# The Effect of Different Types of Scaffolding in a Multimedia Program on Students' Ability to Define a Complex Problem: A Pilot Study

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# INTRODUCTION

A critical element of problem solving is the area of problem finding. Albert Einstein is often quoted in this area as saying, "To raise new questions, new possibilities, to regard old questions with a new angle, requires imagination and marks real advance in science" (cited in Czarnik & Hickey, 1997, p. 2). In order to solve complex real-world problems, scientists and other problem solvers must first be able to define the problem situation. The challenge of problem finding becomes evident in research conducted by Rowell, Gustafson, and Guilbert (1999). When the researchers asked engineers how they learned to solve technological problems, many responded that defining the problem was the hardest part for them to learn. The issue is that problem finding is not typically taught in schools. One engineer crystallized this problem in her statement:

> I think the traditional method [of instruction] is to be given all the right information in the problem and it's all set up for you and all you have to do is take this equation and you just plug in those things. There is no intermediate analysis that needs to be done before you do it and engineering requires that you do that. It's something that you don't learn in school. (Rowell et al., 1999, p. 112)

Thus, this pilot study focused on the problem-definition phase of problem solving. In order to study this area, I developed a software program called "Pollution Solution."

> *In Pollution Solution, the students take on the role of an intern for an environmental consulting firm. They are given a client who is facing a number of environmental issues and are asked to identify the problem and recommend a solution for the company. To do this research, the students "interview" experts and "conduct" site visits. The students also get to hear multiple perspectives on these topics so they can wrestle with these issues and draw their own conclusions.*

This learning environment presents students with a complex, ill-structured problem, based on principles from the cognitive flexibility (CFT) and situated learning theories. For example, this learning environment employs aspects of CFT by providing students with different expert perspectives on the issue, presenting multiple cases for contextualizing the problem, stressing the overlapping connections between the related domains of knowledge, and providing opportunities to construct knowledge (Jacobson & Spiro, 1995). Although

CFT does not prescribe that the cases be authentic, situated learning complements CFT because cases drawn from the real world are inevitably richer and more complex than ones that are made up (Li & Jonassen, 1996). The drawback of utilizing CFT for the purposes of engaging young learners is that it was developed for advanced (post introductory) knowledge (Sprio, Feltovich, Jacobson, & Anderson, 1991). As a result, most of the research on applications based on CFT have focused on adult learners (Balcytiene, 1999; Demetriadis & Pombortsis, 1999; Fitzgerald , Wilson, & Semrau, 1997; Jacobson & Spiro, 1995; Li & Jonassen, 1996). One study by Demetriadis and Pombortsis examined novices' use of a CFT environment. Although the subjects in this study were in their 1st and 2nd years of college, they were novices in computer networking and had never learned with a computer-based instructional environment. In order to support novices learning in this type of environment, the researchers provided scaffolding to guide the users. Given the promising results of this study, layers of scaffolding were added to Pollution Solution through an iterative design-and-development process, including formative evaluations with teachers and students, over a three-year period. As a result of this process, I conceptualized a new instructional model that builds on CFT and incorporates situated cases and scaffolding elements from a variety of constructivist theories and models. This scaffolding helps foster students' cognitive processes, provides supportive guidance through modeling and coaching, and helps students with time management. For the purposes of this discussion, I will refer to this model as the scaffolded flexibilty model (SFM). The design of this study will test how these different scaffolds affect students' ability to define a complex problem.

Problem finding covers a wide range of activities from problem identification to hypothesis generation (Runco & Nemiro, 1994). One important skill in defining a problem is formulating good questions. “The hard part is figuring out the questions” commented one of the engineers in the study by Rowell, et al. (p. 112). Formulating questions can help students invent new problems or define a given problem. Some studies focused on students defining new problems (Cuccio-Schirripa & Steiner, 2000; Keys, 1998). These studies analyzed the connection between student-generated questions and the type of investigations or experiments that result, and also addressed the relationship between this activity and student interest.

Some researchers have investigated the nature of students' questions about a given problem (Chin, Brown, & Bruce, 2002; Czarnick & Hickey, 1997; Dori & Herscovitz, 1999; Olsher & Dreyfus, 1999). There is an underlying assumption that students with a deeper understanding of the problem will ask better questions. One study by Olsher & Dreyfus found students' questions were correlated to some extent with their knowledge acquisition. Cuccio-Schirripa and Steiner (2000) recommended the need for future research in determining the effect student questioning has on students' knowledge and achievement.

One issue with analyzing student questions before and after a treatment is the difficulty in ascertaining whether the students asked better questions due to increased expertise or some other factor. To address this issue, some studies looked at other factors including achievement (Cuccio-Schirripa & Steiner, 2000; Dori & Herscovitz, 1999), learning approach (Chin et al., 2002), and different teachers and classrooms (Cuccio-Schirripa & Steiner). None of the studies examined how students' problem-solving abilities affected their questioning skills. Since questioning is an important part of the problem-solving process, the effect of students' problem-solving abilities on student knowledge acquisition and questioning skills is an important area for further analysis.

In order to address the questions raised in these prior research studies, this pilot study investigated how different types of scaffolding in an SFM environment affect young learners' ability to define a complex problem. The students' performance was measured by their knowledge acquisition or understanding of the problem and their ability to formulate questions and hypotheses. In order to determine whether scaffolding type affected these measures, different treatments were developed with varying amounts of scaffolding. In addition, students' problem-solving ability was assessed to determine whether it was be a factor in explaining students' ability to define problems.

## CONCEPTUAL FRAMEWORK

In order to design a program for young learners, this environment employs the scaffolded flexibility model (SFM) which builds on the cognitive flexibility theory (CFT). In addition to CFT, SFM situates the learning environment within an authentic scenario and utilizes a range of scaffolding techniques selected to provide additional structure and support while still allowing the learners to develop flexible knowledge structures about complex issues.

### Cognitive Flexibility Theory

The main theoretical framework used in the development of this model is the cognitive flexibility theory. CFT is a theory that was developed by Spiro and his colleagues at the University of Illinois's Center for the Study of Reading in the late 1980's. This theory specifically addresses the deficiencies of advanced knowledge acquisition. Spiro, Coulson, Feltovich, and Anderson (1988) hypothesized that many of the learner failures came about because complex knowledge was oversimplified and consequently learners developed misconceptions. To counteract these learning failures, they developed a theory "that emphasizes the real-world complexity and ill-structuredness of many knowledge domains" (Spiro, et al., 1991, p. 24). Out of this theory, they developed a set of recommendations for the development of hypertext learning environments. These recommendations are to incorporate multiple representations, include case examples, avoid oversimplification, utilize the web-like nature of knowledge, and provide opportunities for knowledge assembly.

*Multiple Representations*. "Cognitive flexibility is dependent upon having a diversified repertoire of ways of thinking about a conceptual topic" (Spiro et al., 1988, p. 5). To represent more accurately the "multifaceted" complexity of knowledge, CFT recommends using multiple themes, schemas, analogies, or intellectual points of view in instructional activities (Jacobson & Spiro, 1995). Spiro and his colleagues use a metaphor of the ill-structured domain as a complex landscape. An explorer of this landscape cannot begin to understand all of its hills and valleys through one traversal. One must cross the landscape via multiple paths to gain an understanding of its complexity (Spiro et al.). In this learning environment, the students have the opportunity to interview experts from various fields. After hearing these experts' different perspectives, students develop their own ideas on the best approach for solving this problem. By wrestling with these conflicting viewpoints, they develop flexible knowledge structures around "real world" issues.

*Case Examples*. Instead of presenting knowledge in a decontextualized format, CFT recommends presenting abstract concepts within multiple cases to provide a variety of contexts and uses of that knowledge. These cases can illustrate the intricacies of the ill-structured domain. In this theory, "the cases are key -- examples are necessary, and not just nice" (Spiro et al., 1988, p. 7). Case examples are used in this program for each expert's viewpoint. Each expert presents a separate case that interprets the student's case from a different perspective.

*Avoid Oversimplification*. Instead of simplifying complex knowledge domains, CFT recommends that the learning environment highlight the complexities and irregularities of the subject during the introduction of the instruction (Spiro et al., 1988). This prepares the learner for deeper study "that is not qualitatively different from the earlier introduction" (Jacobson & Spiro, 1995, p. 304). In the problem introduction, the students learn that this case can be examined from multiple perspectives and that they need to integrate these different perspectives into their recommendations in the final report.

*Interrelated or web-like nature of knowledge*. There is a tendency to separate complex domains into separate chapters. As an alternative, CFT proposes that the learning environment stress the interconnectedness of the multiple domains of knowledge. Rather than compartmentalizing topics, the environment should demonstrate how the domains overlap. Multiple paths should be established to enable the learner to "criss-cross" the "conceptual landscape" through different paths (Spiro et al., 1988, p. 8). In this program, the cases interrelate to information presented in the resource books, which provide links to relevant web sites. The telephone, the help system in this application, can help students make connections between the various sources of information.

*Knowledge Assembly*. In order to create flexible knowledge structures that enable the transfer of information, CFT stresses that learning environments provide opportunities for learners to combine and synthesize multiple sources of information in different ways to solve various problems (Spiro et al., 1988). In this environment, analyzing the various alternatives to the problem and synthesizing this information into a final report helps the students develop their own recommendations for the client's situation.

## Situated Problem

SFM prescribes that the ill-structured domain be situated in a meaningful context, which is not necessarily the case with CFT.

> While cognitive flexibility theory does not particularly prescribe that the cases for the student to criss-cross should be authentic real life cases, it is not difficult to see that cognitive flexibility theory can go hand in hand with situated learning in case-based environments, especially when the domain of instruction is illstructured and the use of domain knowledge is often expected in real life situations. (Li & Jonassen, p. 425)

Situated problems address the issue of students learning concepts decontextualized from how they are used by practitioners. For example, the way an engineer uses a math formula is very different from how students use this formula in school. In school, "it is common for students to acquire algorithms, routines, and decontextualized definitions that they cannot use and that, therefore, lie inert" (Brown, Collins, & Duguid, 1989, p. 33).

Instead of learning authentic applications of science and mathematical concepts, they learn how to use these concepts in relation to the culture of the school environment. "Thus, students may pass exams (a distinctive part of school cultures) but still not be able to use a domain's conceptual tools in authentic practice" (Brown et al., p. 34). If students are learning material primarily for a test, they soon forget the material because they have not made connections between the new information and its applications. When asked to apply this knowledge to a similar situation on another exam or even later in life, the students have difficulty retrieving this "inert" knowledge. One way to counteract this problem is to create authentic activities so that students can simulate "real world" uses in the classroom. To that end, this learning environment uses real experts within its cases who share their actual experiences with the learners.

## Scaffolding

The scaffolding strategies in SFM use elements from constructivism, analogical reasoning, problem-based learning (PBL) model, metacognition, and cognitive apprenticeship. The lower area of figure 1 depicts the layers of scaffolding that provide additional structure to support learners in maneuvering through the multifaceted problem domain. This scaffolding includes: time management to help pace the students during problem solving, cognitive processing to assist students in finding, organizing, and integrating their knowledge of the problem; and supportive guidance that provides modeling and coaching.

The program is divided into two parts, the problem introduction and the situated problem-solving environment. During the problem introduction, students become acquainted with the case they will work with during the course. As shown in Figure 1, the scaffolding in the problem introduction is required (i.e. the learners cannot bypass the scaffold) and its timing is controlled by the system. The situated problem-solving environment provides students with the tools necessary to help them define and eventually solve the problem. In the situated problem-solving environment, only the time management scaffold is both required and controlled by the system. The cognitive processing scaffolds are required, but learners have control over when they access them. On the other hand, the supportive guidance is completely optional in the problem-solving environment. The diagram illustrates how the scaffolding fades as one moves across and down the model.

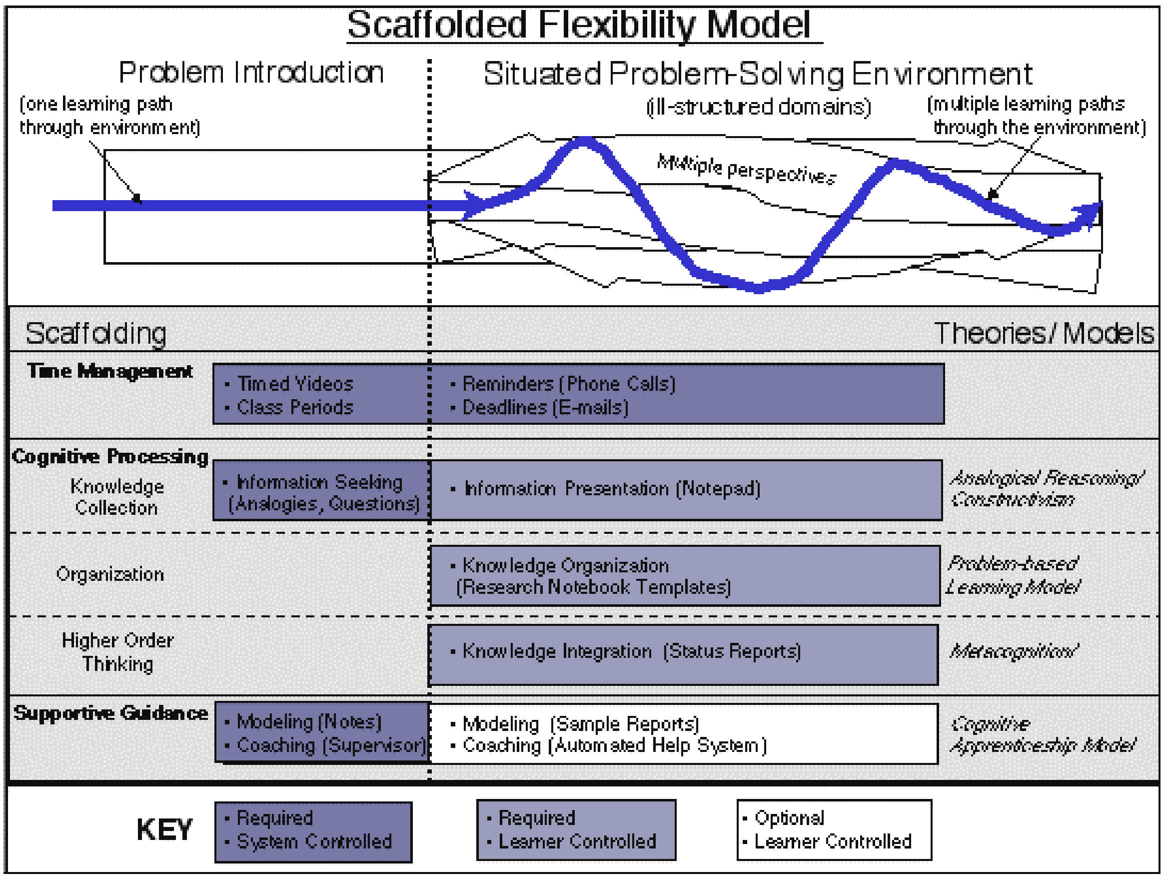


*Figure 1*. Diagram of scaffolded flexibility model

*Cognitive Processes*

To enable students to find and solve complex problems, scaffolding can be used to support students' memory and metacognitive processes. Effective memory strategies can help students understand the complex domain knowledge and apply it to the problem situation. Metacognitive strategies can help students monitor their understanding of the problem and their progress toward reaching their end goal (Lajoie, 1993).

Scaffolding elements that support cognitive processes are based on the cognitive tool classifications developed by Iiyoshi and Hannafin (1998). Iiyoshi and Hannafin used the cognitive processes (seeking, selecting, organizing, integrating, and generating) as a way to classify their cognitive tools. The five cognitive tool classifications included: information seeking tools, information presentation tools, knowledge organization tools, knowledge integration tools, and knowledge generation tools (Iiyoshi & Hannafin). In this learning environment, a similar classification system was employed including: knowledge collection, organization, and higher-order thinking.

*Knowledge Collection*

The knowledge collection scaffold combines the information seeking and information presentation tools from the Iiyoshi and Hannafin model. They help learners retrieve prior knowledge as well as find and record new information (Iiyoshi & Hannafin, 1998). Questioning helps learners retrieve their prior knowledge; an orientation tool helps learners identify and find new information; analogies help learners relate the new knowledge to their prior knowledge; and a note-taking tool helps learners record the new information.

For example, in this program, questioning is used when the supervisor asks the interns questions about what they currently know about the problem and what they need to know in order to solve the problem. There are also pauses in the program for the classroom teacher to facilitate discussions to evoke students' prior knowledge about this topic. An orientation is provided at the beginning of the problem-solving environment. In this orientation, the supervisor gives students a "tour" of their office. An animation sequence demonstrates what information is located within the filing cabinets, research notebook, and reference manuals as well as how to use the phone, e-mail, and notepad. The notepad is an interactive computer tool that allows students to record new information they find within the program. To help the students write their research proposal, an analogy is used to compare proposal writing to a laboratory experiment in a science class.

*Organization*

The organization scaffold has two levels. At the macro-level, the organization scaffold breaks the problem into smaller problems and divides the overall task into subtasks. The organization scaffold is based mainly on the PBL model. In the PBL model, students are encouraged to articulate the problem, develop a hypothesis, gather information to solve the problem, re-examine the problem, and revise the hypothesis as needed. At the end of the process, students abstract the knowledge they have learned and summarize their findings (Savery & Duffy, 1996). The design of the research notebook is based on these principles. Different tabs within this notebook help students break down the problem and organize their tasks.

At the micro-level, the organization scaffold provides templates within each section of the research notebook "to help learners interpret, connect, and organize the represented information meaningfully" (Iiyoshi & Hannafin, 1998, p.3). These templates are based on Iiyoshi and Hannafin's knowledge organization tools. The research plan, the first section of the research notebook, provides headings and related questions to help students organize the information that they record in their notes. Since this study dealt with the problem-definition phase of problem solving, only the micro-level organization scaffold, the research plan template, was considered.

*Higher-order Thinking*

The higher-order thinking scaffold consists of Iiyoshi and Hannafin's knowledge integration tools in that they facilitate processing of content at a deeper level. These tools employ metacognitive strategies that help learners "monitor knowledge construction process as well as their knowledge status" (Iiyoshi & Hannafin, 1998, p. 3). This higher-level thinking allows problem solvers to recognize what they do not know about the problem (Winn & Snyder, 1996). To prompt this type of thinking, reflection was utilized in the design.

"Reflection refers to students looking back over what they did and analyzing their performance" (Collins, 1991, p. 130). This type of "assessment enables learners to focus not only on performance outcomes, but on diagnosing the cognitive processing components, strategies, and knowledge structures that underlie performance" (Choi & Hannafin, 1995, p. 64). In this program, students are asked to reflect on what they have learned and what questions they still have as they move through the process. One way to "provoke reflection [is] by periodically posing questions that possess deeper conceptual significance" (Chee, 1994, p. 496). These questions are posed to the student when the supervisor asks for a status report on their research.

### *Time Management*

An important part of problem solving is time management. Problem solvers must learn how to work within time constraints, to meet a final deadline by defining smaller deadlines, and to work at a fairly even pace rather than leaving all the tasks until the last minute. In this project, deadlines are given to keep students on track with completing the final report. Students are reminded of these deadlines through phone calls and e-mails that they receive while using Pollution Solution.

### *Supportive Guidance*

Scaffolding can also be used to help learners engage in cognitive activities that are beyond their capabilities. This type of scaffolding is based on Vygotsky's zone of proximal development. This learning construct established the notion that coaches or more capable peers could help learners move beyond their actual development level to meet their potential development (Vygotsky, 1935/1978). The cognitive apprenticeship model applied this learning construct to computer environments by creating a computer coach. "Coaching is the thread that runs through the entire apprenticeship experience" (Collins, 1991, p. 8-9). The coach provides hints and scaffolding, challenges students, offers encouragement, and gives feedback. The coach models learning activities and advises students on how to improve performance (Winn, 1993, p. 18). In this application, the computer coach takes the form of an internship supervisor. Students become interns for a consulting company and ostensibly become the apprentices of the internship supervisor. The supervisor offers examples from previous clients and provides advice or “hints” to the student as to how to approach the problem. In additional to the computer coach, students also receive coaching through working in teams with their peers and receiving feedback from their classroom teacher.

## RESEARCH QUESTIONS

This study investigated the effectiveness of different types of scaffolding in a multimedia program for helping students define a complex problem situated in an environmental context. Specifically, this study examined how different scaffolding affected students’ problem understanding and ability to formulate questions and hypotheses about the problem. In order to determine this, different treatments of the software were developed with varying amounts of scaffolding to support the learners in defining the problem. The following research questions were asked as part of this study:

1. What is the effect of scaffolding type in a multimedia program on students' understanding of the problem when controlling for problem-solving skill?
2. What is the effect of scaffolding type in a multimedia program on students' ability to formulate hypotheses when controlling for problem-solving skill?
3. What is the effect of scaffolding type in a multimedia program on students' ability to formulate questions about an ill-defined problem when controlling for problem-solving skill?

## DESIGN OF THE STUDY

### Sample

I used a convenience sample for this study. My criterion for selecting subjects was that they attended eighth-grade earth science classes at a New York City public school where the Pollution Solution software was piloted. According to the 1999-2000 Annual School Report, the ethnic breakdown of the students at this school was: 52.3% White, 15.8% Black, 17.4% Hispanic, and 14.6 % Asian and others including Pacific Islanders, Alaskan Natives, and Native Americans. Approximately two-thirds of the students were female. About 46% of the students were eligible for free lunch. As of 2000, there were no students enrolled as English Language Learners (ELL) (The New York City Board of Education, n.d.). One hundred twenty-eight students ranging from 13 to 14 years of age used the software in their class. The students were randomly divided into four earth science classes that were all taught by the same teacher.

Data were not collected for seven students because they either requested not to have their data collected for the study or they did not hand in their consent forms or their families' consent forms. Factors that might affect the results of the study were analyzed to determine if they were consistent across the four classes. Some exceptions that were found inconsistent across the classes were students who were absent, students who did not complete or handed in late their final assignment, or students who had to share a computer. Students with these exceptions were eliminated from the pool of students to be selected for the sample. Other factors such as working at home (with the exception of one outlier who was removed), using a computer without internet access, or losing data due to technical problems were found consistent across the classes and, thus, were not eliminated. After eliminating cases with inconsistent factors, 15 students from each class were randomly chosen to be included in the sample for a total of 60 students.

## Independent Variables

*Treatment*. The treatment was the problem-definition phase of a problem-solving project. During this phase, the students defined the problem that they had to solve over the course of the project. To solve this problem, they used an SFM learning environment called “Pollution Solution."

During the first part of the program, the students were presented with the client issue. Their client was sued by the Justice Department on behalf of the Environmental Protection Agency for defying anti-pollution regulations and illegally contaminating the air.

The government had accused the company of modernizing the power plant without updating their pollution controls as required by the Clean Air Act. The company had received bad publicity as a result of the lawsuit, which caused its stock prices to fall. This company had to decide whether to pay expensive legal fees to fight the lawsuit and risk paying possible fines or settle the lawsuit and find alternative solutions to reduce emissions. The company also needed to start some type of promotional campaign to address its public relations issue. Based on this issue, the students were asked to define the problem and come up with hypotheses for solutions.

The classes were randomly assigned to one of four treatment groups who each received different versions of the software. All treatments explained the client issue through opening videos with the internship supervisor and client and also provided resources for the students to solve the problem. However, the different treatments included varying types of scaffolding to help the students define the problem.

For this study, I chose to focus on scaffolds that support cognitive processing because these scaffolds are critical during the problem-definition phase of problem solving to help students understand and synthesize the complexity of the problem. All treatments included the knowledge collection scaffolding. This scaffolding consisted of the analogies, questioning, and an orientation, which helped the students retrieve their prior knowledge about the problem, as well as a note pad, an interactive tool for recording new information. Treatment 1 was the control group and offered no additional tools. Treatment 2 included the organization scaffold, the research plan template, which provided the students with headings and focusing questions to organize their research. Treatment 3 included the higher-order thinking scaffold, a status report. The status report gave the students reflective, higher-order thinking questions to help them integrate their new ideas with their prior knowledge. Treatment 4 was a combination of Treatment 2 and 3 and included the research plan template and the status report.

*Problem Solving*. Given that problem finding is part of the problem-solving process, it was hypothesized that students' problem-solving abilities might influence their ability to generate problems. Students' prior problem-solving abilities were measured by a problem-solving test comprised of one section of the 61-item instrument (KR(20) = .86) used by Reed and Palumbo (1992). This sub-test was selected because it is most relevant to the problem-definition phase of problem solving. It requires students to determine whether they have too little, too much, or exactly enough information to solve a problem. Since only one section of this test was used for this pilot study, the reliability of this instrument was retested (K-R 20 = 0.61 for the entire pool of students (113) who took the test prior to the treatment. Eliminating one suspected outlier, the reliability dropped slightly to 0.56).

## Dependent Measures

The dependent measures were the students' problem understanding and ability to formulate hypotheses and questions (as measured by problem type, problem specificity, and problem perspectives).

### *Problem Understanding*

Students' problem understanding was assessed by their description of the legal, environmental, scientific, economic, and public relations factors associated with the problem in their research plans. A student received 1 point for each possible factor. An additional point was given if a student provided an extra factor that went above and beyond those specified in the table. For example, one student mentioned how the company could lose business because the state recently moved to allow competition in the energy market. This student received an extra point for this insightful comment. Problem understanding scores ranged from 0 to 6 points.

### *Hypothesis Formulation*

The students were asked to write about their ideas for possible solutions in their research plans. The total number of hypotheses was computed. In addition, the quality of the students' hypotheses was assessed by the following criteria: its definition, relevancy to the problem, feasibility, originality, consideration of more than one perspective, and evaluation of those perspectives. Students received 1 point for each criterion that they met. Hypothesis quality scores ranged from 0 to 6. A mean hypothesis-quality score was calculated for each student. Each hypothesis was multiplied by its quality score and then summed together. Then, this sum was divided by the total number of hypotheses generated by the student in order to compute his or her mean hypothesis-quality score.

*Ability to formulate questions*

After the treatment, the students were asked to generate questions about the complex environmental problem. The students' ability to formulate these questions was measured by problem type, problem specificity, and problem perspectives.

*Problem Type*. The students' questions were evaluated to determine whether they were "inside" or "outside" the problem domain. The questions categorized as "inside" dealt with factors connected with the client's objectives and goals. These factors included the political and legal considerations of the problem, environmental factors, economic aspects, ethical issues, or the public relations problem. The problems considered "outside" the problem domain dealt mostly with the general subject knowledge. An example of a question outside the problem domain was "What is the clean air act?" Whereas, a question inside the problem domain was "How much sulfur dioxide are energy companies allowed to emit according to the Clean Air Act?" A question could also be categorized as a misconception or as unknown. Unknown questions were questions that could not be categorized as either inside or outside the problem domain because the rater could not tell why the student asked the question. For example, "Where is the plant?" is an important question because the laws can vary by state, past cases are in different states, the pollution travels differently depending on the location of the source. If the student asked this question because of one of these reasons, the question would be considered inside the problem domain. However, if the student asked this question merely out of curiosity, the question would be considered outside the problem domain. Thus, it was impossible to categorize the question and it was given a rating of unknown. Unknown questions were eliminated from the total. Misconceptions were rated a 0, questions outside the problem domain were rated a 1, and questions inside the problem domain were rated a 2.

Since students with increased expertise in the problem have been found to ask more questions inside the problem domain (Czarnick & Hickey, 1997), the problem-type score evaluated students' ability to formulate questions inside the problem domain. In order to account for the varying number of questions generated by each student, percentages were calculated from the number of questions generated inside the domain to the total number of questions generated by each student.

*Problem Specificity*. Previous research has also shown that students with increased expertise about the problem ask more specific questions (Czarnick & Hickey, 1997; Silver, Mamona-Downs, Leung, & Kenney, 1996). Thus, the students' questions were also coded for level of specificity. An ambiguous question was a statement about the person’s feelings or an incomplete thought. A general question dealt with general content knowledge such as “What are alternative energies?" An example of a specific question was "How much do alternative energies cost?” A specific question elicited data required to solve the problem, but required further questions to get to a more precise answer; whereas, a very specific question did not require any further questions. For example, in the previous question, the student would need to know how the different types of alternative energies work. A very specific question dealing with this same topic could be "How much does it cost to install solar energy panels, which would generate the same amount of energy that the plant currently produces?"

Ambiguous questions were coded a 0, general questions were given a 1, specific questions were rated a 2, and very specific questions were coded a 3. A mean problem-specificity score was calculated for each student. To obtain this score, the total number of questions generated by the student in each category was multiplied by the value of that category. The sum of these calculated values were divided by the total number of questions generated by the student in order to compute his or her mean problem-specificity score. For example, if a student generated one ambiguous question, five general questions, two specific questions, and two very specific questions, his or her mean problem-specificity score would be 1.5.

*Problem Perspectives.* To determine students' ability to grasp the multiple perspectives of an ill-structured problem, the students' questions were also evaluated for what perspective they represented. It was expected that students who understood the different perspectives of the problem would ask questions from the various perspectives of the experts. Thus, each question was judged for whether it was a legal, economic, environmental, or technical. Questions were coded as unknown if its perspective could not be determined (e.g. "Where is the plant?"). The percentage of questions for each perspective was calculated as well as the total number of perspectives represented by the questions. To calculate the total number of perspectives, students received 1 point for each perspective found in their questions. The total number of perspectives ranged from 0 (no perspectives) to 4 (all four perspectives). Thus, if a student had two legal questions, three economic questions, and no engineering or environmental questions, he or she would receive 2 points for number of perspectives (1 point for legal and 1 point for economic).

## Procedures

The classes were randomly assigned to one of four comparison groups who each received different treatments of the software: control group, organization scaffold, higher-order thinking scaffold, and organization and higher-order thinking scaffolds. During five 60-minute class periods, the students used the Pollution Solution software to become familiar with the environmental problem. During the first day, students were given their code numbers and assigned to planning teams. Although students worked individually to complete assignments, team members provided each other with technical assistance and acted as sounding boards for one another. Then, the students completed a 10-minute problem-solving test. After the test, the class watched the introductory videos where they met their supervisor and saw an acid rain overview video. For homework, the students were asked to research two web sites about acid rain to gain a better understanding about the pollution problem.

On the second day, the teacher reviewed the students' homework and facilitated a class discussion about the causes and effects of acid rain. Then, the class met their client and learned about the acid rain problem faced by the company. The planning teams discussed what they needed to know in order to solve the problem. Following the planning team discussions, the students reported out to the class some areas they planned to research. Then, the teacher distributed the computers to the students and they signed onto their computers. At this time, they entered their names, code numbers, class number, computer number, and their team members. This information was saved in a log file so their computer would remember them each time they signed on.

On the third day, I demonstrated how to use the interface because the orientation tool was not developed for the prototype of the software. Then, the students worked independently researching and taking notes. The next day, the students started writing their research plans, which they finished on the fifth day. After completing their research plans, the students with the higher-order thinking scaffolds also completed the status report. All comparison groups had the same amount of time to use the computer resources; however, the students who had to complete the status reports had 10 minutes less time to work on their research plans.

After the treatment, the students were given10 minutes to complete the final assessment. For this assessment, the students had to generate as many questions as they could think of that would help them to solve the problem. The students continued to use the software and participate in class activities to solve the environmental problem after the conclusion of the study. At the end of the unit, the students filled out a questionnaire about the usefulness of the software. Usability of the program was also evaluated through classroom observations of the students while the students were working with the software.

## Analysis of the Data

First, a one-way ANOVA was run on the problem-solving test scores to see if there were any differences in problem-solving ability between the classes. Since the difference in the problem-solving test scores between the classes was marginally significant ($F(3,56) = 2.362$, $p = .081$), ANCOVAs were run on the outcome measures (problem understanding, number of hypotheses, quality of hypotheses, problem specificity, problem type, and problem perspectives) with scaffolding type as a factor and problem-solving ability as a covariate. When the ANCOVAs found statistically significant F-results, pairwise comparisons, with a Bonferonni adjustment, were run to determine which means were different from one another. For all the analyses, the assumptions of normality, linearity, homogeneity of variance, homogeneity of regression, and reliability of covariates were tested and the results were satisfactory. In addition, the residual errors were analyzed and these results were acceptable as well.

In addition, a MANCOVA was run on the percentages of the questions from different perspectives because these percentages are interrelated to one another. The percentage of legal, economic, engineering, environmental, and unknown questions were the dependent measures with scaffolding type as a factor and problem-solving ability as a covariate.

# FINDINGS

The findings from this pilot study are preliminary. The purpose of conducting the pilot study was to detect any issues with the research design and make improvements for the final study. A larger sample and additional controls will be added for the later study.

## Students' Problem Understanding

Students described the problem that they were asked to solve in their research plans. Students' understanding of the problem varied significantly for different treatments

($F(3,55) = 5.604$, $p = 0.002$, $\eta^2 = 0.234$). Students who used the organization scaffold had significantly higher problem understanding than the control group ($p$ =0.006) and the students who used the higher-order thinking scaffold ($p$ =0.034). Students who used the combination scaffolding of organization and higher-order thinking also had significantly higher problem understanding than the control group ($p$ =0.043). Table 1 depicts the differences between the means for problem understanding for the different treatments.

Table 1

*Means and Standard Deviations for Problem Understanding for Different Treatments*

| **Treatment** | **Mean** | **Std. Deviation** |
|---|---|---|
| Control | 2.033 | 1.433 |
| Organization | 3.467 | 1.141 |
| Higher-order Thinking | 2.333 | .724 |
| Comb 2 & 3 | 3.200 | 1.236 |
| Total | 2.758 | 1.281 |

Problem-solving ability was not found to have a significant effect on the differences in students' problem understanding.

## Students' Ability to Formulate Hypotheses

Students were also asked to develop hypotheses in their research plans. There was no significant difference found between the treatment groups for the total number of hypotheses generated. However, the scaffolding type did have a significant effect ($F(3,55) = 3.690$, $p$ =0.017, $\eta^2 = 0.168$) on the quality of students' hypotheses. Students who used the organization scaffold developed significantly better hypotheses than the control group ($p = 0.029$). Table 2 illustrates the differences between the mean hypothesis quality scores for the different treatments.

Table 2

*Means and Standard Deviations for Hypothesis Quality Scores for Different Treatments*

| **Treatment** | **Mean** | **Std. Deviation** |
|---|---|---|
| Control | 1.500 | 1.338 |
| Organization | 3.089 | 1.286 |
| Higher-order Thinking | 2.842 | 1.657 |
| Comb 2 & 3 | 1.878 | 1.749 |
| Total | 2.327 | 1.623 |

The quality of students' hypotheses was not significantly effected by students' problem-solving ability.

## Students' Ability to Formulate Questions

After completing their research plans, the students were asked to write as many questions as they could think of that would help them to solve the problem. These questions were then judged for their type, level of specificity, and perspective.

### *Problem Type*

Scaffolding type did not have a significant effect on the type of problem asked by the student. However, students who used the organization scaffold tended to ask more questions inside the problem domain. Table 3 shows the mean differences for problem type.

Table 3

*Means and Standard Deviations for Problem Type for Different Treatments*

| **Treatment** | **Mean** | **Std. Deviation** |
|---|---|---|
| Control | 47.995 | 19.496 |
| Organization | 68.889 | 32.538 |
| Higher-order Thinking | 50.052 | 25.101 |
| Comb 2 & 3 | 51.984 | 32.272 |
| Total | 54.729 | 28.407 |

### *Problem Specificity*

The level of specificity of the questions generated by the students significantly differed between treatments ($F(3,55) = 3.328$, $p = 0.026$, $\eta^2 = 0.154$). Students who used the organization scaffold asked significantly more specific questions than students who used the higher-order thinking scaffold ($p = 0.049$). In addition, the organization scaffold approached a significant difference over the control group ($p = 0.056$). Table 4 displays the differences in means and standard deviations for the problem specificity scores for the different treatments of the software.

Table 4

*Means and Standard Deviations for the Problem Specificity for Different Treatments*

| **Treatment** | **Mean** | **Std. Deviation** |
|---|---|---|
| Control | 1.471 | .4777 |
| Organization | 1.955 | .5221 |
| Higher-order Thinking | 1.467 | .3933 |
| Comb 2 & 3 | 1.694 | .5871 |
| Total | 1.647 | .5273 |

Students' problem-solving ability did not significantly effect the differences between students' problem specificity scores.

*Problem Perspectives*

There was no significant difference found in the number of perspectives represented by the students' questions. However, the results from the MANCOVA showed that percentage of legal questions ($F(3.55) = 5.045$ and $p = 0.004$) were significantly different between treatments and the difference between percentage of engineering questions ($F(3,55) = 2.302$ and $p = 0.081$) was marginally significant. Students who used the higher-order-thinking scaffold asked significantly fewer legal questions than the control group ($p = 0.012$) or the combined scaffolding ($p = 0.005$). Students who used the higher-order thinking scaffold also asked more engineering questions than the control group, although these results were not significant. Please note that these results are preliminary and need to be verified through nonparametric techniques because many of the assumptions of the MANCOVA were violated. Although the total number of perspectives did not differ among the treatments, the students who used the higher-order thinking scaffold had a more even distribution of questions across the different perspectives. Figure 2 shows how the questions from each perspective differ for each treatment.

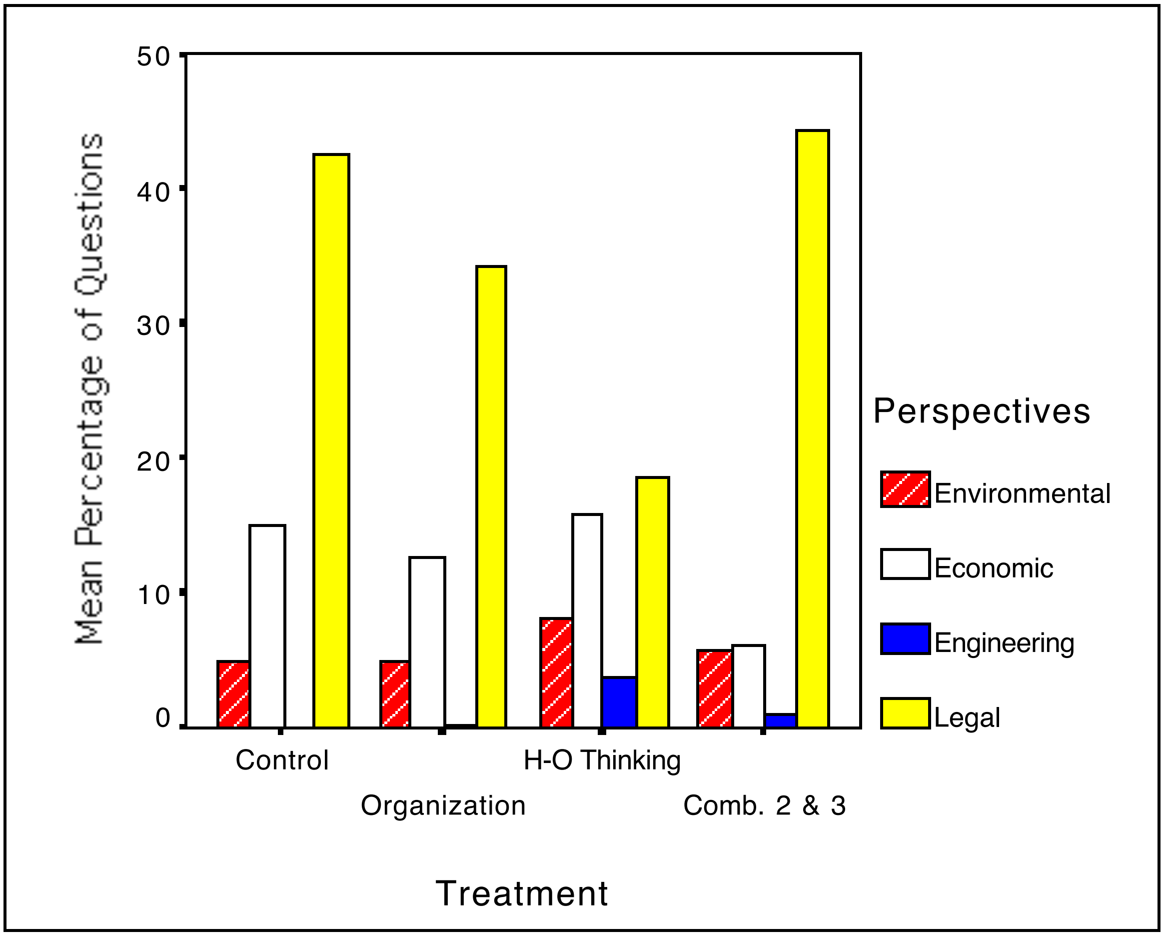


*Figure 2*. Percentages of Questions from Each Perspective for Different Treatments
*Note*. Questions with an unknown perspective were eliminated.

# DISCUSSION

## Effect of Scaffolding Type

This study investigated different cognitive processing scaffolds to determine which was most effective in helping students to define complex problems. The scaffolds evaluated were organization and higher-order thinking, as well as the combined effect of both.

*Organization Scaffold*

The organization scaffold significantly helped students to understand the problem, formulate hypotheses, and ask highly specific questions. According to the Iiyoshi and Hannafin model (1998), organization helps learners to connect new information with their prior knowledge and to organize this information meaningfully. Thus, it would make sense that the organization scaffold would improve students' understanding of the problem. Increased understanding of the problem leads to students asking better questions that are more specific and connected to the problem domain (Czarnick & Hickey, 1997). It would also follow that the better a student understands a problem, the better he would be able to develop hypotheses for solving the problem.

The organization scaffold also improved students' ability to ask questions inside the problem domain; however, these results were not significant. This may have been caused by the fact that 48 questions were eliminated from the analysis because the students' reason for asking these questions was unknown. For future studies, I plan, in addition to asking the students to generate questions, to have them explain why they asked them. Also, in observing the students, I noticed that the students did not seem to take the question generation assessment as seriously as the work that they did on the computer. To correct for this problem, the software will be enhanced to include this questioning activity.

*Higher-order Thinking Scaffold*

The higher-order thinking scaffold tended to help students ask questions that were more evenly distributed across the different perspectives. Higher-order thinking helps students to integrate knowledge and process it more deeply (Iiyoshi & Hannafin, 1998). It follows that the students who reflected on the problem may have been prompted to think more about the problem from different perspectives. Along this line of thinking, one would also expect that the higher-order thinking scaffold would also increase the total number of perspectives represented in the students' questions. However, this was not the case. This disparity between expected and actual results might have been caused by the fact that the students appeared to spend most of their time watching the videos and taking notes on the different expert perspectives regardless of the scaffolding used. This fact was confirmed by the usability surveys where many of the students reported that the videos were their favorite part of the software. To verify this hypothesis in future studies, I will capture the amount of time students spend watching the videos and the number of videos viewed to determine if there is a relationship between watching the expert videos and students' ability to grasp the multiple perspectives of the problem.

### *Organization and Higher-order Thinking Scaffold*

One would expect that combining the organization and higher-order thinking scaffolds would combine the effects of the individual scaffolds and improve all student outcomes. Although the combined scaffolding significantly helped those students over the control group, students who used this combined scaffolding had a slightly lower problem understanding than the students who just received the organizational scaffold. This may have been caused by the fact that the students with the combined scaffolding had less time to complete the research plan than students who did not have to respond to the reflective questions posed in the status report. Although the treatment time for all the comparison groups was the same, it is important for future studies to ensure that all groups have the same amount of time to complete assignments that are evaluated. In order to give all treatment groups the same amount of time to complete the assignment, the order of the tasks will be changed. After researching the problem, the students with the higher-order thinking scaffold will complete the reflective questions. The students who do not have this scaffolding will continue to do their research. All students will start writing their research plan at the same time and will have the same amount of time to complete it. In addition, reversing the order will permit the evaluation of the higher-order thinking scaffold on the students' research plans and, in turn, their problem understanding.

Students' ability to formulate hypotheses and questions should have been improved by the combined scaffolding because it included the organization scaffold; however, these students actually did only slightly better than the control group in the quality of their hypotheses and their ability to ask question inside the problem domain. These students also did not ask as many specific questions as students who used just the organization scaffold. These discrepancies between my expectations and what actually occurred may also be attributed to the lack of time to complete the research plan. However, another explanation may be that this group typically did not perform as well academically as the other classes, according to their science teacher.

### *Control Group*

The control group performed as expected because they did not receive either the organization or higher-order thinking scaffold to support their learning. However, there were other possible explanations for their performance. Although this group typically was one of the better classes academically, this class had a substitute teacher in their homeroom for the last three months of school and this may have contributed to their distractions during the study. In addition, on the day that they completed their research plans and question generation assessments, their earth science teacher was absent and they had a substitute teacher. Students who used the higher-order thinking scaffold also had a substitute teacher on this day; however, they seemed more focused in completing their work than the control group.

## Effect of Problem-solving Ability

Students' problem-solving ability had no significant effect on the students' outcome measures. It could be that problem-solving ability does not have as strong a relationship with students' aptitude for defining a problem as originally hypothesized. This follows logically since engineers who are most likely good problem solvers found it more difficult to define a problem than to solve it (Rowell, et al., 1999). If problem-solving ability had a strong influence on problem finding, then it would probably come more naturally to these professionals. Problem finding could be a different skill set than problem solving. On the other hand, the section of the problem-solving test was found to be less reliable than the entire problem-solving test used by Reed and Palumbo (1992).

## Conclusion

This pilot study sought to investigate which scaffolding type most effectively helped students to define a complex, ill-structured problem. These preliminary findings indicated that the organization scaffold was most effective in helping students to understand the problem, develop hypotheses, and ask more specific questions inside the problem domain. The higher-order thinking scaffold was somewhat effective in helping students grasp the multiple perspectives of the problem. However, the combined scaffolding did not do as well as these scaffolds did individually. Further research needs to be done to determine if this was due to lack of time or some other issue. Problem-solving ability was not found to have a significant effect on student outcomes. For future studies, it may be interesting to investigate if other individual differences influence students' ability to define complex problems.

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