffolding, is the premise behind the design, development, and evaluation of an online learning environment that we have titled Multi-Scaffolding Environment: Geographic Information Systems, or MSE:GIS. Next, we will present MSE:GIS and its theoretical underpinnings, explain the PBL model underlying the learning environment, and empirically evaluate the use of MSE:GIS with regards to learners’ cognitive load and problem-solving ability.

Multi-Scaffolding Environment: Geographic Information Systems

MSE: GIS creates opportunities for students to learn content with geospatial technologies by solving authentic complex problems in an online environment. MSE: GIS is built on the premise of providing a cognitive apprenticeship (Collins, Brown, and Newman, 1989) by situating the learning within an authentic setting while providing opportunities for legitimate peripheral participation (Lave and Wenger, 1991). To support cognitive apprenticeship, scaffolding and features of coaching are used to assist learners (Enkenberg, 2001).

A scaffold is a support that a teacher or learning environment provides to a learner to assist him or her in a range of cognitive tasks, from the understanding of a task and mastering of a skill to the solving of a problem. Scaffolding is an important feature of Vygotsky’s (1962) social development theory, which focuses on the role of social interaction and the assistance provided to a learner in their zone of proximal development (ZPD). Achieving the full development of ZPD, this theory holds, requires social interaction through expert guidance and peer collaboration. This expert guidance and peer collaboration are both available through

MSE:GIS, but what sets MSE apart from traditional forms of scaffolding is the gradual withdrawal of support. Within MSE, all scaffolds are available at all times, and the fading, although encouraged by the expert, is a decision to be taken by the learner. This approach is supported by Duffy and Cunningham (1996) where they discuss that the metaphor of scaffolding is "unfortunate" as it focuses on the teacher-centered approach of assisting learners to a definitive end (p. 183), while it should be a "learner-centered strategy whose success is dependent on the adaptability to the learner's needs" (p. 185). To this end, MSE is a supportive, rather than directive scaffolding (Lenski & Nierstheimer, 2002) online learning environment that can be used within a face-to-face or distance learning context. It provides learners with four levels of learner-controlled scaffolds that engage them in solving authentic problems. Learners are placed in the role of a geographer, working towards solving an authentic geographic problem while using the choice of scaffolding that they deem appropriate. The scaffolds have been designed to successfully model and demonstrate the use of geospatial technologies in PBL while maintaining an appropriate level of difficulty and reducing unnecessary frustration. Unlike typical instruction or instructional resources, the MSE scaffolds assist the learners within their ZPD as they provide challenges to learners based on their current knowledge while still making sure the challenge is attainable, thus, not leading to frustration. The scaffolds are not based on difficulty, but are portals to the different parts of knowledge a learners must know to solve the problem. Furthermore, MSE supports intersubjectivity (Rogoff, 1990; Tharp and Gallimore, 1988) between learners and between learners and experts as they have a shared understanding within the environment of the task that needs to be solved along with the mechanisms to discuss the issues and receive expert guidance reducing conflict.

The scaffolds for this environment are: situated movies, screen-capture videos, conversational agents, and collaboration zones. The first of these scaffolds, a *situated movie (SM),* is a movie that announces, situates, and gives pertinent data about the real-world problem in an authentic context using real-world video clips and situations. Supporting the heart of cognitive apprenticeship as a method of learning, the video footage is taken from authentic locations and actual scenarios. In its entirety, the situated movie lasts 2 minutes and 20 seconds. Learners have the opportunity to view the movie in its entirety or as four segments – *Introduction, Problem Statement, Data & Task*, and *Recommendations*. The *introduction* is the call for action from the television station "WGIS" stating that there are "breaking news" and that the learners' assistance is needed. The *problem statement* is what the problem is within the region of study. The *data & task* presents the data that learners need to use and their task to solve the problem within the region. The *recommendations* are what the learners should do once they believe they have solved the problem and how the result of their work may have an impact on this region. The MSE situated movie is based on theories of situated learning (Lave and Wegner, 1991) and anchor-based instruction (CGTV, 1990) in that it is intended to situate the learners within an authentic context while giving them adequate information to solve the problem. The Cognition and Technology Group at Vanderbilt (CGTV, 1992), which developed and studied the effectiveness of using videos to anchor science instruction, has found that their use significantly enhances science learning by giving students a task with clues within an authentic setting. For example, in "Rescue at Boone's Meadow", learners need to figure out the fastest way to rescue a wounded eagle given clues such as the fuel capacity and speed of an ultralight plane (CGTV, 1992, pp. 70). The second type of scaffold, *screen-capture videos (SCV),* demonstrates how to effectively use GIS to solve the authentic problems posed in the situated video. Watching these screen recordings is equivalent to having an expert instructor in front of class demonstrating the procedural steps of utilizing a GIS. There are three sections to the SCVs. The first section is the *Tools Overview,* which gives a brief description of all of the GIS functionalities that are needed when using ArcView when solving the problem. For example, it shows how to use the magnifying glass and identify tool. The second section is titled *Understanding Turtle River* and has four subsections that include: *Analyzing Watersheds, Exploring Acquifers, Acquiring Data,* and *Mapping Data.* The third section is titled *Selecting a Site* and has three subsections that include: *Analyzing pH, Analyzing Oxygen,* and *Analyzing Conductivity.* Each of the section movies are, on average, three minutes in length. Doering (2004) found that the SCV both increased students' confidence and their procedural and declarative knowledge when using GIS to learn geography.

The third scaffold, a *conversational agent (CA),* is an artificial intelligence avatar able to dynamically converse with learners in speech and text form. The avatar responses represent expert knowledge as the data that are extracted from the database have been developed based on questions geography learners have posed when solving the specific problem presented within the situated movie. The answers are presented to learners when they pose a question to the CA. Conversational agents developed for pedagogical purposes have been shown capable of enacting socio-cultural aspects of learning in online learning contexts (Gulz, 2004) and of actively and collaboratively working with students to solve problems (Baylor, 1999) - what Jonassen (1995) calls learning *with* technology rather than learning *from* technology. The CA used in this study is an adaptation of the CAs used in previous studies we conducted. We have provided a full specification of the underlying technology and artificial intelligence engine in Doering, Veletsianos, and Yerasimou (in press). Regarding this study, the knowledge base of the CA was expanded to include questions and answers relevant to the content area we are examining in this paper. To that respect, we identified sixty-one possible questions that users could ask the CA. We then broke down those questions into keywords such that we could match different questions to different keywords. For example, the answer to the question "Where is the Turtle River?" could be given with any combination of the keywords "turtle," "river," "turtle river," "where," and "watershed." The answer to this question is "The Turtle River is in the watershed of the Red river Valley on the border between Minnesota and North Dakota."

The fourth scaffold, the *collaboration zone (CZ),* allows learners to discuss the task at hand and elicit assistance in real-time as needed from both their peers and an expert moderator or coach (Enkenberg, 2001) within the environment. A CZ situates conversations in a social context, allowing learners to interact and negotiate meaning (Vygotsky, 1978) and to actively participate in their learning (Jonassen, 2000) by collaborating to solve a common task (Bransford, Brown, & Cocking, 1999). The CZ allowed learners to discuss any problems they were having at any time – ranging from procedural to content. As learners entered the MSE environment, they were automatically entered into the CZ where they could discuss as they wished.

The scaffolding within the MSE is also designed to reduce learners' cognitive load while using the online learning environment. Bunch and Earl Lloyd (2006) argue that cognitive load theory and cognitive load management are fundamental in representing geographic information because maps provide large and complex amounts of geospatial information. Cognitive load theory posits that effective instructional materials facilitate learning by "directing cognitive resources toward activities that are relevant to learning rather than toward preliminaries to learning" (Chandler & Sweller, 1991, p. 294). Chandler and Sweller note that unnecessarily forcing learners to work with disparate sources of mutually referring information leads to ineffective instruction and to increasing their cognitive load before the intended learning actually begins. Therefore, MSE, instead of requiring learners to utilize specific instructional materials before commencing their learning, allows them the freedom to employ any of the four scaffolds at any time as they deem them necessary to their understanding and solving of the problem.

Geographic Inquiry: Thinking Geographically

Within a PBL geography environment, one of the main goals is to encourage the learner to think as a geographer. Thinking as a geographer means more than simply understanding what geography is, but means fulfilling the steps of geographic inquiry, which is the goal of MSE. The steps of geographic inquiry include: (a) asking geographic questions, (b) acquiring geographic resources, (c) exploring geographic data, (d) analyzing geographic information, and (e) acting upon geographic knowledge (Malone, Palmer, and Voigt, 2002). All of these steps can be accomplished by utilizing a geographic information system.

INSERT FIGURE 1 ABOUT HERE

Asking geographic questions involves taking an observation and turning it into a form of a question. This observation can range from the simple to the complex, but it sets up the condition to investigate the question and/or problem. Acquiring geographic resources entails thinking about the problem and considering the data and necessary resources to solve the problem. Exploring geographic data requires turning the acquired data and resources into maps, tables and charts, thereby allowing for visual exploration. This step involves searching and confirming relationships that may lead to the answer through analyzing the information. Analyzing geographic information necessitates learners to investigate the maps, tables, and charts in detail as investigations move from the basic to the detailed. This step encompasses confirming and disconfirming previous hypotheses, which may lead learners to an answer or may require them to return to acquire additional data. Finally, if the data acquired, mapped and analyzed lead to a feasible answer, the knowledge can be acted upon. This involves presenting the findings to an individual, a class, or reporting them to the local community and/or government. Table 1 provides an example of the levels of geographic inquiry. The problem presented in this table requires learners to identify the best location for a trout habitat restoration project in the Turtle River within the Red River Valley in North Dakota, and it is the problem upon which MSE was designed and developed.

INSERT TABLE 1 ABOUT HERE

Purpose

In this study, we sought to understand: (a) how students utilize the MSE when using GIS to solve an authentic problem, and (b) the relationships between the scaffolds utilized within MSE and the students' cognitive load and problem-solving ability. Once again, the authentic problem used in this study concerned extensive water pollution in the Turtle River within the Red River Valley in North Dakota. The students' task was to identify the best location for a trout habitat restoration project using MSE and the GIS program ArcView. We were interested in addressing the following questions regarding students' accomplishment of this task:

1. What are the relationships between MSE scaffolds and students' ability to solve an authentic task?
2. What are the relationships between MSE scaffolds and cognitive load when solving an authentic task?
3. How do students respond to the use of MSE to solve an authentic task?

Method

Participants

Pre-service and in-service teachers (hereafter *participants*) from two educational technology courses participated in this study. Fifty participants were invited to voluntarily take part in the study, and 42 elected to participate (32 women and 10 men). The reported mean age of participants was 32.3 years (SD = 10.3).

Materials

MSE. Participants had access to the Multi-Scaffolding Environment (Figures 2, 3, 4, and 5) to assist them in solving the authentic task. While working with MSE, the software unobtrusively collected the following data for each participant: (a) the number of times they accessed each scaffold, (b) the amount of time for which they accessed each scaffold, and (c) the order in which they accessed each scaffold.

INSERT FIGURES 2, 3, 4, and 5 ABOUT HERE

ArcView. Participants also had access to ArcView, a GIS program that allowed them to manage, visualize, and analyze the data relevant to the problem at hand. ArcView is a software application that allows learners to layer any type of information in a visual format. Learners can then turn on and off layers to analyze any place on earth. For example, during the weather forecast section of the evening news, meteorologists are using a GIS program to show viewers the local weather maps. There are numerous layers within the forecasting maps that include streets, towns, geographic borders, clouds, and forecasting temperatures. Every layer can be turned on and off as needed to forecast the weather. Within this study, learners had access to layers encompassing watershed, river, county and state border, and pH river data.

Cognitive load recording instrument. A rating scale technique was used to measure cognitive load, in which participants subjectively reported the mental effort they had exerted from 1 to 7, with 7 representing extremely high and 1 extremely low. Paas (1992) and Paas and van Merriënboer (1993) report obtaining coefficients of reliability for this scale of $\alpha = 0.9$, and $\alpha = 0.82$ respectively, leading them and Paas, van Merriënboer, and Adam (1994) to claim that such scales are valid, reliable, unobtrusive, sensitive to relatively small differences in cognitive load, and the most frequently used measures of cognitive load in cognitive load research. Learners were presented the paper-based cognitive load assessment and were trained how they should record the mental effort throughout the task accordingly.

Problem-Solving Ability (PSA) Measure. The learner's problem-solving ability was measured by the learner's ability to answer open-ended questions and the justifications he/she gave for their identification of the best area for a trout habitat restoration project. The most important measure was the learner's justifications as it revealed how he/she accomplished the steps of geographic inquiry.

Post-task questionnaire. An online survey consisting of 32 closed and open-ended questions was used to collect demographic information on each participant and quantitative and qualitative data relating to participants' MSE experience.

Procedure

Upon accepting the invitation to take part in this study, participants met in a computer lab in which they had access to personal computers equipped with headphones, the MSE, ArcView, the cognitive load data recording instrument, and the online survey. Upon receiving a 10-minute introduction on using the MSE and how they would record their cognitive load, participants had 60 minutes to solve the geographic problem. Although 60 minutes may be insufficient time for problem-solving, it does represent the typical amount of time a teacher has to teach a problem as this within the K-12 classroom. At 20-minute intervals, participants were asked to record their perceived cognitive load on the paper-based 7-point scale. At the end of the 60 minutes, participants completed the post-test survey and were debriefed and thanked for their participation.

Data Analysis

Participant performances were documented based on the number of answers they provided that accurately led to the solving of the problem (problem-solving ability) along with their cognitive load (CL) score. Moreover, the total amount of time participants spent using a scaffold (SA) within the MSE environment was recorded and analyzed.

Upon analyzing the descriptive statistics along with the treatment means of the dependent and independent variables (Table 2), multiple linear regressions were used to examine the relationship between problem-solving ability, cognitive load, and access to the scaffolds. An alpha level of .05 was used to determine if there was a statistically significant relationship between the dependent and independent variables.

INSERT TABLE 2 ABOUT HERE

Qualitative data were analyzed using a constant comparative method (Glaser & Strauss, 1967). First, the data were read noting emerging patterns across individuals. The patterns were then compiled, shared among co-authors and reread, and searched for confirming and disconfirming evidence for the patterns, until a consensus was reached on the salient patterns that emerged from the data.

Results

Descriptive Statistics

Table 2 presents the number of times participants accessed each scaffold and the amount of time spent on each scaffold. These data indicate that the collaboration zone and the screen capture videos were accessed more frequently than the agent and the situated movie. The time spent on these two scaffolds was also greater than the time spent with the agent and the screen capture videos. Additionally, our data indicate that the students exchanged 126 messages in the collaboration zone, and asked 53 questions of the conversational agent. Ninety-six percent of these questions and answers were directly related to the task assigned.

Quantitative Results

When analyzing the quantitative data, we were interested in examining the relationships between cognitive load (CL) over time, participant problem-solving ability (PSA), and the utilization of scaffolds. Change in CL was identified by using three measures from each participant: difference in CL between 20-40 minutes (CL-A), 40-60 minutes (CL-B), and 20-60 minutes (CL-C). Specifically, our regression model for problem solving ability was expressed as:

$$\text{PSA} = \text{Constant} + \alpha(\text{Situated Movie SA}) + \beta(\text{Screen Capture Movie SA}) + \gamma(\text{Conversational Agent SA}) + \delta(\text{Collaboration Zone SA}) + \text{error} \quad (1)$$

Similarly, our regression models for the three measures of cognitive load were:

$$\text{CLA-A} = \text{Constant} + \alpha(\text{Situated Movie SA}) + \beta(\text{Screen Capture Movie SA}) + \gamma(\text{Conversational Agent SA}) + \delta(\text{Collaboration Zone SA}) + \text{error} \quad (2)$$

CLA-B = Constant + α(Situated Movie SA) + β(Screen Capture Movie SA) + γ(Conversational Agent SA) + δ(Collaboration Zone SA) + error (3)

CLA-C = Constant + α(Situated Movie SA) + β(Screen Capture Movie SA) + γ(Conversational Agent SA) + δ(Collaboration Zone SA) + error (4)

The regression results are displayed in Table 3.

INSERT TABLE 3 ABOUT HERE

Problem-solving ability and utilization of scaffolds. A multiple linear regression with problem-solving ability as the dependent variable (Equation 1) indicated a positive and significant relationship between problem-solving ability and time spent viewing the screen capture video. This result indicates that as time spent viewing the screen capture video increases by one minute, participants' problem solving ability increases by about half a point. Even though time spent viewing the situated movie does not appear to have a significant relationship with problem solving ability, this relationship is positive, indicating that as time spent viewing the situated movie increases by one minute, participants' problem solving ability also increases. The relationships between problem-solving ability and time spent in the collaboration zone and conversing with the agent are negative and insignificant. This result signifies that as time spent collaborating with others and conversing with the agent increases, participants' problem solving ability decreases.

Cognitive load and utilization of scaffolds. A multiple linear regression with CL-A as a dependent variable (Equation 2) signifies positive and significant relationships between time spent on the situated video, screen capture video, and collaboration zone. This result indicates that as time spent viewing the situated movie, inspecting the screen capture video, and collaborating with others increases by one minute, the mental effort exerted on the task between 20 and 40 minutes increases by about half a unit for each independent variable. Even though we observed a positive relationship between the time spent conversing with the agent and the change in cognitive load, this relationship is insignificant.

To explain changes in mental effort exerted between 60 and 40 minutes, we used Equation 3. Our results indicate that none of the four independent variables sufficiently explains variations in cognitive load alterations. Albeit insignificant, the time spent on the situated movie and on the collaboration zone is positively related with changes in cognitive load between 40 and 60 minutes. In other words, as time spent viewing the situated movie and cooperating with other participants increased, the mental effort exerted on the task between 60 and 40 minutes also increased. Conversely, the time spent on the screen capture video and conversing with the agent is negatively related to changes in cognitive load between 40 and 60 minutes. This result implies that as participants spend more time viewing the screen capture video and conversing with the agent, their exerted mental effort between 40 and 60 minutes decreases.

Our last regression equation also yielded insignificant results. Similarly to CL-A, positive relationships were discovered between time spent on the situated movie, screen capture video, and collaboration zone, and the change in cognitive load between 20 and 60 minutes. In other words, as time spent viewing the situated movie, observing the screen capture video, and collaborating with others increases, the mental effort exerted on the task between 20 and 60 minutes also increases. On the contrary, as participants spent more time conversing with the agent, their cognitive load between 20 and 60 minutes decreased.

Qualitative Results

The qualitative data revealed that participants reported that (a) access to scaffolds was an asset for their learning, (b) a positive MSE experience required having adequate time to complete the task, (c) they used scaffolds depending on what they desired and needed, and (d) they viewed the MSE and multi-scaffolding concept as valuable for teaching and learning.

Access to scaffolds is an asset for student learning. Participants reported enjoying using all four scaffolds within MSE. Every participant made a positive comment about the MSE environment and the availability of the numerous scaffolds for support. Scott, for instance, said, "I thought the scaffolding tools were very helpful - wished there were more of them!" Samantha noted, "I see the possible benefits of the MSE environment. I think having the 4 scaffolds available for learners is great. It is much better than having only one option. I wanted to have more than one open at a time." Sue stated, "I liked that the environment had multiple options, one of which fit my learning style best (tutorial videos)." Every learner identified a favorite scaffold that they utilized most often.

Positive MSE experiences require adequate time. No participants had prior experience utilizing the MSE, and only one had any extensive experience utilizing a GIS. This lack of prior knowledge was reflected in the participants' descriptions of their MSE experience, as over 50% of them stated that, having never utilized a GIS before, they were frustrated and wanted to have additional time to use the scaffolds to assist them in their use of the GIS software. As Mandy noted, "I found the environment helpful in providing assistance as I attempted to solve the problems presented in the exercise. Although the MSE provided me with additional direction and instruction, I still felt limited in my ability to effectively navigate the GIS mainly because of time." Even though Mike found the MSE environment "interesting, very entertaining, and requiring thinking, much like an intellectual game," Jessie said that "as a person never having known or used anything with GIS before, the tasks were pretty difficult."

Use of scaffolds is based on students' desires and needs. Over 80% of the participants made reference to a specific scaffold that they deemed most beneficial. Prior to implementing the MSE environment, we hypothesized that learners would utilize the situated movie and screen capture videos as primary scaffolds as these two scaffolds help frame the problem and provide instruction to the tool that learners used to solve the problem. However, data revealed the collaboration zone was accessed most frequently, followed by the screen capture movie and situated video. Mark noted that he used the collaboration zone the most because "chatting with others who were trying to complete the same tasks made me feel less frustrated when I knew that others were having the same problems and questions as I did. I also liked chatting because we were able to help each other." Jennie noted that she used the collaboration zone and the agent the most because she enjoys interacting with others, while Brooke stated "If I couldn't find something, [the collaboration zone] was an easy way to ask and use someone else's experience." Nevertheless, it appears that participants did not find the assistance provided by the conversational agent useful. Chad summed up this feeling: "I hated Joan or whatever the super-agent lady was called. She asked me at one point, 'Are you testing me?' like we were going to have some sort of a confrontation or something. I've never wanted to hurt a digital person before!"

MSE and the multi-scaffolding concept as valuable for teaching and learning. Over 90% of participants noted that MSE would be a valuable tool in teaching and learning. Peter noted, "I think that this would be an incredible learning experience for students because it creates problem-solving skills and it incorporates interaction and collaboration between peers."

Jenna added, “It is great to encourage exploration and curiosity with support and coaching. Instead of just being given the information, I was exploring the area myself. I felt that I had the resources I needed for help.” Brad made a similar comment:

> MSE could assist in teaching because it encourages independent learning and exploration. Teachers could better individualize instruction and spend one-on-one time with students, and students would have confidence knowing that the scaffolds are also there for support. Especially in an online environment in which I teach, this format would be very helpful and beneficial for my students working from home.

Simon elaborated on MSE’s ability to be used in non-traditional learning environments:

> I think it would be quite helpful in assisting learning in online or distance learning environments, where instructors are less accessible to assist in learning. The MSE would also be effective in alternative learning environments, for students who struggle in traditional didactic settings. I think these tools would promote learning because they give students choices and engage them with interactive tools.

Mary commented on the positive impact the MSE environment could have within a traditional classroom:

> I think that MSE could help those students who never have a confidence and sense of independence to take the time to figure it out. Some kids get so dependent on their teachers for all the answers and all the steps that they are afraid to try on their own and never take risks. I think the MSE would be perfect for helping them learn at the same time as breaking that cycle.

Finally, Jack extended the benefits of MSE to domains beyond geographic literacy: “I think that exercises like that are very educational, motivating, and fun to do. It gives students a taste of independent scientific research (formulating the problem, analyzing data, interpreting results).”

Discussion

Focusing on geographic education, in this study we examined the concept of and relationship between multiple scaffolds and learners’ cognitive load and problem-solving ability in the context of PBL. We presented MSE as an online learning environment that provides authentic assistance to learners who are involved in solving an authentic task where scaffolds are learner- rather than expert-controlled. Specifically, learners could utilize the MSE scaffolds as they deemed necessary throughout their engagement with the task.

The qualitative data collected to examine learner experiences were mostly positive, revealing that the multiple scaffolds (a) elicited scaffold-specific responses, and (b) provided the necessary support throughout participants’ learning experiences. Although participants responded having mostly positive experiences, they also requested more time to use the scaffolds and work on the geographic problem. Albeit excited and motivated to use the environment, the complexity of the task combined with the difficulty of using ArcView may explain the insignificance of some of the quantitative results.

The quantitative data revealed that time spent on the screen-capture video was positively and significantly related to problem solving ability. In light of the complex nature of problem-solving with GIS and the fact that participants in this study had limited knowledge of using GIS, this result is of practical importance. It indicates that screen capture videos that demonstrate the procedural tasks to solve a problem may be valuable in assisting learners. Familiarity with a tool required to solve a task is paramount and as such, screen capture videos may be a viable scaffold in assisting learners in becoming competent in the use of the tool.

Even though we expected the situated movie and the collaboration zone to exhibit significant relationships with problem solving ability, we did not observe such a result. We believe that we may have overestimated the inherent significance of the situated movie. Specifically, learners may have returned to view the situated movie to gain more clues and data about the problem to be solved. If repeated viewings of the movie did not provide additional data to learners, viewing the situated movie for those additional minutes does not change learners' problem solving ability, while at the same time increasing time spent on the situated movie. This possibility may help explain why we did not observe a significant relationship between participants' problem solving ability and the time the spent viewing the situated movie. The same holds true for the collaboration zone: Time spent collaborating with others does not necessarily mean that learners gained any additional knowledge by being in the collaboration zone. In the future, we will collect additional data on each of these scaffolds. For example, after each time accessing a scaffold we could have queried learners on whether they gained any *new* and relevant information on the problem that they needed to solve. This could have helped us discriminate between two levels of the situated movie variable: times where watching the situated movie yielded new and relevant information in solving the task, and times where watching the situated movie did not provide any additional information.

The conversational agent did not bear any significant relationship to problem solving ability or cognitive load. We believe this could be explained by the limited time the learners had to solve the geographic problem and the relative inefficiency with which the agent provided answers to the learners. As argued elsewhere (Doering, Veletsianos, & Yerasimou, in press), conversational agents need to be programmed with advanced, highly detailed, and relevant knowledge to adequately provide support to learners within electronic learning environments.

Regarding cognitive load, only the CL-A measurements were significantly related to the situated movie, screen-capture video, and collaboration zone scaffolds. A possible explanation for this result is that the situated movie presented the problem in its entirety along with the clues and data required. Thus, as participants spent more time watching and returning to the movie to collect vital details such as necessary pH and dissolved oxygen levels, their cognitive load increased as they anticipated the challenge ahead. Moreover, as the students were initially working to understand and solve the problem, they were learning the utility of the scaffolds and the ArcView program. For example, as student learned how to use ArcView to solve the problem they frequently visited the screen capture videos to gain procedural knowledge thereby exerting mental resources. Additionally, one may expect that cognitive load would not decrease in relatively novice problem-solvers, but would actually increase due to the complexities of the problem.

Qualitative results indicate the perceived positive value of the collaboration zone - the scaffold that was accessed most frequently. Participants enjoyed the presence of others. They could ask questions while reading what others were discussing and the problems they were encountering. Therefore, it appears that social interaction and collaborative work were valued more highly than the rest of the scaffolds, even though, theoretically, one could solve the posed problem without accessing the collaboration zone. The benefits of collaborative work in the solving of a task and the roles learners take in supporting each other have long been proposed in previous work (e.g. Johnson and Johnson, 2004, pp. 790) and our results indicate the perceived benefits of real-time collaboration which support the concept of intersubjectivity between learners and between learners and experts.

Finally, it should be noted that participants were excited about MSE and the potential for the design of environments that can support online learners within PBL contexts. Although the results of this study are mixed, participant responses indicate that online learning environments encompassing multiple levels of complementary support for learners may be beneficial for teaching and learning. Future research in this direction and in identifying the reasons students used specific scaffolds may help illuminate the differential quantitative impact of each scaffold on learning and problem-solving ability. Specifically, experimental evidence on the effect each individual scaffold has on learning would be valuable in developing a hierarchy of scaffold effectiveness within electronic learning environments that utilize multiple levels of support.

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Table 1

Levels of Geographic Inquiry for the Trout Habitat Restoration Project

Geographic Inquiry Steps	Examples
Ask a geographic question	At which sites is the Turtle River healthy? Which sites will support trout habitat restoration? What influences the water river of the Turtle river?
Acquire geographic resource	Obtain GPS points of all the sites. Determine protocol for collecting water-quality data. Collect water-quality data for each of the sites, for all four seasons. Record data in a table that can be imported into ArcView. Obtain basemap data of the area (river locations, state boundaries, and aquifers).
Explore geographic data	Thematically map each water-testing variable using graduated symbols and colors, and bar and pie charts where appropriate. Join new data tables to existing data. Visually analyze patterns in data.
Analyze geographic information	Visually analyze each test to identify temporal and spatial trends. Overlay aquifer data to explain identified trends. Repeat study to see how patterns change over time.
Act on geographic knowledge	Summarize results. Prepare and practice presentations for interpretive programs, television interviews, and local conferences. Give presentations. Supply Red River Regional Council with data for trout habitat restoration.

Note. From Community in Geography: GIS in Action (p. 18), by K. Z. English and L. S. Feaster, 2003, Redlands California: ESRI Press. Copyright 2003 by the ESRI.

Table 2

Variable Means and Standard Deviations

	Mean	Standard Deviation
Times accessed SV	1.94	1.31
Times accessed SC	3.39	2.91
Times accessed chat	5.50	4.73
Times accessed agent	2.33	1.65
Time spent on SV	6.06	5.65
Time spent on SC	11.12	8.61
Time spent on chat	15.05	11.54
Time spent on agent	3.07	2.71
Cognitive Load at 20min	5.03	1.30
Cognitive Load at 40min	5.16	1.01
Cognitive Load at 60min	4.79	1.75
Problem-Solving Ability	8.63	5.90

Table 3

Summary of Multiple Regression Analyses for Variables Predicting Problem Solving Ability, Change in Cognitive Load from 40 to 20 Minutes, Change in Cognitive Load from 60 to 40 Minutes, and Change in Cognitive Load from 60 to 20 Minutes (N = 42)

	Problem Solving Ability			Change in Cognitive Load from 40 to 20 Minutes			Change in Cognitive Load from 60 to 40 Minutes			Change in Cognitive Load from 60 to 20 Minutes		
Variable	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*
Situated Video	.33	.23	.27	.10	.04	.47*	.06	.09	.17	.17	.09	.44
Screen Capture Movie	.41	.17	.53*	.06	.03	.44*	-.03	.07	-.12	.01	.07	.03
Collaboration Zone	-.01	.07	-.01	.03	.01	.50*	.01	.03	.10	.04	.03	.35
Conversational Agent	-.72	.47	-.28	.09	.07	.19	-.26	.18	-.35	-.14	.19	-.18
R^2		.49			.59			.19			.32	
F		3.88*			5.80*			0.82			1.68	

*$p < .05$.

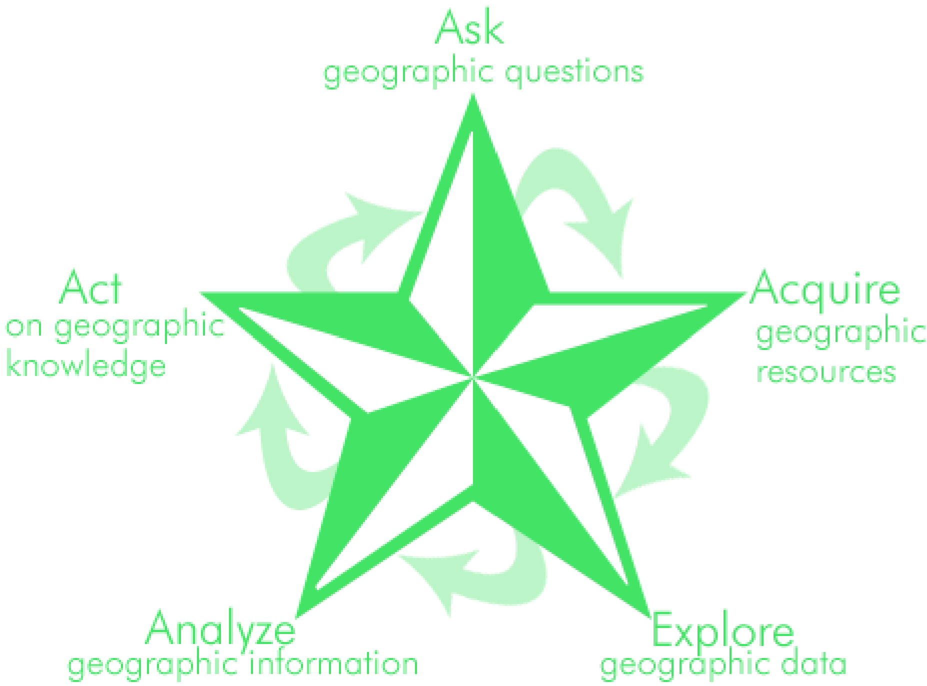

Figure 1. Geographic Learning Problem Based Learning Model.

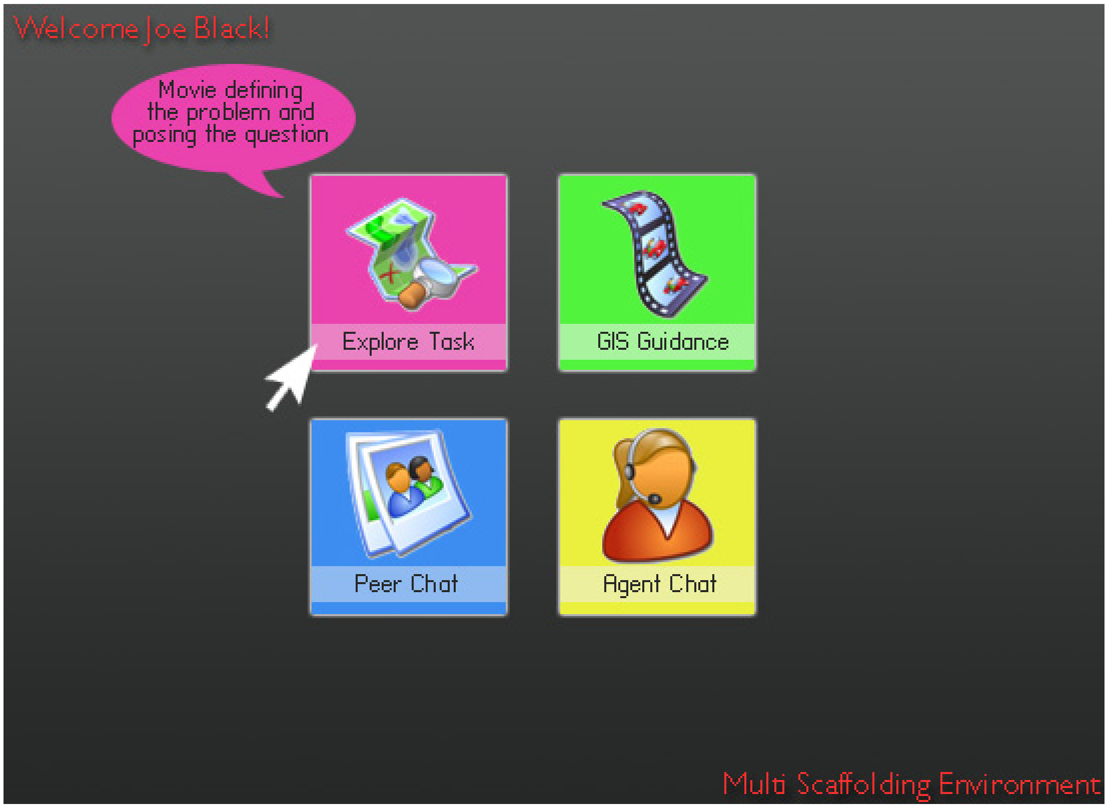

Figure 2. Multi-Scaffolding Environment: scaffold access screen.

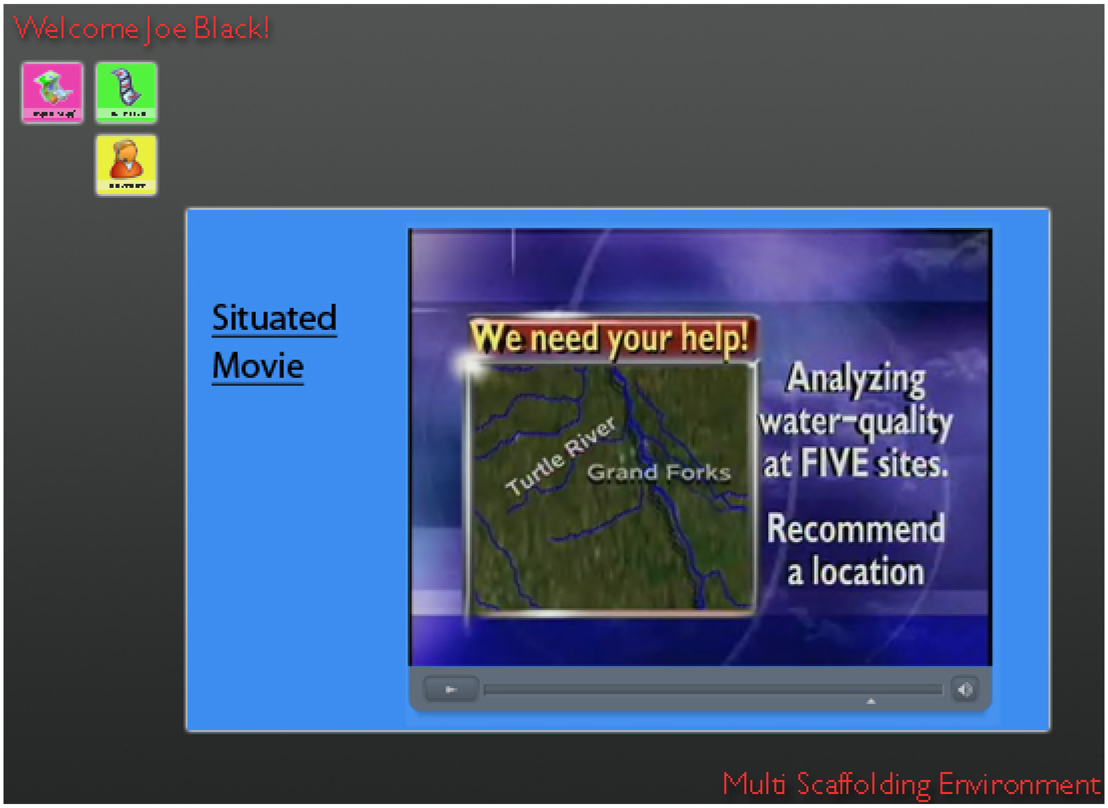

Figure 3. Multi-Scaffolding Environment: situated movie.

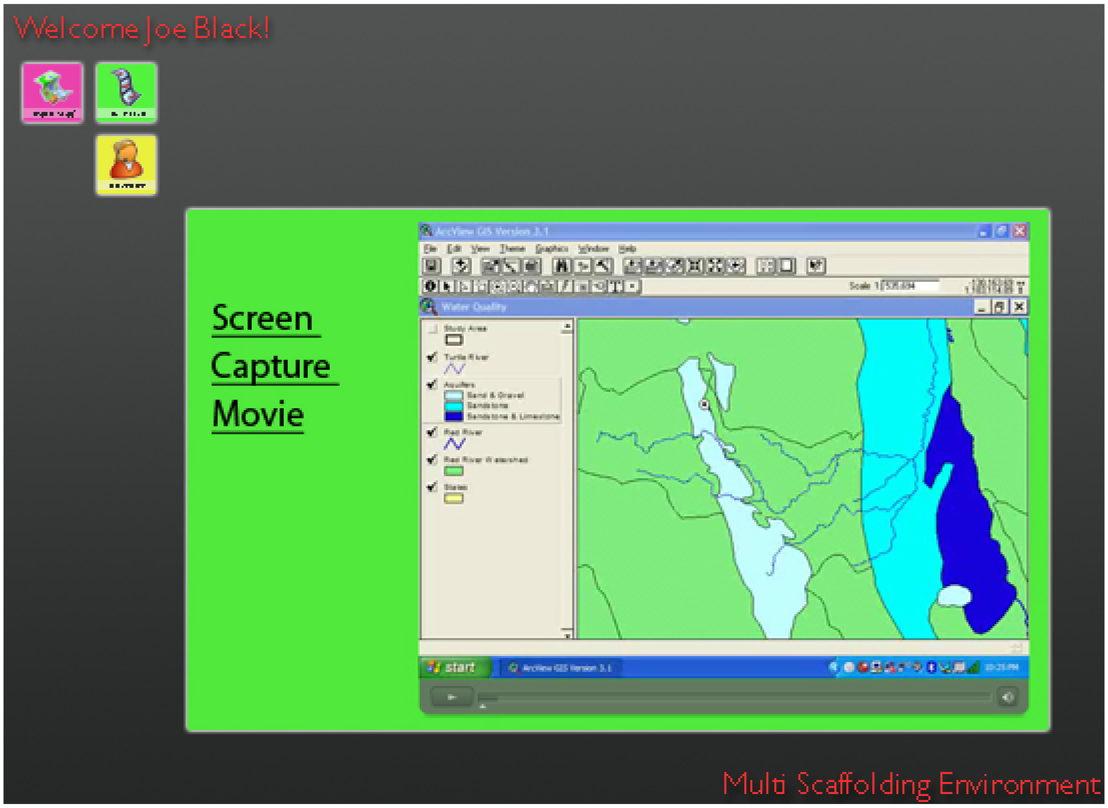

Figure 4. Multi-Scaffolding Environment: screen capture movie.

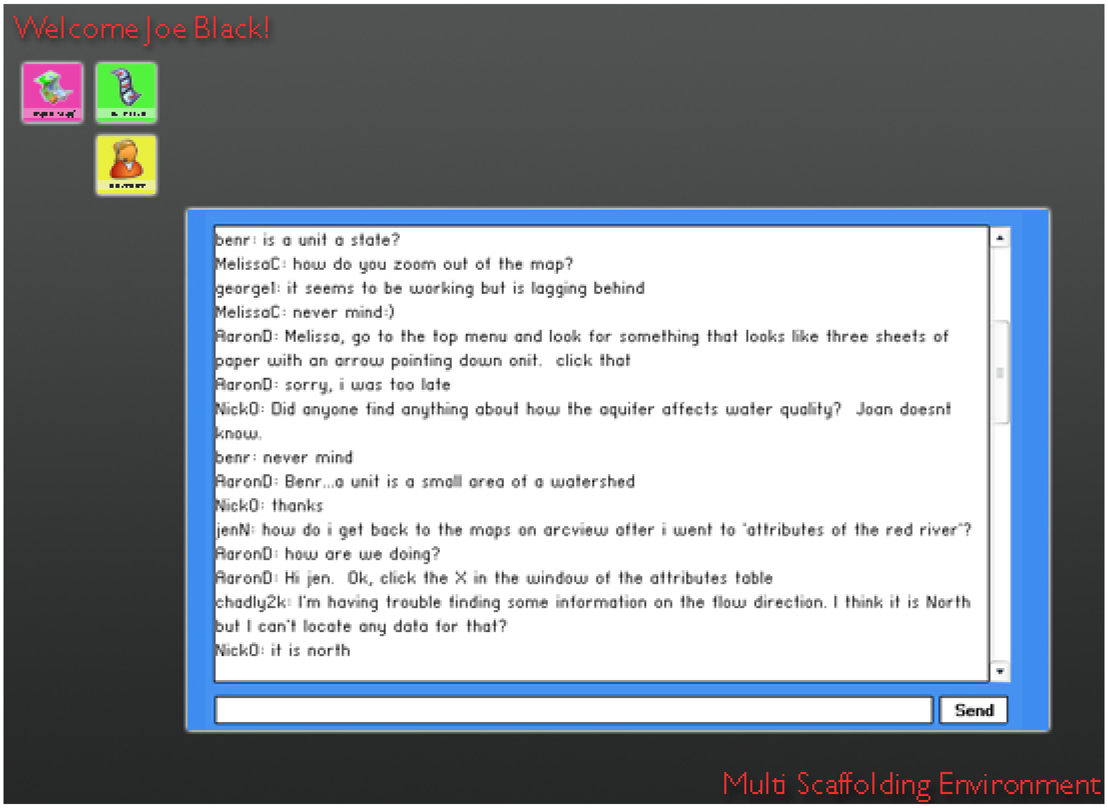

Figure 5. Multi-Scaffolding Environment: collaboration zone.