The effect of multiple scaffolding tools on students’ understanding, consideration of different perspectives, and misconceptions of a complex problem

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ABSTRACT

This study investigated the effectiveness of multiple scaffolding tools in helping students understand a complex problem. In order to support students with this task, a multimedia learning environment was developed based on the cognitive flexibility theory (CFT) and scaffolding through computer-based tools. Seventy-nine 10th-grade students in an urban high school participated in this study. A quasi-experimental method was used to compare the effectiveness of different scaffolding tools within this learning environment. Scaffolding used in conjunction with CFT principles did not affect students’ ability to consider multiple perspectives or their numbers of misconceptions. On the other hand, scaffolding tools had varying effects on students’ problem understanding, and a significant interaction was found between the different scaffolding tools used. This study raised questions about the effectiveness of combining multiple scaffolding tools within a multimedia environment.

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1. Introduction

“When students try to understand a problem in only one way, especially when that way conveys no conceptual information about the problem, they do not understand the underlying systems in which they are working” (Jonassen, 2003, p. 364). In traditional teaching methods that use a linear presentation of materials (e.g., textbooks, lectures), students gain knowledge at the most basic level and memorize scientific facts without understanding the underlying concepts (Cepni, Tas, & Kose, 2006). As a result, misconceptions about these concepts can develop. Misconceptions can be strongly held ideas, and these ideas are difficult to change with traditional instructional methods (Yenilmez & Tekkaya, 2006). More recently, researchers are beginning to examine the effect of more innovative teaching approaches that utilize computer-based learning environments to improve students’ understanding (e.g., Demetriadis, Papadopoulos, Stamolos, & Fischer, 2008; Demetriadis & Pombortsis, 1999; Jacobson & Archodidou, 2000; Jacobson, Maouri, Mishra, & Kolar, 1996; Jacobson & Spiro, 1995; Li & Jonassen, 1996) and reduce their misconceptions (e.g., Cepni et al., 2006; Gazit, Yair, & Chen, 2005; Yenilmez & Tekkaya, 2006).

Traditional linear models of instruction are particularly ill-suited for complex domains of knowledge. “Linearity of media is not a problem when the subject matter being taught is well structured and fairly simple. However, as content increases in complexity and ill-structuredness, increasingly greater amounts of important information are lost with linear approaches” (Spiro & Jehng, 1990, p. 163). It becomes more and more difficult to represent complex content through a linear approach because as content areas becomes more complex, the domain of knowledge becomes more ill-structured, non-uniform, and overlapping with other domains. Moreover, in complex learning, the goals of instruction shift from providing a basic understanding of the concepts and procedural rules to fostering a mastery of knowledge and transfer of that knowledge to other applications (Spiro & Jehng, 1990). To accurately represent this complexity, instruction “cannot be compartmentalized, linear, uniperspectival, neatly hierarchical, simply analogical, or rigidly prepackaged” (Spiro & Jehng, 1990, p. 168). When complex knowledge is oversimplified in this manner, Spiro, Coulson, Felstovich, and Anderson (1988) argue that many learners fail to grasp the complexity of the concepts. To counteract these learning failures, they argue that learning environments should emphasize “the real-world complexity and ill-structuredness of many knowledge domains” (Spiro, Felstovich, Jacobson, & Coulson, 1991, p. 24). Based on this notion, Spiro et al. developed a theoretical framework for designing computer-based learning environments called the cognitive flexibility theory (CFT).
Over time, CFT has evolved into a framework for the design of multimedia environments for complex learning. These environments use the following design principles for preserving the complexity of an ill-structured domain, such as providing multiple perspectives and case examples, highlighting the interconnections between related domains of knowledge, and giving students opportunities for knowledge construction (Jacobson & Spiro, 1995). The goal of these environments is to help learners develop flexible understandings of complex situations.

Much of the research on CFT-based environments has focused on students’ knowledge acquisition, conceptual understanding, and knowledge transfer. This research has provided evidence that CFT-based environments are better utilized for more complex types of learning than acquiring simple declarative knowledge. On the other hand, there was limited research found on the use of CFT-based environments on students’ consideration of multiple perspectives or their misconceptions of the underlying concepts: two key objectives of CFT. Thus, the purpose of this present study was to examine the effectiveness of a CFT-based environment on students’ understanding of the problem, their grasp of the different perspectives on the problem, as well as their misconceptions about the underlying scientific concepts.

Another issue explored by this study was whether CFT-based environments could be used effectively with young students. Since this theory was developed for advanced (post introductory) knowledge (Spiro et al., 1991), most of the research has focused on adults. One exception was a study by Jacobson and Archolidou (2000), who found that scaffolding within a CFT-based environment helped a small sample of high school students understand the underlying conceptual models of evolution. This present study sought to better understand high school students’ use of scaffolding tools within a CFT-based environment.

1.1. Cognitive flexibility theory learning environments

Although CFT is relatively new, a variety of computer-based learning environments have been developed based on the design principles of CFT. Researchers have begun to test this theory using these environments. Most of the research found that computer applications based on CFT significantly improved students’ knowledge and understanding through a wide range of subjects, ranging from understanding children’s mathematical reasoning (Koehler, 2002) to behavioral disorders in children (Fitzgerald, Wilson, & Semrau, 1997; Kraus, Reed, & Fitzgerald, 2001).

While CFT-based learning environments have been found to improve students’ knowledge acquisition, studies that compared CFT-based learning environments to more traditional environments found that the CFT-based environments were more effective at helping students with more complex thinking than assisting students with acquiring factual knowledge. For example, Li and Jonassen (1996) compared the relative effectiveness of an application based on CFT with a concept-based application on helping business students make inferences and predictions about information systems. They found that the CFT group performed significantly better than the concept-based group in making inferences, but they performed equally well in making predictions. A similar study by Demetriadi and Pomboris (1999) investigated the differences between a case-based environment founded on CFT principles and a linearly structured electronic book on students’ acquisition of domain knowledge of computer networking and ability to synthesize and transfer knowledge to new situations. They discovered that students performed the same on declarative questions, but the CFT group outperformed the group that used the linear environment on questions that required synthesis or knowledge transfer. Another comparison study by Jacobson and Spiro (1995) evaluated two learning environments about the impact of technology on 20th century society and culture: a hypertext environment based on CFT and a more traditional drill-and-practice program. They found that students who used the CFT-based environment performed significantly better than the drill-and-practice group on the knowledge-transfer questions by the end of the treatment. However, the drill-and-practice program was more effective at promoting acquisition of declarative information. In a more recent study, Lima, Koehler, and Spiro (2004) found that business students and professionals favored CFT-based environments over the Harvard Business Method on dimensions of integrated thinking. Although CFT-based environments can be used to help improve students’ declarative knowledge, this review of research has shown that the benefits of CFT-based environments may be better realized for more complex types of learning.

On the other hand, some researchers have found that learning environments based on CFT were not effective in improving students’ learning (e.g. Balcytiene, 1999; Niederhauser, Reynolds, Salmen, & Skolmoski, 2000). These findings might be due to the fact that these studies focused mainly on the “criss-crossing” navigational element of CFT (i.e. traversing the domain through multiple paths). Harvey, Godshall, and Milheim (2001) also found that criss-crossing navigation did not have a significant effect on knowledge transfer. Thus, it might be necessary to combine the principle of criss-crossing overlapping domains of knowledge with other aspects of CFT in order for these learning environments to be effective.

There was limited research found on the investigation of CFT-based environments on students’ misconceptions about underlying concepts or their thinking about concepts from multiple perspectives. Specifically, there was only one study found in the literature that examined the use of CFT-based environments on either of these measures. For example, Fitzgerald et al. (1997) found that graduate students who used a CFT-based environment made significant gains in their understanding of the importance of having a team that provides multiple perspectives in order to meet the needs of children with behavioral disorders. However, they did not make significant gains in altering their own personal perspectives. On average, students selected “only one or two perspectives as the basis of their opinions as educators and did not demonstrate substantial change in their perspectives towards children with behavioral disorders with exposure to additional case studies” (Fitzgerald et al., 1997, p. 68). However, these researchers did not collect data prior to the treatment, so it was difficult to determine if completion of the initial training might have altered their perspectives. Thus, additional research is needed to determine whether CFT-based environments can help students’ consideration of multiple perspectives.

Another relatively unexplored area was whether CFT-based computer environments could be used effectively with young students. Since this theory had been developed for advanced post introductory knowledge (Spiro et al., 1991), most of the research has focused on adults. The one exception was the study by Jacobson and Archolidou (2000) who examined how a learning environment that utilized principles of CFT affected high school students’ underlying conceptual models of evolution. In order to support these learners, these researchers added scaffolding to guide students through the learning environment. These results held promise that scaffolding might be effective in supporting young learners in this type of environment. However, this study was conducted with a very small sample of students; thus, these researchers recommended the need for future studies with larger samples of students to test this concept.
1.2. Scaffolding and CFT-based learning environments

Scaffolding or support is often needed to help students succeed with open-ended, complex, problem-solving environments (Liu, Bera, Corliss, Svinicki, & Beth, 2004), such as CFT-based environments. Scaffolding in these environments can assist learners in reaching an achievement level beyond their ability level (Wood, Bruner, & Ross, 1976). Although the original notion of scaffolding involved mentoring by a more experienced person (e.g., Palincsar, 1986), more recently educators have become interested in scaffolding provided through computer-based tools because of the difficulty of trying to provide individual assistance to each student in a large class. Computer-based tools can offer additional support to students and provide data to teachers to enable them to provide more focused attention to students having specific problems with a particular concept. While the original concept of scaffolding implied that the support provided by the teacher would be faded over time, computer-based scaffolding does not always provide this option due to technical limitations of adding a mechanism to adaptively fade the tool. Thus, it is often up to the teacher to decide when the students are ready to work independently without the support of the computer-based tools.

Several studies used scaffolding to support learners in CFT-based learning environments (Demetriadis & Pombortsis, 1999; Demetriadis et al., 2008; Jacobson & Archodidou, 2000; Jacobson et al., 1996). For example, Demetriadis and Pombortsis (1999) studied 1st- and 2nd-year college students who were novices in computer networking and had never learned with a computer-based instructional environment. The scaffolding used in this environment was highly structured. The authors noted that “students were guided toward which case to select next, what themes to study in each case-section, and what links to follow in the cross-crossing activity” (Demetriadis & Pombortsis, 1999, p. 261–262). These researchers found that the structured scaffolding used in this CFT-based environment was effective in improving novice students’ flexibility in learning. In a more recent study, Demetriadis et al. (2008) studied 32 computer science students on the use of cognitive scaffolding within a CFT-based environment on students’ conceptual knowledge and knowledge transfer. The cognitive scaffolds used in this study were in the form of question prompts, which can be defined as questions that facilitate the learning process by offering cognitive and metacognitive supports (Ge & Land, 2003). Demetriadis et al. (2008) used these question prompts to help students with the cognitive processes of perception, memory recall, and reasoning. They found that students who used the question prompts significantly outperformed students who did not receive these prompts.

Some studies examined combinations of scaffolding tools within CFT-based environments. For example, Jacobson and Archodidou (2000) found multiple scaffolds to support high school students’ learning about biological evolution. One scaffold was a Story Maker that allowed the learner to construct the problem from a list of statements, ranging in level of understanding from naive to expert. Another scaffold was “guided conceptual cross-crossing” in the form of hyperlinks that connected the domain knowledge to the cases and highlighted the interrelationships between the concepts stored in the library (Jacobson & Archodidou, 2000, p. 162). The researchers found these scaffolding tools to be effective in supporting these young learners. However, given the exploratory nature of this study, it was difficult to ascertain whether the combination of tools was necessary or if one tool was responsible for most of the students’ improvement.

A different study by Jacobson et al. (1996) examined the use of varying levels of scaffolding. Although they found the CFT-based environment with the highest degree of scaffolding helped students with complex epistemic beliefs about learning in synthesizing their knowledge, they thought that it might have interfered with students’ acquisition of declarative knowledge. The researchers speculated that the scaffolding used in this environment might have enhanced the recognition of domain structures and the generation of solutions. They found that the scaffolding used was effective in helping students develop flexible or non-inert understandings of the content and thus lead to the comparable levels of performance on the problem-solving essays” (Jacobson et al., 1996, p. 270). Thus, more research is needed to assess the use of multiple tools on students’ performance in these types of learning environments. An earlier iteration of this present study assessed the use of multiple tools as scaffolding in a CFT-based environment.

1.3. Purpose and context of the present study

This present study investigated the effectiveness of multiple scaffolding tools in a CFT-based environment on high school students’ understanding of the problem, their grasp of the different perspectives on the problem, as well as their misconceptions about the underlying scientific concepts. In order to determine this, a learning environment called Pollution Solution was developed specifically for this research. Pollution Solution incorporated the design principles of CFT by providing students with multiple perspectives on the problem, offering numerous cases, illustrating the connection between diverse disciplines, and allowing students to integrate their knowledge of the topic (Jacobson & Spiro, 1995). For example, Pollution Solution presented students with a complex air pollution problem. To learn the varying viewpoints on this problem, students watched video cases of real experts, who disagreed about the best way to solve the problem. During their investigation, students needed to grapple with these different perspectives in order to develop a solution to the problem. In order to make a recommendation for solving the case, students researched a wide range of disciplines that cut across the problem, such as law, economics, environmental science, and engineering.

In addition to CFT principles, Pollution Solution also employed a range of scaffolding techniques to provide additional support. These scaffolding tools were designed to foster students’ cognitive processes. For example, one scaffold was an organization tool called the research plan template, which included headings and question prompts to provide a structure for students to organize information about the problem. This organizing template was designed to help learners connect new information with their prior knowledge and conceptually organize this information, thereby improving students’ understanding of the problem (Iiyoshi & Hannafin, 1998). Another scaffolding tool called a status report was designed as a higher-order thinking tool. This tool utilized a series of reflective question prompts to facilitate processing content at a deeper level. These reflective questions helped learners monitor their construction of knowledge (Iiyoshi & Hannafin, 1998). The goal of this tool was to help learners reflect on the different perspectives on the problem, which in turn would help them uncover gaps in their understandings and reduce their misconceptions.

To determine the effectiveness of these different scaffolding tools within a CFT-based environment on students’ flexible understanding of a complex issue, different treatment conditions of Pollution Solution were developed with varying types of tools to support the learners.
2.2. Treatment materials and treatment assignment

Students participated in full-class discussions throughout the study. Various solutions to the problem, the students provided the viewpoint of their assigned perspective. In addition to these group discussions, the students were assigned to consultant teams of three or four students. The consultant teams utilized a jigsaw format, where each team member represented one of the four experts related to the problem: an environmental scientist, an economist, a lawyer, or an engineer. At the beginning of the project, the students needed to familiarize themselves with all the expert viewpoints in order to grasp the complexity of the problem. Later on, when debating about various solutions to the problem, the students provided the viewpoint of their assigned perspective. In addition to these group discussions, the students participated in full-class discussions throughout the study.

2.2.1. Participants and setting

This study took place in an urban public school. Seventy-nine 10th-grade students (15–16 years old) participated in this study. The ethnic breakdown of the students at this school was: 39.4% White, 18% Black, 22.4% Hispanic, and 20.2% Asian and others including Pacific Islanders, Alaskan Natives, and Native Americans. There were slightly more males (53.5%) than females (46.5%) (New York City Department of Education, n.d.). For additional information about the characteristics of this sample population, please see Zydney (2008), which provides additional details on these participants from a related study.

The students were divided into four biology classes. One science teacher taught all four biology classes in the same classroom at different times of the day. This teacher was a relatively new teacher who had been teaching at the same school for 4 years. She completed her undergraduate education in biology and psychology and her graduate degree in educational technology; thus, she was very comfortable using technology in her classroom. She used a combination of direct instruction and constructivist approaches in her teaching. Prior to the study, the teacher was given a demonstration of the software and a teaching manual, which provided daily lesson plans for implementing the software in the classroom.

In the classroom, there was an LCD projector for providing demonstrations of the software. The classroom was configured in a team setting with six square tables with three to four students at each table. One student sat on each side of the table with his or her own laptop and spent the majority of the study working individually on the computer. In addition, the students were assigned to consultant teams of three or four students. The consultant teams utilized a jigsaw format, where each team member represented one of the four experts related to the problem: an environmental scientist, an economist, a lawyer, or an engineer. At the beginning of the project, the students needed to familiarize themselves with all the expert viewpoints in order to grasp the complexity of the problem. Later on, when debating about various solutions to the problem, the students provided the viewpoint of their assigned perspective. In addition to these group discussions, the students participated in full-class discussions throughout the study.

2.2.2. Treatment materials and treatment assignment

In Pollution Solution, students learned about the complex air pollution problem they were going to solve. The students were assigned a client, a fictitious utility company that was sued by the Justice Department on behalf of the Environmental Protection Agency for defying anti-pollution regulations and illegally contaminating the air. As a result of the lawsuit, environmental activists began protesting outside the corporate offices. Consequently, the company's public image was tarnished and their stock prices began to fall. While the students were researching the problem, they were introduced to various experts (through digital video cases) who had very different perspectives on the nature of the problem and, thus, how it should be solved. The students needed to wrestle with these divergent perspectives in order to draw their own conclusions.

To research the problem, students were given a virtual office, which included filing cabinets, research notebook, and reference manuals as well as a phone, e-mail, and notepad. Different versions of this office environment were developed to create different treatment conditions. Groups of students were assigned to each of these conditions. During their research, students wrote a research plan, which included a qualitative description of the problem. All groups received the same directions on how to write the research plan. One group was provided with an organization tool in the form of a research plan template, which provided headings and question prompts. The headings in the research plan template included problem, hypothesis, questions, and resources. These headings were selected because they were similar to the headings students use in creating a science lab report, which is something with which they were very familiar. Fig. 1 shows the question prompts that appeared under the problem headings in the research plan template. Another group was given a higher-order thinking tool in the form of a status report, which presented students with a series of reflective question prompts to assist them in processing the content more deeply. Fig. 2 depicts the reflective question prompts within the status report. The combination group included both the organization and higher-order thinking tools, and the control group received neither of these tools.

Intact classes were randomly assigned to the treatment conditions. Although it was logistically necessary to assign classes (as opposed to students) to treatment conditions, the students were randomly assigned to these classes at the beginning of the academic year. Moreover, the classes were considered academically equivalent, according to their teacher. Given the equivalent nature of the classes and due to the time constraints within the science curriculum, no test of prior knowledge was administered.

2.3. Measures

The dependent measures were students' multiple perspectives, misconceptions, and problem understanding. All dependent measures were assessed through rubrics (provided in Appendix A), which an earth science teacher, with expertise in assessing these areas, reviewed to confirm their validity. Two evaluators rated each of the dependent measures independently and then came together again to discuss discrepancies. These evaluators were not affiliated with the Pollution Solution project. The evaluators were blind to the treatment condition
the students had used. In addition, students' work was randomly mixed to prevent the raters from detecting the students' assigned condition. Inter-rater reliabilities are reported in the sections describing each variable.

2.3.1. Multiple perspectives

Since one of the main objectives of this environment, based on the underlying CFT principles, was to help students see the different perspectives of the problem, students' research plans were analyzed to see which expert perspectives (e.g., environmental, economic, legal, and engineering) were incorporated in the plan. Students received 1 point for each perspective represented in their plan. One additional point was given if a student specified an extra perspective not provided in the software (e.g., social perspective). Multiple perspective scores ranged from 0 to 5 points. A high multiple perspective score was 3 points or higher, and a low perspective score was fewer than 3 points. See Table A1 in Appendix A for the rubric to evaluate the multiple perspectives of the problem. The inter-rater reliability was .95.

2.3.2. Misconceptions

Another objective, based on the CFT principles embedded in this learning environment, was to lower learners' misconceptions. Students received 1 point for each misconception in their research plans. For example, several students had the misconception that the power plant emitted acid rain. This statement indicated that these students neither understood the byproducts of energy production nor the chemistry
of how acid rain is formed from these byproducts. Students received 1 point for each misconception included in their description of the problem. Simple errors or mistakes (e.g., the wrong date for the Clean Air Act) were not counted. A low misconception score was fewer than three misconceptions, and a high misconception score was three or more misconceptions. See Table A2 in Appendix A for the rubric used to evaluate misconceptions. The inter-rater reliability was .93.

2.3.3. Problem understanding
The scaffolding in the learning environment was designed to improve students’ understanding of ill-structured problems; thus, students’ qualitative descriptions of the problem were assessed for the inclusion of the factors contributing to the problem. Each factor was worth 1 point. Scores ranged from 0 to 6 points. A high problem understanding score was greater than 5 points, a moderate understanding score was between 2 and 5 points, and a basic understanding score was fewer than 2 points. See Table A3 in Appendix A for the rubric used to evaluate problem understanding. The inter-rater reliability was .81.

2.3.4. Controls
Potential factors that might affect the results of the study were collected. These factors included students’ number of absences during the study, amount of time worked at home, level of discussion outside of class, amount of technical problems/loss of work, and amount of time on the computer. Survey and computer log file data were used to collect this data. This data were analyzed to determine if any of these factors were inconsistent across the classes.

2.4. Procedures
During six class periods that ranged from 50 min to 1 h and 20 min, the students participated in the study. First, the class was introduced to the problem scenario, and then students learned how to use the software. After learning how to use the software, the students researched and took notes about the problem. During the fifth and sixth sessions, the students completed their research plans. All groups had the same amount of time to use the computer resources and to write their research plans. After completing their research plans, students answered a few survey questions to determine if they were absent, worked at home, lost any data during the study, or discussed their work outside of class. After the study ended, the students continued to use the software to analyze the problem and write their recommendations.

2.5. Data analysis
First, the control factors were analyzed to see whether these factors varied across the classes. None of the factors were found to affect the final results. For the dependent measures of multiple perspectives and misconceptions, the assumptions of the ANOVA were violated; thus, a non-parametric equivalent test called Kruskal–Wallis test was used. As a follow-up to a previous analysis, which indicated the presence of a possible interaction in the combined scaffolding condition (see Zydney (2008)), a two-way ANCOVA was computed with problem understanding as the dependent measure, the organization and higher-order thinking scaffolds as factors, and amount of time on the computer as the covariate. Pairwise comparisons, with adjustment for multiple comparisons set to Bonferroni, were used to determine which means were different from one another. An $a$ level of .05 was used to judge significance.

3. Results

3.1. Multiple perspectives
Overall, students’ ability to consider the problem’s multiple perspectives was high. The average number of total perspectives represented in the research plans was 3.24 (SD = 1.14). Approximately 81% of the students considered at least three perspectives in total. As shown in Table 1, the average number of perspectives in the research plans was similar across all conditions. This descriptive analysis was confirmed by the Kruskal–Wallis test, which revealed that there were no significant differences in students’ perspectives between groups, which received the different scaffolding tools ($\chi^2 = 4.69, df = 3, p = .17$).

3.2. Number of misconceptions
Overall, students’ misconceptions were minor. The majority of the students (61%) did not have any misconceptions, and most of those students who had misconceptions had two or fewer (98%). No one had more than three misconceptions. Table 2 depicts the average number of misconceptions for the different treatment conditions. There were no significant differences in students’ misconceptions for the different treatment conditions ($\chi^2 = 1.73, df = 3, p = .20$).

Table 1
Means and standard deviations for multiple perspectives for different treatment conditions.

<table>
<thead>
<tr>
<th>Treatment conditions</th>
<th>N</th>
<th>M</th>
<th>SD</th>
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</thead>
<tbody>
<tr>
<td>Control</td>
<td>21</td>
<td>2.86</td>
<td>1.46</td>
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<tr>
<td>Organization</td>
<td>20</td>
<td>3.45</td>
<td>1.15</td>
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<tr>
<td>Higher-order thinking</td>
<td>18</td>
<td>3.06</td>
<td>0.90</td>
</tr>
<tr>
<td>Combination</td>
<td>20</td>
<td>3.60</td>
<td>0.88</td>
</tr>
<tr>
<td>Total</td>
<td>79</td>
<td>3.24</td>
<td>1.14</td>
</tr>
</tbody>
</table>


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3.3. Problem understanding

Students demonstrated a basic understanding of the problem ($M = 1.78, SD = 1.07$). Table 3 shows the means and standard deviations in problem understanding for the different treatment conditions. A two-way ANCOVA showed a significant main effect for the organization tool ($F(1, 74) = 5.09, p = .03, \eta^2_p = .06$), and no significant main effect for the higher-order thinking tool ($F(1, 74) = .51, p = .48, \eta^2_p = .01$). There was a significant interaction between the organization and higher-order thinking tools ($F(1, 74) = 3.79, p = .05, \eta^2_p = .05$). Amount of time on the computer was also found to significantly co-vary with problem understanding ($F(1, 74) = 4.68, p = .03, \eta^2_p = .06$). As shown by the interaction in Fig. 3, in the absence of the higher-order thinking scaffold, there was a significant increase in problem understanding scores ($p < .01$) when the organization scaffold was present. However, in the presence of the higher-order thinking scaffold, there was no difference in problem understanding scores regardless of whether the organization scaffold was present or not. Moreover, in the presence of the organization scaffold, problem understanding was significantly higher ($p = .05$) if the higher-order thinking scaffold was not included. Thus, it appeared that the higher-order thinking scaffold had a moderating effect on the organization scaffold’s effectiveness in improving students’ problem understanding.

3.4. Summary of classroom observations

During each day of the study, either a research assistant or this researcher observed the students and took detailed field notes. The following summary of these notes highlights student behaviors, teacher interactions, and technical issues.

During the demonstrations and class discussions, students were generally attentive and eager to participate in the discussion. When the students worked independently on the computer, the classroom was quiet, as the students intently watched the videos of the experts and took notes with the note-taking tool. A few students interacted with the videos and actually spoke back to the people in the videos. Occasionally, students helped one another out on the computer. During group work, the classroom became quite noisy as students debated

<table>
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<th>Table 3</th>
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Means and standard deviations for problem understanding for different treatment conditions.

<table>
<thead>
<tr>
<th>Treatment conditions</th>
<th>$N$</th>
<th>$M$</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
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<td>1.38</td>
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<tr>
<td>Organization</td>
<td>20</td>
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<td>Higher-order thinking</td>
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<td>1.57</td>
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<tr>
<td>Total</td>
<td>79</td>
<td>1.78</td>
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![Fig. 3. Estimated marginal means of problem understanding.](image)
about the best way to solve the problem. Despite the fact that the students participated in the project at the very end of the school year, the majority of students expressed enjoyment in the project. However, a few students complained that the project required too much work for the end of the year. The biggest problem with student behavior was absenteeism and lateness. Twenty-two students were absent at some point during the study. In order to minimize the influence of these absences, the students were required to make up their missed work during lunchtime or after school. One class had more behavioral issues (e.g. lateness and disruptive talking) than the other classes, and the teacher disciplined them for these negative behaviors.

The teacher displayed a great deal of energy and enthusiasm throughout the project. She facilitated lively class discussions. During individual and group work, she maneuvered around the classroom, answering questions and probing students to think more deeply about the problem. For example, after a student came to a swift decision that their client should settle with the Environmental Protection Agency, the teacher prompted him to investigate more of the facts: “You are coming up with an opinion already. Let’s wait and hear all the facts.” In addition to coaching the students, she effectively managed the classroom activities. The classes were on a rotating schedule, so different classes were at a different point in the study each day, but the teacher appeared used to this and easily kept track of everything. To the extent possible, the teacher closely followed the instructor guide and made the directions and sequence of the class activities consistent across the four classes.

During the study, there were several technical issues noted. For example, the batteries did not work on the laptops so the teacher had to plug all the laptops into the wall, creating a spider web of wires that hindered movement around the classroom. Unfortunately, this issue was not caught prior to the study and, as a result, caused some of the students to lose their work. Another technical issue was that some students had difficulty logging onto the computer because of a software bug. Twenty students reported having some technical difficulties during the project. These issues were similarly reported across all four classes.

4. Discussion

This study examined the effect of scaffolding in conjunction with CFT principles on students’ consideration of multiple perspectives, their misconceptions, and understanding of the problem.

4.1. Multiple perspectives

One of the main goals of this learning environment was to help learners see issues from multiple perspectives. This was grounded in the idea from CFT that the environment should provide learners with different intellectual viewpoints and multiple paths through the environment (Spiro et al., 1988). Moreover, the scaffolding in the environment was designed to help students organize, make connections, and reflect on the different perspectives on the problem.

On the whole, students did very well in considering the different perspectives of the problem. Prior to using the software, the students had not been exposed to this environmental problem or its different perspectives in their curriculum. While using the software, students were presented with four different perspectives. After using the software, approximately 81% of the students included at least three of these perspectives in their qualitative descriptions of the problem. All groups did statistically the same on this measure. Thus, the scaffolding did not affect students’ consideration of the different perspectives on the problem. Previous research on scaffolding in the Pollution Solution environment also indicated that scaffolding did not have a significant effect on students’ grasp of multiple perspectives (Zydney, 2005). One possible explanation is that the CFT principles alone were sufficient in helping students grasp the different perspectives on the problem. This speculation is in line with similar conclusions drawn by Jacobson et al. (1996). After finding that the scaffolding within a CFT-based environment did not significantly alter students’ knowledge synthesis in their problem-solving essays, these researchers hypothesized that the CFT principles alone were sufficient to help students develop flexible understanding of the content. Fitzgerald et al. (1997) also found that CFT principles alone assisted students in understanding the need to gather different perspectives on a behavioral disorder problem.

4.2. Misconceptions

Another objective of the Pollution Solution learning environment was to lower the number of students’ misconceptions. This idea was based on a CFT principle, which recommended that learning environments emphasize the complexity of the issue instead of oversimplifying the material (Spiro et al., 1988). In addition, the scaffolding was designed to help learners reflect on their understanding of the problem, assisting them in reducing their misconceptions.

Overall, the number of student misconceptions was very low. None of the students had more than three misconceptions, and the majority of students did not have any misconceptions. In addition, there was no significant difference between the different scaffolding tool types on the number of misconceptions held by the students. One possible explanation is that the number of misconceptions was similar for the different conditions because the design features associated with CFT were consistent for all four comparison groups. Thus, as was found with the multiple perspectives measure, it may be that the CFT principles alone were sufficient in reducing the number of misconceptions held by the students.

Even though lowering misconceptions is one of the objectives of CFT, no studies on CFT-based environments were found that examined students’ misconceptions. However, this present study related to other studies that have examined the effect of computer-based environments on students’ misconceptions. For example, Cepni et al. (2006) found that computer-assisted instructional material compared to traditional instruction was more effective in reducing many of the students’ misconceptions about photosynthesis. These researchers concluded that the computer-based environment helped to reduce the misconceptions because the activities were directed at students’ comprehension and application of the scientific concepts. These researchers felt that the misconceptions could be reduced further if they had required students to work in groups. This idea was also reflected in the research of Yenilmez and Tekkaya (2006) who found that the social interaction provided through the online discussions encouraged students to share their ideas, debate the accuracy of those ideas, and adjust their ideas if incorrect. It is possible that the low numbers of misconceptions in the present study were a result of students working in groups; thus, additional research is needed to test this hypothesis.
Another suggestion for reducing misconceptions in computer-based environments was to provide scaffolding or guided reflection (Gazit et al., 2005). Gazit et al. inferred from their findings that “the emergence of misconceptions is a direct consequence of the lack of such mentoring” (p. 468). They recommended incorporating within their computer-based, virtual reality environment several tools, such as a built-in smart agent, a playback feature to promote peer feedback, and hints or suggestions, to reduce students' misconceptions and promote greater understanding. The inclusion of scaffolding tools is supported by the findings of this present study. Although the scaffolding tools did not significantly reduce students' misconceptions beyond the CFT elements alone, these tools promoted a greater understanding of the problem.

4.3. Problem understanding

The scaffolding in this learning environment was designed to improve students' problem understanding. This study found that different scaffolding tools have varying effects on students' problem understanding. The organization tool significantly helped increase students' problem understanding. This tool was designed to assist learners with organizing knowledge to help them improve their conceptual understanding by integrating new problem information into their conceptual framework (Jonassen, 2003). These findings lend support to Reiser's (2004) notion that scaffolding can provide additional structure to support students in solving the problem, while, at the same time, can help students to "problematize" an issue. By providing a framework to describe the problem, scaffolding can assist students in articulating their understanding of the underlying scientific concepts. The results from this study were also consistent with findings from other studies on the use of scaffolding tools within CFT-based environments (Demetriadis & Pombortsis, 1999; Demetriadis et al., 2008; Jacobson & Archodidou, 2000).

On the other hand, the higher-order thinking tool did not significantly improve students' problem understanding. This tool was designed to help learners in thinking about what they needed to learn more about in order to solve the problem. The intention of this prompt was to have students think about the additional data that they needed to gather about the problem. Researchers have suggested several factors that can alter the effectiveness of higher-order-thinking tools, including changing the wording, altering the timing/location (Davis, 2003), and providing more time to use the tool (Brush & Saye, 2001). More research is needed to see whether a modified higher-order thinking scaffold might have improved the students' results.

The combination tool group did not perform as well as expected. One explanation for the discrepancy between expected and actual results was the interaction found between the organization and higher-order thinking scaffolds. The higher-order thinking scaffold appeared to interfere with the effectiveness of the organization scaffold in improving students' problem understanding. One possible cause for this interference might be that the students had less time for researching because they were required to use both tools. Their performance might have been negatively affected by the increased workload of having multiple scaffolding tools to use (Demetriadis et al., 2008). The students also might have required more time to become comfortable using multiple tools (e.g., Liu & Bera, 2005). However, these explanations should be interpreted with caution because this group was observed to have behavioral issues (e.g., lateness, talking at inappropriate times, and high noise levels) and may not have produced the most reliable data. For additional details about the qualitative characteristics of this classroom environment, see Zydney (2008). Although future research is needed to confirm whether these findings were due to the behavioral issues observed or an interaction, it is important to note that the combined scaffolding in the earlier iteration of this study was also found to not be as effective as the individual tools (Zydney, 2005).

The results from this study were reflective of the mixed findings in the literature on the use of multiple computer-based tools for scaffolding within CFT-based environments. Jacobson and Archodidou (2000) found the use of multiple scaffolds within a CFT-based environment to be effective; whereas, Jacobson et al. (1996) found higher degrees of scaffolding within CFT-based environments to not be successful. There may be certain conditions that limit the effectiveness of combined scaffolding tools or higher degrees of scaffolding, such as when learner background knowledge is low (Land & Zembal-Saul, 2003) or when epistemic beliefs about the nature of learning are simple (Jacobson et al., 1996).

5. Conclusion

One relatively unexplored area in the literature on CFT-based learning environments was the use of scaffolding in supporting young learners in understanding complex problems. Thus, this study sought to test this type of environment with high school students and found it to be effective in improving their problem understanding. Moreover, the earlier iteration of this study was conducted with middle school students (Zydney, 2005), which provides further evidence that scaffolds can be used to support young learners in using a CFT-based environment to understand a real-world issue.

Another contribution made by this present study was the investigation of CFT-based environments on students' misconceptions and grasp of multiple perspectives: two key features of CFT. No prior research examined the effect of CFT-based environments on students' misconceptions of underlying concepts, and only one study examined the use of a CFT-based environment on students' understanding of different perspectives. This present study provided a starting point for understanding the use of CFT-based environments on these measures. Specifically, the results indicated that the CFT design features alone were sufficient in promoting flexibility in understanding.

Finally, this study contributed to our understanding of the use of multiple scaffolds within a CFT-based environment. This study, along with its earlier iteration (Zydney, 2005) found that the class that received multiple scaffolds did not do as well as the class that received just the organizational scaffold. These findings highlight the importance of testing the effects of individual tools in addition to testing the effect of the combined scaffolding tools used. It also raises questions about whether multiple tools necessarily provide greater scaffolding than a single tool or whether there is a potential for these tools to interfere with one another.

Acknowledgements

This article is dedicated to the memory of W. Michael Reed for his guidance and mentorship. I would like to acknowledge the invaluable contributions of Jan L. Plass as well as many others from the NYU community, including Maaike Bouwmeester, Annie Chien, Robert Norman, Richard C. Richardson, Marc Scott, Francine Shuchat Shaw, and Jennifer Yamron. I am also extremely grateful for the generosity of time and expertise from Arne Bathke, Allison Godshall, and Megan Roberts.
Appendix A. Rubrics

See Appendix Tables A1–A3.

Table A1
Multiple perspectives assessment.

<table>
<thead>
<tr>
<th>Perspective</th>
<th>Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental</td>
<td>The student’s definition of the problem includes the effects of acid rain and sulfur dioxide pollution on the environment and people -or-. The student’s hypothesis mentions that it is important to find a solution that has minimal environmental impact.</td>
</tr>
<tr>
<td>Economic</td>
<td>The student’s definition of the problem includes the economic aspect – losing business, stock prices dropping -or-. The student’s hypothesis mentions that it is important for the solution to be cost-effective.</td>
</tr>
<tr>
<td>Legal</td>
<td>The student’s definition of the problem includes legal aspect of the problem including the EPA lawsuit -or-. The student’s hypothesis mentions that it is important for the solution to be in compliance with the Clean Air Act.</td>
</tr>
<tr>
<td>Engineering</td>
<td>The student’s definition of the problem specifies the plants’ technical improvements -or-. The student’s hypothesis mentions that it is important for the solution to be technically feasible.</td>
</tr>
<tr>
<td>Other</td>
<td>(For example, citizen’s perspective, sociologist perspective, etc.).</td>
</tr>
</tbody>
</table>

Note: 1 point given for each perspective represented.

Table A2
Misconceptions score assessment.

<table>
<thead>
<tr>
<th>Misconception</th>
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<tbody>
<tr>
<td>A misconception is defined as a statement that indicates that a student does not understand a learning concept related to the problem. The number of sentences with misconceptions were counted.</td>
</tr>
<tr>
<td>An example of a misconception is: “The company uses sulfur dioxide to create energy.” This statement indicates that the student does not understand that sulfur dioxide is actually a byproduct of creating energy from burning coal.</td>
</tr>
<tr>
<td>Simple mistakes or errors should not be counted. For example, the wrong date for the creation of the Clean Air Act would not be considered a misconception.</td>
</tr>
</tbody>
</table>

Table A3
Problem understanding assessment.

<table>
<thead>
<tr>
<th>Criteria for assessing problem factors</th>
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</thead>
<tbody>
<tr>
<td>1. By burning fossil fuels to create energy, the energy company is polluting sulfur dioxide which causes acid rain.</td>
</tr>
<tr>
<td>2. The environmentalists and community activists are angry because acid rain is killing plants, trees, and fish, and destroying buildings and sculptures. Sulfur dioxide exacerbates respiratory problems like asthma.</td>
</tr>
<tr>
<td>3. The energy company is losing business and the stock prices are going down.</td>
</tr>
<tr>
<td>4. The energy company is being sued by the EPA for violating the Clean Air Act.</td>
</tr>
<tr>
<td>5. The energy company believes that they do not need to comply with the Clean Air Act’s stricter rules because they were “grandfathered” in (i.e. They were established prior to the Clean Air Act being enacted).</td>
</tr>
<tr>
<td>6. The energy company has a decision to make: should they fight the lawsuit or settle with the EPA and bring their plant up to code?</td>
</tr>
<tr>
<td>7. Extra factor: ————</td>
</tr>
</tbody>
</table>

Note: Students will receive 1 point for each factor and can receive 1/2 points for including part of a factor from the list above.

References


