SCAFFOLDING IN TECHNOLOGY-ENHANCED SCIENCE EDUCATION

A Dissertation

by

HUI-LING WU

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2010

Major Subject: Educational Psychology

SCAFFOLDING IN TECHNOLOGY-ENHANCED SCIENCE EDUCATION

A Dissertation

by

HUI-LING WU

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Approved by:

Chair of Committee,	Susan Pedersen
Committee Members,	Ernest Goetz
	Cathleen Loving
	Victor Willson
Head of Department,	Victor Willson

May 2010

Major Subject: Educational Psychology

ABSTRACT

Scaffolding in Technology-Enhanced Science Education. (May 2010)
Hui-Ling Wu, B.A., National Cheng Kung University;
M.S., Indiana University, Bloomington
Chair of Advisory Committee: Dr. Susan Pedersen

This dissertation focuses on the effectiveness of scaffolding in technology-enhanced science learning environments, and specifically the relative merits of computer- and teacher-based scaffolding in science inquiry. Scaffolding is an instructional support that helps learners solve problems, carry out tasks, or achieve goals that they are unable to accomplish on their own. Although support such as scaffolding is necessary when students engage in complex learning environments, many issues must be resolved before educators can effectively implement scaffolding in instruction. To achieve this, this dissertation includes two studies: a systematic literature review and an experimental study.

The two studies attempted to reveal some important issues which are not widely recognized in the existing literature. The primary problem confronting the educator is how to determine which of the numerous kinds of scaffolding will allow them to educate students most effectively. The scaffolding forms that researchers create are often confusing, overlapping, or contradictory. In response to this, the first study critically analyzed the ways that researchers have defined and applied scaffolding, and provided suggestions for future scaffolding design and research. Moreover, studies tend to focus only on computer-based scaffolding rather than examining ways to integrate it with teacher-based instruction. Although researchers generally recognize that teacher-based support is important, research in this area is limited. The second study of this dissertation employed a quasi-experimental design with four experimental conditions, each of which include a type of computer-based procedural scaffolding (continuous vs. faded) paired with a type of teacher-based metacognitive scaffolding (early vs. late). Each class was assigned to use one of the four conditions. The findings indicated that students receiving continuous computer-based procedural and early teacher-based metacognitive scaffolding performed statistically better at learning scientific inquiry skills than other treatment groups. Students using faded computer-based procedural and early teacher-based metacognitive scaffolding showed the worst performance. However, among the four groups there existed no statistically significant difference in terms of the effect on students' ability to learn science knowledge. Moreover, teacher-based metacognitive scaffolding did not have a significant impact on either science content knowledge or scientific inquiry skills.

DEDICATION

To my father – the greatest man I’ve ever met in my life.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Susan Perdersen, and my committee members, Dr. Ernest Goetz, Dr. Cathleen Loving, and Dr. Victor Willson, for their guidance and support throughout the course of this research. Thanks also go to my friends for making my time at Texas A&M University a great experience and my coworkers in Instructional Technology Services for sharing their friendship and professionalism; specially, I will never forget the great support I received from Dr. Snell and Dr. Carol Henrichs. I also want to extend my gratitude to the teachers and students who were willing to participate in the study.

Without the encouragement, love, patience, and support from my family, this dissertation would not likely exist. Thank you, Dad and Mom! Your endless love and support motivated me to persevere through to the end of this long journey. From now on, I am proud to say that that I am the daughter of Mr. Ming-Fang Wu and Mrs. Tien-Huang Yang Wu. Thank you also to my sisters (Hui-Feng & Hui-Hwa) and brothers-in-law (Alex and Johnson)! Your great support and understanding have meant so much to me. Thank you, my in-laws (Mr. and Mrs. Hilton) for your unconditional love and support, and most importantly, thank you for having such as a great son, Brian, who puts up with my constant stress and not-so-good temper, provides non-stop, professional, and free editing services for me, has a strong belief in my abilities, stands by me and helps me in all events. Thank you, my husband.

TABLE OF CONTENTS

CHAPTER

LIST OF TABLES

CHAPTER I

INTRODUCTION

Rather than training students to recall a great number of facts, contemporary science instruction tends to prepare students become critical thinkers by providing opportunities for them to engage in contexts related to the world's activities. Through the process of participating in inquiry-oriented activities, students are encouraged to perform tasks in scientific ways in order to understand the ways scientists study and explain the natural world (Guzdial, 1994). These science inquiry activities often require students to conduct multiple tasks, including posing questions, creating hypothesis, gathering data, and constructing evidence-based explanations. However, students may encounter difficulties when they engage in such complex learning tasks. Especially, technology-enhanced learning, often requiring students to complete activities through the analysis of a lot of information, further complicates students' learning process. As such, students often need appropriate support to develop higher levels of cognitive development (Veermans & Tapola, 2004).

One way to resolve these issues is by using scaffolding. Scaffolding is an instructional support that helps learners solve problems, carry out tasks, or achieve goals that they are unable to accomplish on their own. Traditional scaffolds involve a more knowledgeable individual, such as a teacher, tutor, or parent, providing learners with appropriate levels of support to help them complete tasks. Scaffolding also aims to

---

This dissertation follows the style of *Educational Technology Research & Development*.

advance the learner's knowledge and develop independent learning by providing them with support that gradually fades. However, researchers have found that several limitations exist regarding the application of scaffolding in large classes and computer-based learning systems. The diverse forms and functions of scaffolding applications also complicate researchers' efforts to develop effective scaffolds, with many important scaffolding features being ignored (Puntambekar & Hubscher, 2005). For example, many scaffolding applications do not fade the support, although fading is a part of traditional definitions of scaffolding. Furthermore, researchers of computer-based learning tend to focus on technology-embedded support but overlook the importance of teacher support.

This dissertation aims to resolve these and other problems regarding the utilization of computer-based scaffolding and teacher support in science learning environments. The first study of this dissertation is a systematic literature review that examines the literature published between 2000 and 2008 to determine the ways researchers have applied scaffolding in computer-supported science learning environments. This review will help to determine how researchers have adapted traditional definitions of scaffolding to suit current technology-enhanced contexts, will reveal the implications of these applications in current educational practices, and will provide suggestions for future scaffolding design and research. The second study empirically investigates the effect of utilizing multiple scaffolds in a computer-based science environment. Although scholars recognize that no single tool can effectively provide sufficient support for student learning, only limited research has explored the interactive effects of various instructional scaffolds.

Also, while metacognitive scaffolding can help individuals to think about their thinking, studies show that students fail to understand the value of metacognitive scaffolding and tend to ignore it if it is embedded in computer programs. As such, this study examines the utilization of teacher metacognitive scaffolding along with computer-based procedural scaffolding. Participating middle school students engaged in a virtual learning environment, *Supervolcano*, to answer five open-ended questions. Each individual student was provided with embedded procedural scaffolding for each question. Moreover, teachers offered metacognitive support at different times during the learning process.

Specifically, this study investigates how the timing of teacher support and different kinds of embedded scaffolding (continuous and faded) influence students' learning outcomes in science inquiry. When should teachers provide students with metacognitive scaffolding in order to maximize student learning in computer-based environments? Even though researchers suggest that students will benefit more if metacognitive scaffolding replaces procedural scaffolding after students are familiar with the content, these assumptions still lack empirical evidence. The outcome of this study will help guide future studies to integrate multiple scaffolds in education.

CHAPTER II

AN ANALYSIS OF SCAFFOLDING IN TECHNOLOGY-ENHANCED SCIENCE LEARNING

Introduction

In recent decades, researchers have increasingly recognized the value of using technology in science education (National Research Council, 1996), a trend which has shifted the focus of science instruction from the simple memorization of basic facts toward the use of learner-entered inquiry strategies. Technology-enhanced science learning facilitates the development of in-depth knowledge and helps learners engage in the scientific thinking process (Lee & Songer, 2003). Moreover, it tends to engage learners in self-regulated environments (Barak & Dori, 2005; Luke, 2006) which motivate them to solve complex questions. However, although technology-enhanced science inquiry provides students with opportunities to learn in authentic contexts, the multiple tasks in open-ended and ill-structured environments which often characterize it can be overwhelming for students (Quintana & Fishman, 2006). Moreover, the numerous sources of information on which students can base their conclusions pose a significant dilemma in that learners may not know how to evaluate the validity of these sources. Many researchers consider scaffolding as an effective way to remedy these and other problems of science learning.

Scaffolding originated with Wood, Bruner, and Ross's study (1976), which suggested that scaffolds might enhance student learning. They argued that beyond modelling and imitation, tutors should control the elements of the task that "are initially beyond the learner's capacity, thus permitting him to concentrate upon and complete only those elements that are within his range of competence" (p.90). To achieve this, scaffolding should *reduce the degree of freedom* which means that instructors should support students by simplify the task to the level that students can manage it.

Beginning in the 1980s, researchers began to associate scaffolding with Vygotsky's (1978) *Zone of Proximal Development* (ZPD) (Rogoff & Gardner, 1984; Bruner, 1985). ZPD is the "distance between what a person can do with or without help" (Verenikina, 2003). Whereas *actual development* refers to the knowledge or skill capabilities that the individual has already obtained, *potential development* refers to the extent to which a student may develop through the assistance of others. According to Vygotsky, knowledge is shared and construed in social and cultural contexts. By interacting with students, teachers utilize a social-constructive approach (Dickson, Chard, & Simmons, 1993) to establish mutual understanding and negotiate potential levels of development. Therefore, learners do not wait passively to learn; instead, teacher and student jointly construct meaning through active interaction. This allows the learner not simply to complete a single task or goal, but rather to gain knowledge through experience by conceptualizing the process of accomplishment (Meyer, 1993). During the process of interaction, teachers can monitor student's current level of skills or knowledge and help students to extend the current abilities to a higher level of competence by providing them with appropriate support (Rogoff & Gardner, 1984).

Traditional notions of scaffolding emphasized the importance of gradually withdrawing support. In order to develop a student's independent thinking and learning abilities, scaffolding, acting as a temporary support, is gradually withdrawn as the student's need for the support diminishes (Applebee & Langer, 1983). As such, the responsibilities of managing tasks are transferring from instructor to students. The techniques of fading help students to establish their confidence that they can master the skills required (Collins, Brown, & Newman, 1989) and further enhance independent learning (Beed, Hawkins, & Roller, 1993).

The creation of innovative educational paradigms and technological improvements has resulted in a diverse array of scaffolding applications which have changed the way researchers define scaffolding. Designing effective scaffolds to help learners improve their cognitive development and inquiry skills first requires an understanding of the current status of scaffolding applications in the literature. In order to examine how researchers define scaffolding and to understand the myriad ways they have applied scaffolding in technology-enhanced science learning environments, this study systematically reviews the existing literature.

Methods

Unlike traditional literature reviews, this study examines the literature in a systematic way. Given the fact that every database system uses different methods to search for information, only the articles published in the CSA Illumina portal were included in this study. The three databases used in the search (Education: A SAGE Full-Text Collection, ERIC, and PsycINFO) were chosen because they are all categorized as educational databases by the Texas A&M University library.

An article search was conducted using the following search criteria: (1) keyword = scaffold*, (2) keyword = computer*, technology*, software*, web*, hypermedia*, or multimedia*, (3) descriptor = scaffold* or teaching method*, and (4) descriptor = computer*, technology*, software*, web*, hypermedia*, or multimedia*. Because this study focuses on scaffolding in science learning, the articles which contain the following keywords or descriptors were not included: (1) keyword = math*, language, or history, (2) keyword = "teacher education" or preschool, (3) article title = teacher, (4) descriptor = reading or writing, and (5) descriptor = faculty, professional, or teacher*. Studies which focused on teacher's use of scaffolding in their instruction were removed. In addition, the studies selected must have been published in a peer-reviewed, English language journal between January 2000 and December 2008.

The search yielded a total of 222 articles. Each article was examined to determine relevancy to the issues on which this review focuses. Those articles which conducted a review and technical report but that did not employ scientific methodology (quantitative, qualitative, or mixed) were not included in this study. Articles which were not related to science learning were also ignored. Only 47 studies met the selection criteria. The references within each of the 222 studies were then examined using the same search criteria. This search yielded another 20 articles. Because this literature review focuses on scaffolding in pre-college education, 11 studies that included college-aged participants were removed. As a result of these deductions, a total of 56 articles were investigated (see Appendix A).

Results

Study characteristics

The reviewed studies tended to examine how instructional materials or activities influenced student learning, especially regarding conceptual understanding (i.e., Butler & Lumpe, 2008) and performance development (i.e., Lajoie, Lavigne, Guerrera, & Munsie, 2001). These studies investigated the effectiveness of scaffolding by either comparing students' pre- and post-test scores or analyzing students' ability to think scientifically thinking (Squire & Jan, 2007; Toth, Suthers, & Lesgold, 2002), make decisions (Pata, Sarapuu, & Lehtinen, 2005; Pata, Lehtinen, & Sarapuu, 2006; Siegel, 2006), create scientific explanations (Sandoval & Reiser, 2004; Sandoval & Millwood, 2005; Smith & Reiser, 2005; Vattam & Kolodner, 2008), reason (Seethaler & Linn, 2004), make arguments (Clark & Slotta, 2000; Clark & Sampson, 2007), and model activities (Fretz, Wu, Zhang, Davis, Krajcik, & Soloway, 2002). In addition, researchers were also interested in investigating students' beliefs (i.e., Jacobson & Archodidou, 2000), attitudes (i.e., Pedersen & Liu, 2002), and even patterns of using software features (i.e., Butler & Lumpe, 2008).

Of the 56 studies, only 7 compared the level of student learning that occurred with and without the use of scaffolding (Table 2.1), but while these studies used control groups, they did not have scaffolding as the controlled factor (Jacobson Archodidou, 2000; Lee, Chan, & Aalst, 2006). This is problematic, because many things other than scaffolded activities may influence learning outcomes. For those studies that did have scaffolding as the controlled factor, some compared situations where scaffolding was either absent or present, and examined such scaffolding forms as concept mapping (Chang, Sung, & Chen, 2001; MacGregor & Lou, 2004), metacognition (Zydney, 2005; Manlove, Lazonder, and de Jong (2007), procedural of the task (Zydney, 2005), and even these scaffolds used in combination (Zydney, 2005; Vreman-de Olde, 2006). In addition to this focus on scaffolding functions, some researchers compared scaffolding strategies, such as whether scaffolding was required (Simons & Klein, 2007) or whether the scaffolding adapted to suit the specific needs of learners (Azevedo, Cromley, Winters, Moos, & Greene, 2005). Some studies found that the use of scaffolding did not always produce positive learning outcomes. For instance, scaffolding sometimes failed to contribute to students' achievement in post-test scores (Vreman-de Olde, 2006; Simons & Klein, 2007), and sometimes even hindered learning outcomes (Azevedo et al, 2005).

In contrast, some studies focused instead on alternative factors that may influence student learning, such as gender (Liu, 2004), prior knowledge (Winters & Azevedo, 2005) and discussion format (Hoadley & Linn, 2000). These studies tended to ignore comparisons between scaffolded and non-scaffolded learning.

Table 2.1 Scaffolded vs. Non- Scaffolded Groups

First author / Year	Scaffolding forms	Scaffolding purposes	Experimental groups	Outcomes
Azevedo (2005)	• Adaptive scaffold o Instruction o Tutor • Fixed scaffold o Instruction o Sub-goals • No scaffold o Instruction	• Adaptive scaffold o Plan learning o Monitor o Use strategies • Fixed scaffold o Promote qualitative shifts in student's mental model	• Adaptive Scaffold • Fixed Scaffold • Control Scaffold	• Declarative knowledge o AS – greater than Fixed scaffolds and No scaffolds groups (matching task: effect size = .157; labeling task: effect size = .1570.302). o FS – indistinguishable outcome with NS for matching task; worst than NS in labeling task • Regulated learning 1. Strategies: o AS – hypothesize, coordinate of information, inferences, use mnemonics, draw, and summarize o FS – searching, skip, select new sources o NS – re-read text, take notes, knowledge elaboration 2.Task difficulty and demands: o AS – seek help o FS – expect adequacy of the information o NS – control the context, plan their time and effort

Table 2.1 Continued

First author / Year	Scaffolding forms	Scaffolding purposes	Experimental groups	Outcomes
Chang (2001)	Concept mapping	Concept mapping	• Construct-on-scaffold • Construct-by-self	The students used the ‘construct-on-scaffold’ version outperformed those used the ‘construct-by-self’ version
MacGregor (2004)	1. Concept mapping template 2. A study guide	Concept mapping	• Concept map • Control	The scaffolds helped students to extract information from Web sites and then to be able to remember, present, and organize that information
Manlove (2007)	Process Coordinator	Regulate inquiry	• Process Coordinator • Control	PC+ dyads wrote better lab reports. PC− dyads viewed the content help files more often and produced better domain models
Simons (2007)	Guiding questions Expert advice	Conceptual Strategic	• Required scaffold • Optional scaffold • Control	Students in the scaffolding optional and scaffolding required conditions performed significantly better than students in the no scaffolding condition on one of the two components of the group project
Vreman-de Olde (2006)	Design sheet	Conceptual Procedural	• Design sheet • Control	The students without scaffolding created more products but less quality than those wit scaffolding. But there was no significant difference in knowledge tests between two groups.

Table 2.1 Continued

First author / Year	Scaffolding forms	Scaffolding purposes	Experimental groups	Outcomes
Zydney (2005)	• Organization o Research plan template • Higher order thinking o Status report • Combination o Organization + Higher order thinking	• Organize research • Reflection • Combination	• Organization • Higher order thinking • Combination • Control	The organization scaffolding was the most effective in helping students to understand the problem, develop hypothesis. The higher order thinking scaffolding was most helpful for guiding students to think about the multiple perspectives of the problem. The combined scaffolding did not do as well as these scaffolds did individually.

The definitions of scaffolding

Although all 56 articles included in this study focused on the implementation of scaffolding, 34 of the 56 articles failed to define scaffolding. The characterizations of scaffolding among the remaining 22 studies included one or more of the following components: (1) receiving support from a more knowledgeable person (such as teacher, peer, or parent) or tools, (2) building a shared understanding of goals between a learner and more knowledgeable person which motivates learners to engage in the task, (3) monitoring each students' learning process and providing appropriate and timely support, (4) helping learners to do activities that they are unable to accomplish on their own, and (5) gradually decreasing support as learners demonstrate competency. As shown in Table 2.2, only Azevedo and colleague's (2005) study included all five components in their definition of scaffolding. 16 of the articles agreed that scaffolding helps individuals to reach goals which may be difficult to reach at their current level of ability. 13 articles concluded that students require support from either a more knowledgeable person or technology-based system, although 7 of these believed that scaffolding must include with ongoing assessment of a learner's current knowledge level. 12 articles also emphasized the importance of fading the support in order to enhance independent learning. 8 articles included both Vygotsky's ZPD and fading in their definitions of scaffolding, but 1 study considered fading as the sole defining feature of scaffolding. Only a few studies mentioned the creation of a shared understanding of goals (4 articles) and individualized support (3 articles).

Table 2.2 Reviewed Articles Defined Scaffolding

First author (Year)	Knowledgeable person or computer support	Shared Understanding	Ongoing diagnosis	ZPD	Fading
Azevedo (2004)	*				
Azevedo (2005)	*	*	*	*	*
Azevedo (2008)	*	*	*		*
Butler (2008)				*	
Chen (2003)	*		*	*	*
Fretz (2002)	*			*	*
Hoadley (2000)	*				
Hoffman (2003)	*		*	*	*
Jamaludin (2006)					*
Lajoie (2001)	*				*
Lumpe (2002)				*	*
Pata (2005)			*	*	*
Pata (2006)	*	*	*	*	*
Puntambekar (2005)	*	*	*	*	*
Reid-Griffin (2004)	*				*
Revelle (2002)				*	
Simons (2007)				*	
Smith (2005)	*			*	
Valanides (2008)				*	
Vreman-de Olde (2006)	*			*	
Wu (2006a)				*	
Wu (2006b)				*	

Applications of scaffolding features

Researchers have difficulty reaching consensus on which features should be included in scaffolding and how these features should operate. Three questions about scaffolding features that figure prominently in the literature are whether the scaffolds should include an ongoing diagnosis of student learning, how and at what rate the scaffolding support should fade, and the extent to which teacher or peer support should be used in today's technology-rich instruction.

In order to provide appropriate and timely support for learners with different ability levels, scaffolds must conduct an ongoing diagnosis of each student's learning during the learning process. However, although researchers recognize the importance of such ongoing evaluations, they rarely implement them in technology-enhanced science education (Puntambekar & Kolodner, 2005). For those that do, they tended to use it with teacher-based scaffolding (Hoffman, Wu, Krajcik, & Soloway, 2003; Pata et al., 2005; Pata et al., 2006). Only Chen, Kao and Shau (2003) incorporated ongoing assessment features within computer systems. Also the adaptive scaffolds utilized in Azevedo et al's study (2005, 2008) diagnosed students' emerging understanding.

Some researchers emphasized that fading is an important feature of scaffolding, yet did not include it in their studies (Fretz et al., 2002; Hoffman et al., 2003; Lumpe & Butler, 2002). Some researchers argued that it may not be helpful or appropriate for certain scaffolds to fade (Azevedo et al, 2005; Azevedo, Moos, Greene, Winters, & Cromley, 2008; Fretz et al, 2002).

Fading is more often found as a feature of teacher-based scaffolding than computer-based scaffolding. 7 studies faded instructor scaffolds (Azevedo et al, 2005; Azevedo et al., 2008; Jamaludin & Lang, 2006; Lajoie, Lavigne, Guerrera, & Munsie, 2001; Pata et al., 2005; Pata et al., 2006; Reid-Griffin and Carter, 2004; Wu & Krajcik, 2006b), while only 2 studies faded computer-based scaffolds. In Zydney's study (2005), for instance, students used mandatory computer-controlled scaffolds to become acquainted with the learning environment, though once students began the problem solving process the scaffolds began to fade. However, among the reviewed studies, only one included a computer program that assessed each individual's learning performance and gradually faded the scaffolding as the learners demonstrated increasing abilities (Chen, Kao, & Sheu, 2003). Rather than fading the teacher or computer-based scaffolds, Puntambekar and Kolodner (2005) faded essential learning units of their curriculum.

New technologies have lead researchers to focus much attention on computer-based scaffolding, and less so on teacher-based scaffolds. Among the 56 reviewed studies, 5 relied only on teacher-based scaffolding, and 3 used both teachers and students as the only means of support. However, 12 studies adopted both human and tool-based (computer-based program or paper-based material) scaffolds; among these studies, only 4 (Fretz et al., 2002; Lajoie et al., 2001; Puntambekar & Kolodner, 2005; Winters & Azevedo, 2005) adopted peer scaffolding.

These three scaffolding features (ongoing diagnosis, fading, human support) often do not occur in isolation; researchers sometimes combine them in a complimentary manner. For instance, many studies concluded that ongoing diagnosis and adaptive support were often best accomplished through the utilization of human-based, rather than paper- or computer-based scaffolding (Azevedo et al., 2005; Pata et al., 2005; Pata et al., 2006). The scaffolds which Chen, Kao, and Sheu (2003) used included both diagnosis and fading features; they implemented computer-based scaffolds which both continuously assessed students' learning and decreased the support when students demonstrated their capabilities. Similarly, in Eslinger and colleagues' (2008) study, students received different levels of scaffolding as they implemented the inquiry steps; the computer system estimated the level of support the students needed and gradually decreased the support at appropriate times.

Scaffolding purposes in science learning

The following section examines how researchers have implemented scaffolding in science learning and what kind of purposes these scaffolds served.

Scaffolds that enhance concept understanding

Because technology-enhanced science learning environments often involve complex science inquiry or ill-structured problem solving activities, students may need additional support to understand concepts. Some scaffolds serve this purpose by prompting students to pay attention to crucial concepts, clarify conceptual knowledge they do not understand, or acquire declarative knowledge in the domain through tool-based (Jacobson & Archodidou, 2000; Lim, Nonis, & Hedberg, 2006; Zumbach, Schmitt, Reimann, & Starkloff, 2006), teacher-based, or peer-based support (Azevedo, Winters, & Moos, 2004; Fretz et al., 2005; Pata et al., 2006; Winters & Azevedo, 2005; Wu, 2003). Many tool-based scaffolds prompted students to articulate their thinking. For example, in Oliver and Hannafin's (2001) study, a question prompt ("What is the problem described by this Web page?") in the note-taking window of their computer program helped students focus on key concepts. Also, Sandoval's (2003) ExplanationConstructor explanation guides worked as conceptual frameworks to help students decide what must be explained about the current problem; they highlighted the important components of domain theories and encouraged students to articulate their answers step by step.

Scaffolding also helps learners organize their concept knowledge. Concept mapping tools, for instance, allow students to arrange information by identifying the relationships among concepts. Chang and others (2001) provided students with an incomplete framework for an expert concept map, and required them to fill in the blanks. By using concept mapping, students developed better higher-order thinking skills than those who had not used this scaffold (Chang et al., 2001; MacGregor & Lou, 2004). The interactivity of concept mapping and reflective assessment rubrics greatly encouraged students to search for and evaluate information, especially when compared with learners provided with either reflective or unstructured writing templates (Toth, Suthers, & Lesgold, 2002). In Toth and colleague's study, although students supported only with concept mapping tools presented fewer hypotheses and data, they were nonetheless able to distinguish the differences and identify the relationships between data and hypotheses better than non-supported groups.

Scaffolds that help students complete tasks

The two general means by which scaffolds help students complete tasks are by either simplifying those tasks or modeling the thinking process. However, it is important to note that these two purposes are not mutually exclusive, but are complementary. One type of scaffolding may help learners focus on activities while also making information salient to learners.

Simplify learning tasks

One of the most important aspects of instructional scaffolds is their ability to decrease the complexity of learning tasks by either making the task structure explicit or prompting the students to begin with simpler activities.

Some scaffolds divide learning tasks into several smaller components or highlight significant aspects of tasks in order to help students identify and accomplish the various steps of the assigned activities (i.e. Bell & Linn, 2000; Eslinger, White, Frederiksen, & Brobst, 2008; Puntambekar & Kolodner, 2005; Sandoval, 2003; Smith & Reiser, 2005; Winters & Azevedo, 2005; Valanides & Angeli, 2008). This type of scaffolding aims to clarify tasks, identify appropriate learning strategies, and remind learners what they need to do, either in printed materials (Hoffman et al., 2003; MacGregor & Lou, 2004) or technology-based systems (Manlove, Lazonder, & de Jong, 2007). For instance, Eslinger and colleagues (2008) used a program called ThinkerTools which pointed out to students the six steps of the inquiry cycle (question, hypothesis, investigate, analysis, model, and evaluation) and facilitated the development of the students' inquiry skills. Also, the process map scaffolds in the Model-It software break down learning tasks into three steps: plan, build, and test (Fretz et al., 2002). One study used a Help button to suggest further steps the student might take to solve the task (Wu, Krajcik, & Soloway, 2001). Zydney (2005) called this type of scaffolding organization scaffolding because it helps students simplify and organize problem solving tasks.

Scaffolding can help manage resources in rich information contexts. Students sometimes were prompted with guiding questions or expert advice on gathering resources and organizing information (Simons & Klein, 2007). For example, some studies used a Knowledge Integration Environment (KIE) to scaffold students' use and understanding of internet resources, thus helping students determine what to do during a learning activity ("Try to understand the many different reasons why buildings collapse") and how to proceed ("Decide with your partner how you will keep track of information described in the core set of evidence") (Clark & Slotta, 2000; Oliver & Hannafin, 2000).

Another way to decrease the complexity of computer-mediated science learning is to start with simpler activities (Hoffman et al., 2003). For example, teachers can direct the initial learning activities of students who have difficulty beginning a complex inquiry process (Wu & Krajcik, 2006a; Wu & Krajcik, 2006b). In one study, students were directed to focus on one specific task first in order to reduce the burden of cognitive loading (Revelle et al, 2002). Alternatively, these scaffolds could prompt students to complete only a part of the assigned tasks, such as in Vattam and Kolodner's (2008) study in which they provided partially filled explanation templates that required students merely to select the appropriate answer from a multiple choice drop-down menu.

Modeling the thinking process

Whereas some scaffolds attempt to facilitate learning by simplifying learning tasks, scaffolding that models the thinking process "leads students to encounter and grapple with important ideas or processes." It does so in a way that may "add difficulty in the short term, but in a way that is productive for learning" (Reiser, 2004).

Constructing scientific explanations

Many science programs helped students to construct scientific explanations (Kyza & Edelson, 2005; Sandoval, 2003; Sandoval & Reiser, 2004; Sandoval & Millwood, 2005; Smith, & Reiser, 2005) or arguments (Bell & Linn, 2000; Clark, & Sampson, 2007; Siegel, 2006). They also prompted students to elaborate upon their decision-making process (Pata et al., 2005; Pata et al., 2006; Puntambekar, & Kolodner, 2005) or scientific reasoning (Fretz et al., 2002). The computer programs in these studies often included organized structures or prompts that encouraged students to model their thinking, thus making their thinking visible.

Two forms of procedural scaffolding in science inquiry are especially useful for helping students construct scientific explanations or arguments: sentence starters as reminders or prompts (Bell & Linn, 2000; Siegel, 2006), and visual outlines of activities (Clark, & Sampson, 2007; Kyza & Edelson, 2005; Sandoval, 2003; Sandoval & Reiser, 2004; Sandoval & Millwood, 2005). By providing students with a sentence starter ("In considering how well this claim explains all the evidence, we think…), Bell and Linn (2000) attempted to make learners more aware of their own thinking processes. They also reminded students to think about evidence-based explanations by offering hints such as "as we prepare for our debate and think about this evidence, we want to remember…" However, in order to ensure that students understand how to construct explanations, many researchers have designed well-structured computer-based environments, such as the Explanation Page in Kyza and Edelson's (2005) Progress Portfolio project and

Sandoval’s (2003) ExplanationConstructor program.

Both Progress Portfolio and ExplanationConstructor are software tools that help students organize and make sense of data, and allow learners to record their inquiry process. Both tools contain sets of prompts and links to data pages; the former helps students explain issues in specific ways, while the latter helps students locate and use sufficient evidence for their claims. Although the organized interfaces within both of these computer-based environments helped students to construct evidence-based explanations, Sandoval and Millwood (2005) found that students might still fail to cite sufficient evidence for their claims.

Engaging in high-order level activities

Scholars suggest that inquiry activities should include metacognitive scaffolding that will prompt learners to conduct specific investigative actions while helping them to monitor their learning progress through sharing their thoughts with others. The applications of metacognitive scaffolding helped learners to enhance their knowledge about their cognition and regulate their learning. The applications included thinking about goals (Azevedo et al., 2004; Azevedo et al., 2008; Puntabekar & Kolodner, 2005), planning (Azevedo et al., 2004; Azevedo et al., 2008; Hmelo, Holton, & Kolodner, 2000), selecting appropriate strategies (Azevedo et al., 2008), grasping multiple perspectives of the problem (Fretz et al., 2002; Hoadley & Linn, 2000; Oliver & Hannafin, 2000; Oliver & Hannafin, 2001; Pata et al., 2005; Pata et al., 2006; Zydney, 2005), and applying prior knowledge to new situations. Because metacognitive scaffolding encouraged learners to make connections between phases of activities

(Puntambekar & Kolodner, 2005), it helped students revisit earlier inquiry decisions, thus connecting new ideas to their prior knowledge (Azevedo et al., 2004; Azevedo et al, 2005; Azevedo et al., 2008; Zydney, 2005).

Researchers used various approaches to encourage students to reflect upon their learning experience. One of the common practices was the use of question prompts or sentence starters to help students articulate and explain their thinking ("In considering how well this claim explains all the evidence, we think…") (Bell & Linn, 2000) and uncertainties ("In thinking about how it all fits altogether, we're confused about…") (Davis, 2000), or to check their understanding ("Pieces of evidence we didn't understand very well included…") (Davis, 2003a). Similarly, some metacognitive scaffolds took the form of notes, such as "My interpretation" or "My reflection" (Hoadley & Linn, 2000; Jamaludin & Lang, 2006; Lee, Chan, & van Aalst, 2006). In responding to these scaffolds, students had to articulate what they were trying to do and what they wanted to accomplish. Through such metacognitive prompts learners were able to develop higher level thinking skills and understand the gap between what they do and do not know. Moreover, metacognitive scaffolds were used to encourage students to reflect upon their beliefs. Lajoie and colleagues (2001) used a computer-embedded visual device – belief meter – to encourage students to indicate how confident they were with a stated diagnosis based on the collected evidence.

In addition to using scaffolds for reflection, researchers sometimes used modeling tools as metacognitive scaffolds to demonstrate the thinking process. For example, Pedersen and Liu (2005) used expert modeling tools to help students self-regulate their learning behaviors. An expert thought aloud about the problem, explained what he was trying to accomplish, and described how he used the tools within the program to conduct his self-questioning strategies.

The content of metacognitive scaffolding influenced the results of learning outcomes, such as how much and what kind of information was provided in the scaffolds. For example, Davis (2003b) found that middle school students who used generic (context-general) prompts developed more coherent scientific thinking than those who used directed (context-specific) prompts. Also, the results of both of Azevedo et al.'s studies (Azevedo , Cromley, Winters, Moos & Greene, 2005; Azevedo, Moos, Greene, Winters, & Cromley, 2008) revealed that students who received teacher-based dynamic metacognitive scaffolding achieved better conceptual understanding and implemented more self-regulatory strategies than those supported only with static scaffolding.

However, many factors might influence the effectiveness of metacognitive scaffolding. If the quality of scaffolding is low, the presence of scaffolding may interfere with learning outcomes. Azevedo and his colleagues (2005) found that students who were not given metacognitive scaffolding gained statistically better declarative knowledge than those given fixed metacognitive scaffolding. Moreover, when students rely upon support from a more knowledgeable peer, the conceptual understanding of the peer did not significantly change. This may be attributed to the fact that they spent most of their time providing metacognitive support for their peers rather than focusing on their own needs (Winters & Azevedo, 2005).

Scaffolds that help students maneuver through a learning environment

With the increasingly complex content and structure of computer-mediated science learning programs, students may become lost within the virtual environments. To rectify this and similar problems, researchers often provided students with organized learning contexts to help them to complete tasks. These scaffolds enhance student learning, such as organizing ideas (Seethaler & Linn, 2004), recording data (Kyza & Edelson, 2005), or seeking resources (Barab, Sadler, Heiselt, Hickey, & Zuiker, 2007; Butler & Lumpe, 2008; Hoffman et al., 2003; Lumpe & Butler, 2002; Revelle, Druin, Platner, Bederson, Hourcade, & Sherman, 2002). However, scaffolds sometimes additionally helped students to avoid distractions, such as spending time locating appropriate web sites when they are engaged in complex learning environments (Hoffman et al., 2003). However, while some studies identified a range of useful scaffolding tools, they did not identify *how* the tools scaffolded student learning (Liu, 2004; Liu & Bera, 2005; Valanides & Angeli, 2008).

In addition to considering the overall structure of software as scaffolds, some researchers tended to concentrate on the functions of specific tools in the program. Therefore, another way researchers utilize this type of scaffolding was to provide students with technical support (Pata et al., 2005; Pata et al., 2006; Davis, 2003b) to use tools embedded in computer programs.

Discussion

By examining 56 studies which utilized scaffolding in technology-enhanced science education, this literature review identified seven major problems:

Problem 1: The over-abundance of scaffolding definitions

Scaffolding definitions have often caused confusion due to a lack of coherence, a problem that inevitably hinders the design of effective scaffolds and weakens the usefulness of scaffolding research. More than half of all the reviewed studies did not define scaffolding clearly. Those that did offer definitions, however, demonstrated no consensus regarding the key features scaffolding should include. One of the reviewed studies included as many as five components in its scaffolding definition (knowledgeable person or tool, shared understanding, ongoing diagnosis, zone of proximal development, and fading), while other studies selected from one to five of these components. The majority of the reviewed studies defined it as merely the assistance which is provided by a more knowledgeable person or system (13 articles) which helps learners to accomplish tasks that they may not be able to accomplish on their own (16 articles).

While providing necessary assistance to learners is the most common consideration in the literature for defining scaffolding, some researchers claim fading is the defining characteristic of scaffolding that distinguishes it from other forms of support (Fretz et al., 2002). However, this view is problematic since certain kinds of software that include fading features are not always considered scaffolding. For example, Chang and colleagues (2001) did not consider the hint feature in their computer-based program as scaffolding even though it was designed to compare the work of students with the work of an expert and tended to decrease the number of hints as students used the program.

Another problem researchers face is determining the form(s) scaffolding may take. Researchers sometimes view any tool embedded in the computer system as part of the scaffolding, such as a data camera for capturing investigative data, and articulation boxes for recording students' writing (Kyza & Edelson, 2003), which may not fully meet the definitions of scaffolding. This suggests that there is no one correct way to arrange scaffolding; it can constitute anything from a guided question (Oliver & Hannafin, 2001) to an entire project (Bell & Linn, 2000).

Problem 2: Insufficient focus on human scaffolding

The decreasing importance of teachers

Traditionally, scaffolding has taken the form of one-to-one interactions, such as a tutor's assistance to an individual child. However, as scaffolds are applied in schools or technology-based instruction, the instructor has become less important. The number of instances in which researchers integrate teacher scaffolding in technology-enhanced science education is very low. The scaffolds in the studies tended to utilize computer-based support to facilitate student learning. Even though researchers recognize that the scaffolding features in computer-based systems were not "automatic and teacher proof" (Lumpe & Butler, 2002, p.564) and still required a teacher's guidance to help students engage in learning, more than half of the reviewed articles did not contain any human scaffolding. Therefore, Meyer's (1993) claim that instructional methods without social interaction cannot be considered as scaffolded instruction does not accord with the literature. With the lack of teacher support, scaffolding applications cannot be as effective in technology-enhanced learning contexts.

Reconsider the role of teachers

Prior studies (Choi, Land, & Turgeon, 2005) showed that computer-based scaffolds alone could not guarantee enhanced student learning. Because students tended to focus on the surface features in technology environments and ignore the learning tools (Blumenfeld, Kempler, & Krajcik, 2006), the scaffolds they receive, even if they helped students to complete tasks, would not enhance the quality of performance. Furthermore, computer-based scaffolds alone could not prevent erroneous thinking among students (Greene & Land, 2000).

Because students may not always be able to translate their learning interests into cognitive engagement, teachers need to encourage students to move toward additional levels of learning. For example, even though students were provided with guidance or information in computer programs, they often had difficulty and sought the teacher's support (Mercer & Fisher, 1992). Also, because computer-based scaffolding may not be appropriate for learners with different levels of prior knowledge, additional teacher support can play supplementary functions. If teacher scaffolding is available, students who do not benefit from certain scaffolds can still have opportunities to learn through teacher scaffolding. Besides, if learners fail to recognize their learning needs, teacher scaffolding can provide additional support to individuals, especially enhancing motivation and metacognition. While teacher-based scaffolding was seldom applied in the technology-enhanced science education literature, researchers rarely expressed concern about stimulating students' learning motivation, maintaining their interests, and highlighting the learning values. Teachers should play the role of "disturber of equilibrium” (Fosnot, 1984, p.203) to facilitate further thinking.

Despite the advantage of teacher scaffolding, further studies are needed. One of the important issues that must be resolved is the integration of human and computer-based scaffolding. What kinds of functions should human scaffolding provide when used with computer-based scaffolding? Should teacher scaffolding serve secondary functions when paired with computer-based support or is it better for teachers to take over the responsibilities of supporting higher-order thinking?

Further research on peer scaffolding is necessary

Although researchers recognize that a more knowledgeable person should provide support to facilitate independent learning, past studies that utilized human-based scaffolding tended to focus on teacher-based, rather than peer-based, scaffolding. This narrow focus on teacher-based support is problematic for a number of reasons. Stone (1998) notes that teacher-based scaffolding is not effective when applied to an entire class because the teacher has to face individuals with different levels of ZPD. In order to remedy this, researchers have suggested that teachers can break their classes into smaller groups of students so that more knowledgeable peers may have more opportunity to help less capable students (Puntambekar & Hubscher, 2005; Winters & Azevedo, 2005; McNeill, Lizotte, Krajcik, & Marx, 2006). In addition, peer scaffolding may motivate other students to learn (Forman, 1989). Also, students may be more willing to express their opinions and engage in discussions when interacting with peers than with teachers (Tudge & Rogoff, 1989).

Despite its advantages, peer scaffolding also has some limitations. One of the challenges is that students cannot provide the same level of support as instructors. More knowledgeable peers may focus on clarifying tasks but may not support the development of higher level thinking. Thus, while students with approximately equal level of abilities can promote discussion (Tudge & Rogoff, 1989), this "bidirectional dialogue" (Puntambekar & Hubscher, 2005, p. 8) may be limited within the group. Students might simply accept the suggestions from their peers even though they may have doubts about the advice they received (Wu & Krajcik, 2006a). Moreover, whereas teachers often provide adaptive support in the form of feedback (Pata et al., 2005; Pata et al., 2006), more knowledgeable peers may not understand how to provide support that adapts to the changing needs of their fellow students.

Researchers need to examine the factors which may influence the effectiveness of peer scaffolding and what kinds of roles peer scaffolding should play in learning. Because peer scaffolding is more helpful for completing tasks than developing higher level thinking skills, it may be more appropriate for students to collaborate with each other rather than relying upon a more knowledgeable peer who acts as a tutor. However, this is not to suggest that students should not work with more knowledgeable peers; instead, this is simply to suggest that researchers should consider the knowledge level of students in order to determine the best way to foster bi-directional cognitive development among students. It may still be worthwhile, for instance, for less knowledgeable students to share their knowledge with others. The increase in computer-mediated educational environments has further complicated the question of how or if a teacher should use peer scaffolding. Researchers found that computer-based scaffolds can be used to facilitate metacognitive discussion among students, although it is still unknown how group dynamics or the involvement of the instructor might influence their learning outcomes (Choi, Land, & Turgeon, 2005).

Problem 3: Moving away from social constructivism

Scaffolding applications have gradually moved away from social constructivism and towards cognitive constructivism. That is, rather than having students interact with others to construct knowledge as suggested by social constructivists, current scaffolding practices tend to help individuals learn through the use of both their own experience and research-based data. In this respect, scaffolding helps transfer new information to individual's cognitive schema and mental models (Whitman, 1993). Instead of facilitating social interaction, scaffolding applications mainly provides learners with computer-based tools which decrease the complexity of tasks, or offer organized interfaces to help learners solve problems. According to Pea (2004), the current computer-based scaffolds appear to function not as "scaffold-with-fading but as scaffolds-for-performance" (p.438), thus allowing learners to continue to use the support in order to achieve the desired goals.

Researchers tended to ignore the development of a shared understanding as a critical feature of scaffolding, even though they recognize that scaffolding requires a shared understanding among participants (Dennen, 2004). According to Tudge and Rogoff (1989), shared understanding, or *intersubjectivity*, is "the joint understanding of a topic achieved by people working together and taking each other's perspective into account" (pp.22). Because an individual's knowledge is shaped by his culture and background, his understanding thus results from the community of learners who discuss their different points of views (Fawcett & Garton, 2005). By developing a shared understanding among participants, scaffolding helps learners to bridge the gap between the levels of current and prospective knowledge.

However, rather than focusing on the shared understanding of knowledge, researchers interpreted it as the understanding of common goals (Stone 2002; Puntambekar & Hübscher, 2005). They emphasized that effective scaffolded instruction required learners' engagement in a joint goal-directed activity because it provides motivation to students to engage in the task. Without the common understanding of learning goals, learners may fail to know how to complete the tasks and even may perceive scaffolds as irrelevant to their goals (Dennen, 2004).

Problem 4: Traditional features of scaffolding are ignored

In addition to social interaction, other important traditional features of scaffolding are overlooked in contemporary scaffolding applications.

Gradual withdrawal of support

Researchers have largely ignored the goal of developing students' capacity for independent learning, as evidenced by the fact that the majority of studies overlooked fading as a key feature of scaffolding. If the support is not gradually withdrawn, a student is not likely to become an "autonomous thinker" (Perkins, 1992, p.163) because he will lack opportunities to manage his own learning and enhance his independent thinking skills.

Although some researchers did implement fading features, their computer-based scaffolds had limitations. Faded computer-based scaffolding applications often lack the flexibility needed to provide appropriate and timely support for each individual learner. By removing the support from the learners at a pre-determined time, scholars assumed that the learners would increase their development level and need less support. Without assessing the current development level of each individual, however, fading the scaffolds at pre-planned moments might be detrimental for some students who are not adequately prepared to proceed without support (Zydney, 2005; Eslinger, White, Frederiksen, & Brobst, 2008).

Ongoing diagnosis of student learning

Although researchers recognized that scaffolding relies upon a more knowledgeable person, they ignore the fact that effective support also required the continuous monitoring of knowledge building in the learning process (King, Staffieri, & Adelgais, 1998) and the provision of support that met learners' changing needs (Puntambekar & Hübscher, 2005). Ongoing diagnosis and adaptive support is especially important for effective fading to occur (Lim, 2004), but is also important for scaffolding in general (Guzdial, 1994); effective scaffolding depends upon the ongoing assessment of learner's current understanding and needs to be designed within each individual's ZPD throughout the course of the learning process. Zumach (2006), for instance, applied adaptive support, but allowed students to control the level of support they should receive. However, researchers have largely ignored the significance of individual differences and ongoing diagnosis. In total, only 7 studies mentioned this feature when defining scaffolding.

Embedded computer-based scaffolding often cannot evaluate student learning and provide appropriate support. Instead of providing adaptive support, researchers rely on generalized computer-based scaffolding in contemporary science education. Along with this drawback, few studies provided feedback to the students. Rimor, Reingold, and Heiman (2008) found that there was a positive relationship between the instructor's responses and students' metacognitive thinking, demonstrating the significance of teacher's feedback to student learning. Although researchers used question prompts to develop students' higher order thinking skills, they ignore the value of feedback. Without appropriate feedback, students might feel unsupported and incompetent to complete the tasks, and might not know how to improve.

Effective scaffolding requires the understanding of learner's current knowledge level (Pressley, Hogan, & Wharton-McDonald, 1996). Because they do not consider the different levels of prior knowledge and learning experience of each learner, generalized scaffolds may impede learning through cognitive overloading of students with lower prior knowledge (Belland, Glazewski, & Richardson, 2008). This is especially important for complex computer-based learning which often involves the integration of multiple tasks. Especially, Azevedo et al. (2005) found that tutor-based adaptive scaffolding helped adolescents to regulate their learning and gain declarative knowledge better than fixed scaffolding.

Problem 5: Researchers ignore motivation

Although Wood, Bruner, and Ross (1976) stated that "the tutor's first and obvious task is to enlist the problem solver's interest in and adherence to the requirements of the task" (p.98), the reviewed scaffolding literature showed that researchers focused more on reducing the size of the task rather than enhancing learner motivation when they applied scaffolding in instruction. When instructors attempt to transfer learning responsibilities to students through the support of scaffolding, they assume that learners will apply metacognitive approaches to conduct appropriate thinking and activities. However, in order to enhance student autonomy, scaffolding should include features that support both a student's motivation and cognitive development. Sungur (2007) emphasized that metacognition would not contribute much to learning if a student lacked motivation. Highly-motivated students tended to believe that the course material was important, useful, and interesting and that their efforts to study would produce results. In this respect, they would use metacognitive strategies more often and make efforts to learn even if they face difficulties. Therefore, because self-regulation depends upon motivation (Paris & Paris, 2001), students need sufficient motivation to engage in learning tasks.

Because students often do not reflect automatically (Ertmer & Simons, 2006), they often encounter difficulty in completing tasks (Lim, Nonis, & Hedberg, 2006). Even though learners are provided with scaffolds to complete tasks or enhance high order thinking, they may still lack sufficient motivation to seek support as needed. After all, presenting students with high-level learning activities cannot ensure student's active engagement, as they may feel a lack of competency regarding completing complex tasks. Therefore, instructors need to be aware of whether scaffolding influences learners' motivation during the learning progress. Moreover, future studies need to investigate further how to improve learner’s motivation.

Problem 6: The need for a clear scaffolding taxonomy

The available literature offers no clear or useful taxonomy of scaffolding types, which hinders researchers’ efforts further to develop our understanding of this important field. One aspect of this problem is that in many cases, supposedly different scaffolding types share similar functions. A good example of this is a comparison between the generic prompts of both Davis (2003a) and McNeill et al. (2006). Davis’ (2003a) generic scaffolds reminded learners to “stop and think” about their learning process and offered basic guidance to help students learn, whereas his directed scaffolds helped learners complete specific tasks by providing more detailed guidance than that offered by generic scaffolding. The generic scaffolds McNeill et al., offer, however, are more similar with Davis’ directed prompts in that they provide more detailed hints.

Another aspect of this problem focuses on researchers’ attempts to classify scaffolding based on the purposes (or functions) that the scaffolding serves. The diversity of scaffolding applications has led to an increasing awareness of these purposes. The resulting abundance of scaffolds and experimentation with scaffolding forms defy easy or useful categorization. Researchers most commonly use the classification systems of either Jackson, Krajcik, and Soloway (1998), Hannafin, Land, and Oliver (1999), or Ge and Land (2004). Though these scaffolding types share some characteristics, they nonetheless have many subtle, yet important differences that hinder researchers’ efforts to design effective scaffolding.

One of the major problems is that researchers have failed to place the various scaffolding types into clear, distinct, and useful classifications. For example, Jackson and colleagues (1998) are unclear about how their *supportive scaffolding* is different from their *intrinsic scaffolding*. While Jackson et al., distinguished supportive scaffolding (support for doing the task) from intrinsic scaffolding (which reduces the complexity of the task), they failed to recognize that the simplification of tasks is, in essence, support for doing the task. Similar problems appeared in Hannafin et al.'s (1999) study in which they defined *metacognitive scaffolding* as support that helps learners manage their individual thinking processes by reminding them to reflect upon their goals, and to relate "a given resource or tool manipulation outcome" (pp.133). They defined *strategic scaffolding* as support that provides learners with alternative approaches or techniques for solving tasks. However, according to van den Boom, Pass, van Merrienboer, and van Gog (2004), when students engage in reflection, they also think about alternative strategies for solving tasks. Hill and Hannafin (2001) also noted this overlap, stating that metacognitive scaffolding could help learners "consider alternative ways to address a goal or problem" (p.45).

Although Hannafin et al., (1999) offered the taxonomy that many researchers have adopted, Hannafin himself has subsequently offered definitions that contradict his original work. While he initially defined *procedural scaffolding* as support that helps learners utilize available tools and resources (Hannafin, Land, & Oliver, 1999), his later article (Wang & Hannafin, 2008) extended this definition by characterizing procedural scaffolding as support that guides learners to finish certain tasks via step-by-step guides. Moreover, without mentioning the consideration of alternative strategies, Hannafin, Kim, and Kim (2004) referred to this scaffolding as one which supports students "in anticipating their interactions, such as analyzing, planning, and making tactical decisions" (p.14).

Another factor hindering easy classification is that some researchers create different names to refer to the same kinds of scaffolding. For example, Fretz and colleagues (2002) used the term "utility scaffolding" to refer to the functions other researchers have identified in procedural scaffolds. Furthermore, MacGregor and Lou (2004) called their concept mapping template "task scaffolding," when their templates serve a purpose similar to that of conceptual scaffolding as defined by Hannafin et al. (1999). Given the fact that the applications of scaffolding are increasingly complex with ambiguous, overlapping, and contradictory descriptions of scaffolding functions, misrepresentations frequently occur. For example, Cagiltay (2006) claimed erroneously that conceptual, metacognitive, and strategic scaffolding, as defined by Hannafin, Land, and Oliver, are, in essence, the same as the supportive, reflective, and intrinsic scaffolding described by Jackson, Krajcik and Soloway (1998), respectively.

Although Hannafin, Land and Oliver (1999) only focused on the utility of available tools and resources, scaffolding in computer-based programs has tended to decompose tasks, giving students step-by-step assistance. These scaffolds decreased the burden of learning and reduced the cognitive loading of learners by elaborating upon and simplifying tasks. Hannafin et al.'s, categories are limited and cannot encompass all possible applications, leading researchers to alter the original definitions or create new taxonomies. Scholars need to simplify this complexity and provide consistent principles for designing scaffolding.

Due to the limitations of current scaffolding taxonomies, we propose classifying scaffolding functions into five categories: cognitive, metacognitive, procedural, contextual, and motivational:

- *Cognitive scaffolding*: support for helping individuals understand the content of learning materials. For example, a prompt provides further details explaining the meaning of a term.
- *Metacognitive scaffolding*: support for helping individuals to develop both the ability to recognize their knowledge and regulate their behaviors based on their reflection. For example, teachers may use question prompts to ask students to reflect upon their strengths and weaknesses.
- *Procedural scaffolding*: support for helping individuals to employ learning processes or strategies in order to complete a task, reach a goal, or solve a problem. For example, an organized framework embedded in the computer-based system provides guidelines for students to solve problems.
- *Context scaffolding*: support for helping individuals to maneuver through a learning environment and to operate tools and resources embedded in the learning environment. For example, a Help button tells students how to operate the tools in the computer program.
- *Motivational scaffolding*: support which helps individuals to increase their perception of their own interests, abilities, and task values. For example, instructors help students to see the value of the learning task and its potential applications

outside of school.

Although the purpose of taxonomies is to distinguish different kinds of scaffolding based on their functions, in reality many scaffolds provide multiple functions simultaneously. For example, when a scaffold gives students clear guidance on how to divide a procedure into smaller tasks, it may simultaneously provide hints to help students develop higher order thinking skills by encouraging them to think about alternative ways to solve the problems. For example, when students are asked to conduct scientific explanations, they may also need scaffolds to seek out resources and understand concepts. Meanwhile, they may need guidance about how to operate the tools in a complex technological environment. Therefore, it is important to note that in some cases scaffolds cannot be clearly separated. While researchers usually utilize more than one kind of scaffolding, the design of scaffolding applications should be considered as an integrated model. Each scaffold must be incorporated in order to effectively enhance students' knowledge or performance.

Problem 7: Increase the validity of scaffolding research

Although the majority of the articles reviewed in this study observed differences between students' pre- and post-test scores, only a few compared the effectiveness different scaffolds had on instruction. It was difficult to identify which part of the instruction influenced the learning outcomes most. Moreover, because some of the studies compared the effects of using various kinds of scaffolding without also examining a control group, it is difficult to determine the extent to which specific scaffolds may benefit students' science learning. Ultimately, as indicated earlier, because of the diverse definitions and forms of scaffolding which the studies applied, it is impossible to determine from a review of the literature which type or types of scaffolding were most effective. Future studies must direct their efforts toward investigating the factors which may contribute to the effectiveness of scaffolding practices, such as students' prior knowledge, the types of scaffolding used, and the interactive effects such factors may have on students' cognitive and metacognitive development.

Conclusion

Although scaffolding is useful for helping individuals to achieve learning that they may not be able to do on their own, scaffolding applications in prior studies are confusing and contradictory. Before researchers can provide useful guidelines for creating an d applying scaffolding, further studies must first explore the gap between traditional notions and practical applications of scaffolding. To answer this question, this study conducted a systematic literature review and found that traditional notions of scaffolding were not fully applied in contemporary technology-enhanced science education. Researchers tended to ignore the human factors (i.e. teacher and peer support) during the process of providing support and, as such, drew attention away from social constructivism toward cognitive constructivism. This is problematic because computer-based support often does not monitor each student's learning and adapt to suit the learners' changing needs. Furthermore, the review revealed that the terms used to describe different kinds of scaffolding were confusing and might weaken the validity of scaffolding applications. To resolve this problem, this study proposed a new taxonomy for distinguishing different kinds of scaffolding. Although this study highlighted issues which may hinder the effectiveness of scaffolding, future research must explore how to resolve these problems and examine ways of creating effective scaffolds featuring different forms and functions in technology-enhanced learning environments. While it is difficult to apply customized scaffolding that supports each individual learner in large classes, how to balance the support between teacher and computer-based scaffolding is critical. Especially, researchers need to consider what kind of support teacher- and computer-based scaffolding should provide in order to enhance learning outcomes.

CHAPTER III

TEACHER INSTRUCTIONAL PRACTICES AND COMPUTER-BASED SCAFFOLDING IN SCIENCE INQUIRY

Theoretical framework

Scaffolding background

Scaffolding is an instructional support which helps individuals to accomplish tasks that are beyond their ability to complete alone. Scaffolds help learners move from their *actual development* level to their *potential development* level, the range between which researchers refer to as the Zone of Proximal Development (ZPD) (Vygotsky, 1978). Whereas *actual development* refers to knowledge and skills an individual can obtain without support, *potential development* refers to knowledge and skills that a learner can achieve with support. Therefore, scaffolding is an organized process of “reducing the scope for failure in the task” that the learner is attempting to achieve (Maybin, Mercer, & Stierer, 1992, p.188). Traditionally, scaffolding is provided through social interaction (Winn, 1994) where a more knowledgeable other, such as a parent or tutor, supports students in their learning (Wood, Bruner, & Bruner, 1976).

In order to enable an individual to internalize knowledge and to achieve independent learning, the more knowledgeable person observes a learner’s ongoing progress and gradually removes support as the learner demonstrates improvement. This process, known as fading, encourages learners gradually to take over educational responsibilities from the more knowledgeable other. By fading the support they provide, educators can help learners become more engaged in the learning process (Wu & Krajcik, 2006b). Because of its potential to help learners develop higher cognitive abilities, many researchers consider fading to be a crucial component of scaffolding (Fretz , Wu, Zhang, Davis, Krajcik, & Soloway, 2002).

Researchers have also determined the need for computer- or paper-based scaffolding as a supplement to the more traditional teacher-based instruction. One reason for this is that teachers in large classes tend to have difficulty monitoring each student's progress and understanding each individual's needs. Teachers simply cannot provide sufficient support that is suited to the specific needs of each learner, nor can they fade support appropriately as each student demonstrates that they no longer require it. As a result, rather than attempting the difficult task of designing support to suit the characteristics of each learner, researchers have developed an array of scaffolds that cater to the needs of the typical student (Jacobson, 2008).

Scientific inquiry learning

Inquiry learning is a "question-driven process" (Wu & Hsieh, 2006, p.1289) involving different levels of investigative activities for solving or explaining real-world problems. Because this approach usually requires the development of scientific research skills (van Aalst, 2006), researchers often refer to it as *scientific inquiry*. Scientific inquiry typically comprises diverse activities, such as asking questions, making observations, conducting experiments, analyzing data, and drawing conclusions (Sandoval & Reiser, 2004). In some studies, inquiry learning includes additional or alternative activities, such as making hypotheses (Pedaste & Sarapuu, 2006), planning investigative processes (Hoffman, Wu, Krajcik, & Soloway, 2003), predicting outcomes (Hsu, 2004), and providing evidence to explain results (McNeill, Lizotte, Krajcik, & Marx, 2006). Because there is no definite rule for how to format the inquiry process, the specific activities educators choose to use in each phase are dependent upon their instructional goals.

Inquiry is a crucial component of science learning (Krajcik, Blumenfeld, Marx, Bass, & Fredricks, 1998). By encouraging students to perform tasks in real-world contexts, inquiry-based learning helps individuals to understand the actual problems that scientists may face (Kolodner et al., 2003) rather than simply concentrating on the memorization of concepts and terminology. Inquiry learning also improves students' understanding of science concepts and enhances their ability to transfer acquired knowledge to new contexts (White & Frederiksen, 1998).

However, because scientific inquiry often situates individuals in complex contexts, it is not enough simply to have students engaged in inquiry (Ge, Chen, & Davis, 2005); it is also necessary to provide students with appropriate scaffolding to support their learning. Among these scaffolds, the two types this study examines are context-general and context-specific.

Context-general vs. context-specific scaffolding

Context-specific (*contextualized*) scaffolds are “hints about the task and what content knowledge to use” (McNeil et al., 2006, p.6). Context-general (*generic*) scaffolds are general frameworks for completing tasks. Researchers have found that using context-general and context-specific scaffolds produce mixed results, such as differences in students' ability to understand subject concepts and to perform learning activities. Davis (2003), for instance, found that students who used generic prompts understood the material better and offered more productive responses than students who used directed prompts.*

However, Tabak, Smith, Sandoval, and Reiser (1996) argue that context-general scaffolding offers insufficient support for students attempting to complete complex inquiry learning activities; additional domain-specific support is needed to help students draw scientific conclusions. McNeil and Krajcik (2006) found that context-specific scaffolds help middle school students to construct better scientific explanations and develop better understanding of science content than context-general scaffolds did. However, another study (McNeill et al., 2006) showed that students supported with context-specific scaffolds that fade to context-general scaffolds constructed scientific explanations better than those students supported only with continuous context-specific scaffolds, although there was no significant difference between the two scaffolds regarding their effects on students' comprehension of science knowledge.

Teacher-based instructional support

The existing literature identifies several shortcomings of computer- and paper-based scaffolds. In the absence of interaction between a knowledgeable individual and a

---

* The continual development of scaffolding as a field of research has led to problems concerning how to label certain kinds of support. For instance, Davis' directed reflective scaffolds, which provide guidelines about how to accomplish tasks, are, in essence, context-specific scaffolds.

learner, computer-embedded scaffolds cannot sufficiently ensure that students internalize the information being presented. In addition, even in those situations where a computer-based environment provides a learner with voluntary support, the student may still exercise the right to ignore such support (Lakkala, Muukkonen, & Kakkarainen, 2005). Also, because students tend to focus on completing tasks rather than expanding their thinking (Krajcik et al., 1998), they often and choose not to use beneficial computer-based reflective prompts (Manlove, Lazonder, & de Jong, 2009).

These shortcomings highlight the importance of using teacher-based support to maximize student learning. As Lizotte, McNeill and Krajcik (2004) have found, teacher-based support has a positive influence on students' inquiry skills and understanding of science knowledge; the teacher helped students develop inquiry skills, such as reasoning, that the students found difficult to learn. Students are often narrowly focused on completing the tasks given them and tend to ignore the development of their inquiry skills. As such, computer-based learning should be supplemented with instructor support. This study focuses specifically on having teachers provide *metacognitive* scaffolds, which help students to plan, reflect, and evaluate their own thinking process (Belland, Glazewski, & Richardson, 2008).

Metacognition and metacognitive Scaffolding

Metacognition refers to knowledge about knowledge, an individual's awareness of his own learning that will allow him to take actions to modify his learning behaviors. Individuals with high metacognitive abilities can monitor, reflect upon, and regulate their own learning. Because reflecting on activities enhances the coordination between doing and thinking, researchers believe that it is necessary to incorporate metacognitive skills in complex learning contexts that contain rich information (Toth, Suthers, & Lesgold, 2002; Fund, 2007). Metacognitive skills are also important because they are required for effective computer-based inquiry learning (Blumenfeld, Soloway, Marx, Krajcik, Guzdial, & Palincsar, 1991).

Recognizing the utility of metacognition, researchers have developed a type of scaffolding that serves to develop high order thinking skills. According to Hill and Hannafin (2001), these metacognitive scaffolds help learners to figure out "what they know and what to do as they learn" (p.45). Metacognitive scaffolds may take the form of either computer or teacher support. For instance, Lin, Hmelo, Kinzer, and Secules (1999) use technology-based process prompts that emphasize "specific aspects of processes while learning is in action" (p. 46). Similarly, teacher-based probing questions can encourage students to elaborate on and explain their thinking, thus leading students to think more deeply about their learning process (Krupa, Selman, & Jaquette, 1985). Using these scaffolds continuously may help learners to rectify their misunderstandings of concepts and procedures (Sharma & Hannafin, 2007). These studies demonstrate that metacognitive scaffolding has the potential to reduce students' cognitive loads (Hill & Hannafin, 2001) and may thus help them experience productive learning that prepares them for future tasks (Reiser, 2004).

However, some debate exists among researchers as to the best point during the learning process at which to introduce metacognitive scaffolds. As opposed to Sharma and Hannafin's recommendation that these scaffolds be provided continuously, some researchers suggest that metacognitive support should be given to students only after they are familiar with the learning procedure and have more knowledge about the content. One reason for providing metacognitive support late in the process is the possibility that introducing them earlier will only add to the difficulty students face in attempting already overly-complex learning tasks (Ertmer & Simons, 2006). Ge and Land (2004) also suggest that metacognitive scaffolds should be introduced later in the process and should gradually replace procedural supports. Conversely, Greening (1998) argues that educators should not use a high initial cognitive load as an excuse to delay support. According to Greening, students invariably begin the learning process with misconceptions about science learning, and such misconceptions, if allowed to persist, will lead to learning that lacks meaning.

Determining the optimal point during the learning process at which metacognitive scaffolds should be introduced is an important step toward maximizing the effectiveness of instruction. Are metacognitive scaffolds best used later in the learning process, when students have grown accustomed to the learning material and can focus more attention on reflection? Or should these scaffolds be applied earlier in the process, helping students to develop inquiry skills that can better enable them to carry out complex tasks? These questions are especially important for those teachers offering instruction in complex learning environments, but who are unsure as to the best way address their students' needs. Although educators should integrate metacognitive scaffolds more closely into their instruction (Bannert, Hilebrand, & Mengelkamp, 2009), few studies attempt to determine when teacher questioning strategies should be used

(Chin, 2007). Future research should therefore create guidelines for implementing metacognitive scaffolding, and offer empirical evidence to demonstrate their effectiveness.

As suggested by Tabak's (2004) *distributed scaffolding* theory, no single tool can provide effective scaffolding for all purposes; different kinds of scaffolding should be applied in different situations. Studies should integrate multiple sources of scaffolding from teachers, peers, and technology, and ensure the maximized learning effectiveness of each tool in a complementary way. Although researchers recognize the importance of teacher scaffolding (Greene & Land, 2000; Kovalainen, Kumpulainen, & Vasama, 2001), few studies examine teacher intervention in computer-enhanced classrooms. Discussions of teacher supports tend to be overly general (Roth, 1993), and produce no explanations as to how various instructor supports may influence learning outcomes (Lizotte, McNeill, & Krajcik, 2004).

Purpose of this study

As indicated earlier, students need teacher support even in computer-based learning environments. Unfortunately, few studies investigate the manner in which teachers should provide such support. Further research is needed to determine the most effective method of implementing teacher-based metacognitive scaffolding when students are simultaneously supported with different types of computer-based scaffolding. This study seeks to determine the scaffolding conditions that optimize learning outcomes. The four conditions examined are teacher-based metacognitive scaffolding offered early and late, and computer-based procedural scaffolding that fades or is offered continuously. These four conditions are examined in various combinations to determine their effects on students' science content knowledge and inquiry skills. The questions this study attempted to answer were:

1. How do different kinds of computer-based procedural scaffolding (continuous and faded) and teacher-based metacognitive scaffolding (provided early or late) influence the development of students' science knowledge?

2. How do different kinds of computer-based procedural scaffolding (continuous and faded) and teacher-based metacognitive scaffolding (provided early or late) influence the development of students' scientific inquiry skills?

3. How are the use of computer-based procedural scaffolding and teacher-based metacognitive scaffolding related to students' satisfaction with using these scaffolds?

Methods

Participants

This study was implemented in eight science classes in two public middle schools, with four classes per school. Each school is located in Texas suburbs, and the two participating teachers have years of experience teaching middle school science courses. A total of 142 8th grade students participated, with two teachers, one from each school, administering the virtual learning program. Of the participating students, 67 were female and 73 were male. Twenty-four percent (n = 35) were African American, four percent (n = 6) were Asian, forty percent (n = 57) were Hispanic, twenty-five percent (n = 35) were Caucasian, and five percent (n = 7) reported themselves as "other." Two students failed to report either their gender or ethnicity. In one of the schools, the students were all involved in the school’s pre-AP (advanced placement) program.

Instructional program

The instructional program used in this study is a virtual learning environment called *Supervolcano: Kikai Caldera*. The story starts with the eruption of the Kikai Caldera volcano, which spews an estimated 65 million tons of sulfur dioxide and ash particles into the air. Four scientists present conflicting predictions about the immediate and long-term effects of the eruption. Students, playing the role of climatologists, take a research ship to the place where the eruption occurred in order to investigate the actual effects of the eruption, and then report their findings. The students must submit answers to five open-ended questions. Due to the large amount of complex data and learning activities involved in *Supervolanco*, the module includes a virtual *Science Notebook* feature that provides students with an easy way to record their inquiry process.

Procedures

This study was conducted during regularly scheduled middle school science classes. On the first day, all students took an online pre-test that measured their concept knowledge and inquiry skills. During the next 10 days, the students worked individually to answer the five questions embedded in the virtual learning environment. Students were expected to complete one task every two days; thus students worked on Task 1 on days 2 and 3, Task 2 on days 4 and 5, and so forth. Students were provided with a variety of scaffolding forms to help them conduct the first four tasks. For the fifth task, the students did not have any scaffolding, thus giving them an opportunity to demonstrate the extent to which the previous scaffolded tasks had prepared them for independent work. On the final (12th) day of the study, each student took a post-test and a satisfaction survey. Both assessments were posted online.

Research design

This study employed a quasi-experimental design. There are four experimental conditions, each of which includes a type of computer-based procedural scaffolding (continuous or. faded) paired with a type of teacher-based metacognitive scaffolding (early or late). Each class was assigned one of the four conditions. Ensuring that all students in a class used the same kind of computer-based scaffolding allowed the instructor to manage the class and learning activities effectively. To avoid possible bias, each teacher administered each of the four experimental conditions to their four classes, respectively. Because this study investigated differences in how various scaffolding types influenced student learning, no control group was utilized.

Computer-based procedural scaffolding

The procedural scaffolding embedded in the program's *Science Notebook* was designed to help students complete inquiry tasks in a scientific way. In the *Science Notebook*; the five questions were organized systematically for each question the scaffolding clearly identified the four inquiry steps, offered hints associated with each step, and prompted students to record their learning outcomes. The scaffolds prompted students to complete inquiry steps that are a modified form of Novak and Krajcik's (2006) general pattern of scientific inquiry in middle school science: (1) study the existing scientific reports and information (i.e., satellite images), (2) predict the outcome of your investigation, (3) collect additional data using the scientific equipment in the virtual environment (i.e., weather balloons, spectrometers), and (4) draw conclusions based on the available evidence.

Each class was randomly assigned one of two types of computer-based scaffolding – continuous or faded. Students using continuous scaffolding were provided with context-specific support customized to suit specific inquiry tasks. These context-specific scaffolds embedded within the virtual learning environment focused on developing students' content knowledge and inquiry skills. For example, solving Task 1 involved measuring the size of particles in the volcanic cloud. Thus, the "collect and record data" segment of the scaffolding, in addition to offering generalized hints about conducting scientific inquiry, included the context-specific hint, "*Consider which piece(s) of equipment detects particles in the air*." Also, if students were still unclear about how to solve the problem, the "analyze data and draw conclusions" segment of the scaffolding provided students with another context-specific hint: "*What did the data you collected tell you about the size of the particles or how long the aerosols will remain in the air?*"

Whereas the embedded context-specific scaffolds remained continuous for some groups of students, the scaffolds of other groups faded to context-general scaffolds as of day 6. Context-general scaffolding provided students with a more general framework that helped them to complete their investigation, but did not offer the same level of detail as context-specific scaffolds; Furthermore, context-general scaffolding remained the same regardless of the learning context, offering such hints as "*Collect data to test your* *prediction and record data of each investigation and the equipment you used,*" and "*What did the data you collected tell you? Do they confirm your prediction? Explain why or why not. Use pictures to support your analysis*." To ensure the validity of study results, the continuous and faded procedural scaffolds in this study were embedded in the virtual learning environment, and faded according to a strict schedule.

Teacher-based metacognitive scaffolding

The teachers provided metacognitive support by asking students reflective questions at the end of each class period. By doing this, they encouraged students to articulate their reasoning process by reflecting upon their learning for each inquiry step. This not only motivated students to maintain active learning but also enhanced the development of more in-depth thinking. Moreover, these reflective questions allow teachers to understand students' learning status. For example, the teachers asked students questions such as "The scientists believe the volcanic cloud will affect which hemisphere?", "What science information can be used to answer this question?", and" Which hemisphere do you predict the volcanic cloud will affect? Why?" Because the teacher only asked neutral questions without providing any feedback, the responsibility to evaluate each student's response shifted to the entire class, thus encouraging students to try to make sense of what their classmates were saying (Chin, 2007).

Teachers provided metacognitive scaffolding to students either early or late in the learning process, depending on which condition the class was assigned. These metacognitive scaffolds for some groups of students were available while working on Task 1 and 2 (days 2-5); for other groups, these scaffolds were available while working on Task 3 and 4 (days 6-9). For example, for students in the early metacognitive condition, near the end of day 2, when the students were expected to have completed the first two inquiry steps (“Examine Background Information” and “Predict Results”) for Task 1, the teacher asked a series of reflective questions specifically regarding those two inquiry steps.

To ensure that the participating teachers understood their responsibilities, the researcher provided a teacher manual that offered information regarding the purpose and design of the study, a list of reflective questions the teacher must ask, and instructions as to how and when to ask those questions (see Appendix B). In addition, the teachers were provided with guidelines as to what they and the students should do during each day of the study. Furthermore, the researcher held a 1-2 hour training session to answer any questions or to clarify any misunderstandings the teachers had about what was expected of them. The teacher tasked with providing metacognitive scaffolding early in the study was given a version of the teaching manual that reflected this condition. Similarly, the version of the manual for the other teacher reflected the fact that he had been tasked with providing support during the latter part of the study.

During the teacher training, the researcher emphasized to the teachers the importance of making no statements regarding the completeness or accuracy of students’ answers. This was important because the purpose of metacognition is to encourage students to think, not to tell them whether they are right or wrong. As Chin (2007) suggested, the questions teachers asked in student-centered learning environments should be used to “diagnose and extend students’ ideas and to scaffold students’ thinking" (p.818). Thus, teachers responded to students' answers in a neutral instead of evaluative way.

Data sources

Science content comprehension test

The computer-based pre-test included the same questions as the post-test, but in a different order. To determine the content validity of the test items, the designers of the *Supervolcano* module created 15 multiple-choice assessment items based on the standards of learning objectives issued by the Texas Essential Knowledge and Skills for Science. Each test item counted one point. The pre-test scores measured students' knowledge of science content gained prior to their participating in the program. The post-test, administered upon completion of the program, evaluated students' knowledge of the science concepts they should have learned in the course of solving the *Supervolcano* tasks. Cronbach's alpha for post-test score was .528, with 19 missing cases (N = 123).

Science notebook

The procedural scaffolds embedded in the program's *Science Notebook* helped students to complete the five inquiry tasks. Each task was composed of four inquiry steps. The participating students solved the tasks by following hints provided at each inquiry step, and simultaneously recording their inquiry process. In addition, an embedded camera feature allowed students to capture screenshots which they may then use as evidence to support their analyses. The *Science Notebook* report that students submitted for Task 5 acted as an indicator of students' inquiry skills. The quality of students' responses to each inquiry step in the *Science Notebook* were rated as either low, medium, or high with corresponding values of 0, 10, and 20, respectively. The values were assigned based upon an evaluative rubric (see Appendix C). To ensure reliability of measurement, the author and a colleague separately graded the student reports, and the two sets of scores were compared. The initial inter-rater reliability coefficient was .75, using the Pearson coefficient method. Any inconsistencies between the raters were discussed and resolved until reliability reached 1.0.

Satisfaction survey

In order to assess the students' perceptions and satisfaction of both the computer-based procedural and teacher-based metacognitive scaffolding, the day after completing the program students filled out a questionnaire designed by the author. The survey, as shown in Appendix D, was composed of twelve questions that measured students' satisfaction with the computer-based scaffolding (4 items), teacher scaffolding (4 items), the overall learning experience (1 item), the difficultly level of the questions (1 item), the amount of time for completing the tasks (1 item), and the use of computer devices (1 item). Item response formats consisted of 7 choices ranging from "strongly agree" to "strongly disagree." Additional items asked about students' characteristics, such as gender and ethnicity.

Data analysis

For the first and second research question (how scaffolding influences content knowledge and inquiry skills, respectively), a 2x2 Analysis of Covariance (ANCOVA) factorial design was performed to assess the effects of the two kinds of instructional support, both individually and in combination. Because participating students were not assigned scaffolding conditions randomly and students did not all attend the same school, the differences in students' preexisting science knowledge might have affected the statistical analysis. To assess this, students were given a pre-test on science content knowledge, and this score was then used as a covariate. For the first question, students' post-test scores were used to determine the effects of scaffolds on the development of students' science knowledge. To answer the second question, students' responses to the four inquiry steps of each question, as recorded in the *Science Notebook*, were calculated together as the dependent variables.

For the third research question (student satisfaction), each student's responses were measured to estimate the percentage distribution of students' levels of satisfaction and dissatisfaction with computer-based and teacher-based scaffolding. A chi-square statistical method was further conducted to determine variation in student satisfaction toward scaffolds that resulted from the use of various computer-based and teacher-based scaffolds.

Results

Science content knowledge

The first research question this study focused on was the effects that different scaffolding conditions had on student science content knowledge. To determine if ANCOVA was an appropriate analytical approach, preliminary data screening procedures were conducted, including examining the assumptions of normality, linearity, homogeneity of variances, and homogeneity of regression slopes. However, 13% of the post-test values were missing. To avoid the possibility of biased parameter estimates and invalid results (Fox-Wasylshyn & El-Masri, 2005), this study first utilized a correlation analysis of the missing variables by using a dummy variable table (no missing data = 1, missing data = 0). As indicated in Table 3.1, the majority of participating students had complete data (n = 106, 74.6%) and each variable (gender, ethnicity, inquiry skills, and survey) had nonzero correlation with the post-test scores. Therefore, the pattern of missing values in this study is considered as *missing at random*, which means that "the probability of response to a variable (X) depends on the response to other variables (Y, Z) in the analysis, but does not depend on the level of (X)" (McCleary, 2002, p.340). Although using conventional imputation methods such as listwise and pairwise deletion is relatively simple, these tend to cause inflated Type I and II errors and reduce statistical power (Grover & Vriens, 2006). For all these reasons, a multiple imputation approach was chosen as the most appropriate method of resolving problems regarding missing data.

Table 3.1 Pattern of Missingness of Variables

Variables						Count
Gender	Ethnicity	Pretest	Inquiry	Posttest	Survey	
1	1	1	1	1	1	106
1	1	1	1	0	0	18
1	1	1	1	1	0	12
1	1	1	0	1	1	2
1	1	1	0	1	0	1
1	0	1	1	1	0	1
0	0	1	1	1	1	1
1	1	1	1	0	1	1

Note: 1 = observed; 0 = missing. Count is frequency of missingess pattern.

Multiple imputation is a technique which takes the uncertainty of missing data into account by generating several possible values for each case of missing data in multiple datasets, followed by the integrated analysis of those datasets. By doing so, the imputation model of missing data in this study comprises all outcome variables (pre-test , post-test , questionnaire), treatments (computer- and teacher-based scaffolding), and indicators associated with the participating students' characteristics (school, class, gender, ethnicity). Using NORM software, 1000 imputations were performed, with an imputed dataset generated after each 50th iteration of the algorithm in order to ensure the independence of the imputed databases. As a result, the imputation process created twenty complete datasets containing all variables for all 142 students.

To obtain an overall inference, the parameter estimates of variables and their associated standard errors from each imputed dataset were aggregated. This was accomplished by using the formula suggested by Rubin (1987). Table 3.2 presents the pooled estimates based on 20 imputed datasets; it included (a) overall parameter estimate and standard error, (b) t-ratio, (c) degrees of freedom for the Student's *t* approximation, (d) *p* value for testing the null hypothesis, and (e) lower and upper endpoint of the confidence interval. The positive sign of parameter estimate in the pre-test score showed that the covariate and the post-test variable had a positive relationship; that is, when students' pre-test scores increased, so did their post-test scores. However, the result revealed that the null hypothesis that *the indicators for treatment were not significantly different from zero* failed to be rejected ($p>.05$); that is, the post-test scores in each group of students with computer-based scaffolding ($t(3941) = 1.0021$, $p=0.32$), teacher scaffolding (*t*(21317) = 0.2651, *p*=0.80), and use of both scaffolds (*t*(1153)=-0.2143, *p*=0.83) did not have a statistically significant difference at the .05 level. Despite this, the large positive coefficient in computer-based scaffolding indicated that the students using continuous computer-based scaffolding outperformed students in the faded condition in the post-test scores by approximately one question. This may suggest that the effects of using computer-based scaffolding on science content knowledge are more significant with larger sample sizes. However, for the comparative condition of students using different teacher-based scaffolds, the reported standard error of variables (0.77584) was larger than its associated absolute value (0.20565). This also occurs in the comparison of students using both teacher- and computer-based scaffolds. The results indicated that the computed values for these two conditions were not very reliable predictors. With 95% confidence, any difference that existed within each group in the sample data was due to chance.

Table 3.2 Parameter Estimates of Variables

Parameter	Estimate	Std.E.	t-value	df	*p*-value	LowEndpt.	HighEndPt.
Intercept	4.66185	0.91590	5.08988	1604.66919	<.0001	2.86668	6.45702
Pretest	0.35675	0.35121	1.01578	89483.04003	0.30970	-0.33162	1.04512
Scaffolding = Continuous	0.79615	0.79446	1.00212	3941.25990	0.31630	-0.76100	2.35330
Scaffolding = Faded	0[a]	.	.	.	.	.	.
Teacher = Early	0.20565	0.77584	0.26507	21317.04027	0.79100	-1.31499	1.72629
Teacher = Late	0[a]	.	.	.	.	.	
Scaffolding = Continuous Teacher = Early	-0.20685	0.96522	-0.21430	1152.76158	0.83040	-2.09869	1.68499
Scaffolding = Continuous Teacher = Late	0[a]	.	.	.	.	.	.
Scaffolding = Faded Teacher = Early	0[a]	.	.	.	.	.	.
Scaffolding = Faded Teacher = Late	0[a]	.	.	.	.	.	

a. This parameter is set to zero because it is redundant.

To examine the reliability of the estimates from the multiple imputed datasets, further analyses were conducted. First, the pattern of missing scores was investigated to explore the extent to which the missing data affected the results. With the low relative increase in variance due to missing data shown in Table 3.3, the analysis indicated that the variability in parameter estimates was stable, and statistical certainty was high. The low rate of missing information in the table also showed that the missing data had a negligible effect on the study results and thus can be ignored. A follow-up analysis was conducted to examine whether the statistics with and without imputed data produced the same results. To do this, information of students who lacked post-test scores was removed from the analysis, resulting in a sample size of 123. Neither of the main effects was statistically significant (computer scaffolding: $F(1, 118) = 2.455$, p=.12; teacher scaffolding: $F(1, 118) = .043$, p=.837). After adjusting for pre-test scores, there was also no significant interaction effect ($F(1, 118) = .053$, p=.819). But there was a significant relationship between the covariate and the dependent variable while controlling for the independent variables ($p<.05$). In sum, the analysis conducted without imputed data yielded results similar to the combined inference from multiple imputation approaches.

Table 3.3 Variances of Missing Data

Parameter	Between variance	Within variance	Total variance	Relative increase in variance	Rate of missing information
Intercept	0.08694	0.74760	0.83888	0.12210	0.00118
Pretest	0.00171	0.12155	0.12335	0.01479	0.00002
Computer Scaffolding	0.04174	0.58735	0.63117	0.07461	0.00049
Teacher scaffolding	0.01711	0.58395	0.60192	0.03077	0.00009
Computer and Teacher	0.11391	0.81205	0.93166	0.14729	0.00162

Because there were no statistically significant results for both computer-based and teacher-based scaffolds, another 2 X 2 between-groups analysis of covariate was conducted which controlled pre-test scores as a covariate and explored the effects of computer-based scaffolding for male and female participants. The result showed that the difference between the post-test scores of male and female students were not statistically significant ($F(1, 116)= .009$, $p=.926$). The interaction effect of scaffolding and gender also indicated that male and female students did not respond differently to the two types of computer-based scaffolding ($F(1, 116)= .105$, $p=.105$).

Scientific inquiry skills

The second research question of this study is the extent to which various kinds of scaffolding in combination with one another increased students' scientific inquiry skills. Before running a two-way ANCOVA analysis, data screening was conducted to examine and remedy potential problems with the data.

The outcome of a preliminary data screening evaluation showed minor violations of some assumptions. Although the scientific inquiry scores met the assumptions of linearity and homogeneity of regression, the outcome of Levene's test failed to show that the variance of scientific inquiry scores was equal in each group ($F(1,134) = 4.469$, $p<.05$). The deviation of data from the black line in a Normal Q-Q plot indicated that the scientific inquiry scores were abnormal; a high positive Skewness and a Kurtosis value (Skewness =1.08; Kurtosis = 1.15) also supported this finding. Moreover, only 11 percent of participating students had more than 40 points, which was half of the total possible score (M = 20.36, SD=14.55). Although scientific inquiry scores violated the assumptions of normality and homogeneity of variance, students' pre-test scores were normally distributed and the number of participating students in each group was identical. As such, the result of an Analysis of Covariance (ANCOVA) *F* test should not be biased (Huitema, 1980). Moreover, according to Glass and Stanley (1995), the probability of having a Type I error will not increase even if normality is violated.

However, compared to the post-test scores, the *Science Notebook* responses had fewer instances of missing data. Because only three participating students did not answer the fifth inquiry question, those students' cases were removed from the analysis.

Scaffolds utilized in this study had greater effects to students' scientific inquiry skills than they have on content knowledge. When the students' pre-test scores were statistically controlled, the effect that different types of computer-based scaffolding had on the final inquiry skill scores was found to be statistically significant in Tests of Between-Subjects Effect ($F\ (1, 134) = 5.017$, $p<.05$, partial $\eta^2 = .036$). Individuals who were given continuous computer-based scaffolding were more likely to gain better inquiry skills (M = 23.240, n = 71) than those supported with faded scaffolding (M = 17.739, n = 68). Moreover, there was a significant interaction effect (*F* (1, 134) = 5.879, *p* <.05, partial η^2 = .042). Whereas the use of both continuous computer-based procedural scaffolding and early teacher metacognitive scaffolding benefited students most in learning scientific inquiry skills (M = 26.075), students who were given both faded procedural scaffolding and early metacognitive scaffolding had the lowest scientific inquiry scores (M = 14.717). Although there was a difference between the scores of students who used early (M = 20.396) and late (M = 20.583) teacher-based metacognitive scaffolding, this difference of the timing of teacher-based metacognitive scaffolding was not statistically significant (*p* =.938). Also, pre-test scores did not seem to predict students' ability to develop inquiry skills (p>.05).

When pre-test scores were not controlled as a covariate, the significance of each treatment remained identical with a slightly stronger effect size. In this case, scaffolding types (*F* (1, 134) = 5.18, p<.05, partial η^2 = .037) and their interactive effects with teacher-based metacognitive scaffolding were also statistically significant (*F* (1, 134) = 5.94, p<.05, partial η^2 = .042). But the timing of teacher support was not statistically significant; the mean between the groups of early (M = 20.40, n =69) and late (M = 20.58, n =70) teacher metacognitive scaffolding was very similar.

Satisfaction survey

Of the142 participating students, 110 chose to complete the satisfaction survey after they finished the program, giving a response rate of 74.6%. The missing data were removed from the analysis.

The outcome of this analysis in many cases indicated that more than 20% of cells had an expected frequency of less than 5 and a minimum expected frequency greater than 1. According to McCormack and Hill (1997), this chi-square statistic is unreliable. In order to solve this problem, the number of categories was reduced by merging the data in the 7-Likert scale. The *disagree* responses (i.e., *strongly disagree*, *disagree*) were coded as 1, and the *agree* options were coded as 3. The neutral option was coded as 2.

The results of the chi-square statistical analysis showed that there was no statistically significant difference between the responses of students who used continuous and faded procedural scaffolding ($p>.05$). This meant that there was no relationship between the kinds of computer-based scaffolding the students used and the students' satisfaction about the clarity and number of inquiry questions, as well as the effects of inquiry tasks in learning scientific inquiry skills and concept learning (Table 3.4).

Table 3.4 Cross-Tabulation of Survey Items with Computer-Based Scaffolding, Showing Chi-Square Statistics

Item	Scaffolding					
	Continuous		Faded			
	Agree Count (%)	Disagree Count (%)	Agree Count (%)	Disagree Count (%)	χ^2	*p*
The hints given in the Science Notebook were clear	36 (67%)	13 (24%)	33 (59%)	15 (27%)	.930	.628
The hints given in the Science Notebook were sufficient.	31 (57%)	8 (15%)	28 (50%)	14 (25%)	1.788	.409
The hints given in the Science Notebook helped me to think more about how to answer the questions.	35 (65%)	11 (20%)	35 (63%)	11 (20%)	.186	.911
The hints given in the Science Notebook helped me to understand science concepts.	36 (67%)	13 (24%)	29 (52%)	14 (25%)	4.312	.116

Note: 1. Judgments were made on combined from the results of 7-point Likert scales (1 = strongly disagree; 7 = strongly agree) and recoded the values to 1 = Disagree, 2 = Neutral, 3 = Agree. 2. N = 110. 3. df = 2.

There was also no statistically significant relationship between the timing of teacher metacognitive scaffolding and students' satisfaction (Table 3.5). Students supported with early and late teacher-based scaffolding reported similar satisfaction levels, including how the scaffolding influenced the accomplishment of inquiry learning and the learning of science concepts. However, when students were asked whether the teacher's assistance should extend beyond the discussion sessions, more than half of participating students agreed that it should. Specifically, students who were provided with early teacher scaffolding tended to agree on this issue (64%) more than those who received late teacher scaffolding (54%). Moreover, students using different types of computer-based procedural scaffolding had significant differences in their satisfaction of teacher scaffolding ($\chi^2 = 7.916$, df = 2, $p < .05$). 70% of students supported with faded computer-based scaffolding felt that teacher-based metacognitive scaffolding needed to be extended, as compared to 46% of students in the continuous scaffolding groups.

Overall, the students' satisfaction toward their learning experiences was positive; the mean of their overall satisfaction on a 7-Likert scale was 4.42. Among the 110 students who took the questionnaire, 36% held positive views of their experiences with 22% expressing negative feelings. The majority of students agreed that their computer skills were sufficient to use this program (94%) and they had sufficient time to complete the five inquiry tasks (73%). Also, 52% agreed that the inquiry questions were difficult to answer, with only 29% reporting that the questions were not difficult.

Table 3.5 Cross-Tabulation of Survey Items with Teacher's Support, Showing Chi-Square Statistics

Item	Teacher					
	Early		Late			
	Agree Count (%)	Disagree Count (%)	Agree Count (%)	Disagree Count (%)	χ^2	*p*
The teacher-led discussions helped me to think more clearly about how to answer the questions.	39 (70%)	12 (21%)	36 (69%)	11 (21%)	.461	.794
The teacher's assistance should extend beyond the discussion sessions.	36 (64%)	12 (21%)	28 (54%)	13 (25%)	2.195	.334
The teacher's support helped me to understand science concepts.	33 (60%)	14 (25%)	38 (73%)	11 (22%)	1.819	.403
Overall, the discussion led by the instructor was helpful.	32 (57%)	13 (23%)	31 (60%)	13 (25%)	.027	.987

Note: 1. Judgments were made on combined from the results of 7-point Likert scales (1 = strongly disagree; 7 = strongly agree) and recoded the values to 1 = Disagree, 2 = Neutral, 3 = Agree. 2. N = 110. 3. df = 2.

Discussion

Although researchers have examined different types of scaffolding in computer-mediated learning, it is still unclear how best to combine teacher- and computer-based scaffolding. This study investigated how the interaction of these two scaffolding types influences students' science content knowledge, inquiry skills, and satisfaction about the use of these scaffolds.

Continuous vs. faded procedural scaffolding

The computer-based scaffolding embedded in the *Supevolanco* software helped students conduct scientific inquiry by modeling the four inquiry steps. The continuous computer-based scaffolding utilized in this study was more effective than faded scaffolding at helping students engage in scientific inquiry activities. This contradicts the findings of the existing literature. According to McNeill, Lizotte, Krajcik, and Marx (2006), students who received faded scaffolding performed better at creating scientific explanations (including claim, evidence, and reasoning) than those who received continuous scaffolding. However, McNeill et al.'s, research covered 36 class days while this study occurred during only 10. Therefore, students who participated in this study might not have been adequately prepared for the support to fade. The results of this study indicated that when instruction occurs over a period of time, continuous procedural scaffolding tends to benefit students more than faded scaffolding.

However, the main effects of both scaffolds on students' science content knowledge were not statistically significant. McNeill et al.'s conclusions corresponded with this finding, showing that the effects of faded and continuous scaffolding on students' post-test scores were not statistically significant. Therefore, although the continuous computer-based scaffolding provided contextual hints for science inquiry, students still need conceptual scaffolds to support their conceptual learning.

The timing of metacognitive scaffolding

Although scaffolding can help middle school students to develop their metacognitive skills (Kolodner et al., 2003), some factors, such as wording and timing

(Davis, 2003), the amount of time to use the tools (Brush & Saye, 2001), and the use of additional scaffolds (Zydney, 2010) may influence the effectiveness of metacognitive support. Though researchers emphasize that learners need to improve their thinking through metacognitive scaffolding, the best time during the learning process to provide metacognitive support to students is still unclear.

The results of this study showed that the timing of teacher-based metacognitive scaffolding was not a useful indicator of student learning; the differences in the effects of late and early metacognitive scaffolding on both content knowledge and scientific inquiry skills were not statistically significant. However, the method of delivering metacognitive scaffolding utilized in this study might explain this result. Although teacher-based metacognitive scaffolding may minimize incidents of students ignoring the support, especially when compared to a student's ability to ignore support embedded within computer-based systems, the number of participating students in each class period was still limited. Instructors engaged a few students in the discussions during each class period in order to ensure that all students would have participated over the course of this study. In this respect, it was assumed that students would benefit from observing from their peers' reflection when they responded to questions from the instructor, and would help each student to regulate their own learning behavior. Pedersen and Liu (2002) found that when students had opportunities to observe how others solve problems, they took appropriate steps to regulate their learning. Further research is required to determine whether the effectiveness of early and late metacognitive scaffolding would change when they are incorporated into computer-based learning systems.

Sungur (2007) found that students' motivation was associated with their use of metacognitive strategies. Highly-motivated students who believed that the course material was important, useful, and interesting and that their efforts to study had influence appeared to use metacognition more often and to make efforts to learn even if they faced difficulties. In order to understand the relationship between the timing of metacognitive scaffolding and student learning performance, further studies should examine how the timing of metacognitive scaffolding influences students' self-efficacy, and belief in his learning capability and learning performance.

However, according to Azevedo and his colleagues (2005), although fixed metacognitive scaffolding guided students to use regulatory processes, they also seemed to impede their learning. They found that students with students with adaptive metacognitive scaffolding developed statistically better declarative knowledge and regulative abilities than those with fixed scaffolding.

The combined effects of procedural and metacognitive scaffolding

Examining students' scientific inquiry processes indicated that the interactive effects of procedural and metacognitive scaffolds were significantly different among the four groups. Whereas students who were supported with both continuous procedural and early metacognitive scaffolding had the best performance in scientific inquiry, students who received faded procedural and early metacognitive scaffolding had the lowest scores. This indicates that when metacognitive scaffolding is given early, it does not always benefit students' scientific inquiry skills. Whether or not the procedural scaffolding faded determined whether students successfully learned the inquiry skills.

Thus, before students can develop higher-order thinking skills, they need first to be comfortable with the inquiry steps. Instructors who want to enhance student self-regulation in science learning must consider if the learners are ready for it yet. If students are not ready for scaffolding to fade, the removal of support, especially procedural assistance, might jeopardize a student's overall performance.

However, it is important that educators not ignore the potential importance of metacognitive scaffolding, especially when procedural assistance fades. Among the students who used faded procedural scaffolding, those who were simultaneously provided with late metacognitive scaffolding performed better in scientific inquiry (M = 20.944) than those provided with early metacognitive scaffolding (M = 14.899). Thus, metacognitive scaffolding can compensate for the limitations of procedural scaffolding. Furthermore, students given a combination of faded procedural and late metacognitive scaffolding had the second highest scores in inquiry skills, suggesting that teacher-based metacognitive scaffolding was important for students when they become acquainted with the complex computer-based learning environments and they no longer required much procedural support.

However, this result conflicts with Meyer and Turner's (2002) assumption that a teacher's metacognitive discourse with students could enhance self-regulation abilities before students are familiar with the procedure of the assigned tasks. Similarly, Zydney (2010) noted that organizational scaffolding, which provides procedural support, could interfere with metacognitive scaffolding, although she failed to identify whether this resulted from metacognitive scaffolding or the fact that students using both scaffolds had less time to complete the tasks than students in other groups who used only one kind of scaffolding.

The differences in the post-test scores of the four groups were not statistically significant, which suggested that combing computer and teacher-based scaffolds might not enhance students' conceptual knowledge. This indicated that students need additional conceptual support to develop science knowledge. More than half of the participating students felt that the inquiry questions were difficult, suggesting that they need more scaffolding to help them understand the content and complete the tasks. Whereas continuous procedural scaffolding that provided students with context-specific support met students' cognitive needs, students who wanted faded procedural scaffolding especially required teacher metacognitive scaffolding to extend beyond the discussions. In complex scientific inquiry requiring high cognitive processes, students who lack sufficient conceptual scaffolding will develop only a limited understanding of concepts.

However, because researchers often recognize that students need to receive support in order to enhance higher order thinking, we need to consider whether other factors which may have influenced the results of scaffolding applications. For example, the research design in the current study only allowed a few students to express their thinking and learning process during each class period due to time limitations; it was assumed that students would regulate their learning by observing their peer's responses. However, Hogan and Tudge (1999) noted that "simply hearing another's more advanced thinking does not necessarily lead to learning" (p.55). Therefore, the effects of using metacognitive scaffolds might change if more interaction with students was involved.

Conclusion

This study examined which combination of computer-based procedural and teacher-based metacognitive scaffolding types most effectively enhanced students' science content knowledge and inquiry skills. The findings indicate that students receiving continuous computer-based procedural and early teacher-based metacognitive scaffolding performed statistically better at learning scientific inquiry skills than students in other treatment groups. Students using the faded computer-based procedural and early teacher-based metacognitive scaffolding had the worst performance. However, among the scores of the four groups there existed no statistically significant difference in terms of the effect on students' science knowledge learning. Moreover, teacher-based metacognitive scaffolding did not have a significant impact on either science content knowledge or scientific inquiry skills.

Although this study expands upon the existing literature regarding the combined use of different kinds of scaffolding, there are some limitations to this study. First, without data from control groups, this study is unable to determine whether an instructor's metacognitive support is helpful. Second, no record was kept of the students' responses to the teacher's reflective questions during the discussions. Third, the missing data found in this study might have influenced the results. Although the datasets with imputed data produced identical outcomes as the datasets that did not include the missing data, it is still possible that a dataset that is based on more completely reported scores might yield different results. Future studies should continue to investigate the effectiveness of using both procedural and metacognitive scaffolding by drawing comparisons with control and treatment groups for early, late, and continuous metacognitive scaffolding.

CHAPTER IV

CONCLUSION

This dissertation explored scaffolding applications in science learning, especially with the support of technological tools. Scaffolding is an instructional support used to help learners solve problems, carry out tasks, or achieve goals that they are unable to accomplish on their own. As such, scaffolding is especially useful for students engaged in complex learning activities. However, because learners come from diverse backgrounds and have a wide range of prior knowledge and experiences, educators may not understand which scaffolding type is most suited to their students' specific needs. The primary problem confronting the educator is how to determine which of the numerous kinds of scaffolding will allow them to educate learners most effectively. Before researchers can develop effective scaffolding applications, however, several issues must first be resolved. This dissertation offers critical analyses of current ways that researchers apply scaffolding and clarifies some of the important themes and problems in the existing literature.

The first study of this dissertation systematically reviewed the existing literature to clarify the myriad ways researchers conceptualized scaffolding and its uses, and to investigate the ways researchers utilized scaffolding strategies. The results of this study revealed that current scaffolding practices have several problems which seriously affect the creation of effective applications, including the emergence of new definitions of scaffolding, the movement away from social constructivism, ignoring of traditional important features of scaffolding and motivational scaffolding, and the lack of a clear scaffolding taxonomy. The result of this study thus provides an important foundation upon which researchers may reconsider the existing scaffolding framework and design effective scaffolding in instruction.

The second study of this dissertation examined the effectiveness of scaffolding in its various forms when it is applied in instruction. Previous studies tend to focus on computer-based scaffolding by itself rather than integrating it with teacher support. To resolve this issue, this study determined how a teacher's participation in combination with different kinds of computer-based scaffolding (context-general and context-specific) affected students' science inquiry learning. The findings indicated that students receiving continuous computer-based procedural and early teacher-based metacognitive scaffolding performed statistically better at learning scientific inquiry skills than other treatment groups. Students using the faded computer-based procedural and early teacher-based metacognitive scaffolding had the worst performance. However, among the scores of the four groups there existed no statistically significant difference in terms of the effect on students' science knowledge learning.

Although this study identified the problems which existed in current scaffolding literature, many issues need to be resolved in order to enhance understanding and allow the creation of more effective scaffolding applications. Future studies need to examine how scaffolding influences student learning outcomes and beliefs during the course of instruction. They should also explore methods of integrating computer and human-based scaffolding to optimize learning outcomes.

REFERENCES

Applebee, A. & Langer, J. (1983). Instructional scaffolding: Reading and writing as natural language activities. *Language Arts*, *60*(2), 168-175.

Azevedo, R., Winters, F. I., & Moos, D. C. (2004). Can students collaboratively use hypermedia to learn science? The dynamics of self-and other-regulatory processes in an ecology classroom. *Journal of Educational Computing Research*, *31*(3), 215-245.

Azevedo, R., Cromley, J. G., Winters, F. I., Moos, D. C., & Greene, J. A. (2005). Adaptive human scaffolding facilitates adolescents' self-regulated learning with hypermedia. *Instructional Science*, *33*(5-6), 381-412.

Azevedo, R., Moos, D., Greene, J., Winters, F., & Cromley, J. (2008). Why is externally-facilitated regulated learning more effective than self-regulated learning with hypermedia? *Educational Technology Research and Developmen*t, *56*, 45-72.

Bannert, M., Hilebrand, M., & Mengelkamp, C. (2009). Effects of a metacognitive support device in learning environments. *Computers in Human Behavior*, *25*, 829-835

Barab, S., Sadler, T., Heiselt, C., Hickey, D., & Zuiker, S. (2007). Relating narrative, inquiry, and inscriptions: Supporting consequential play. *Journal of Science Education and Technology*, *16*(1), 59–82.

Barak, M., & Dori, Y. J. (2005). Enhancing undergraduate students' chemistry understanding through project-based learning in an IT environment. *Science*

Education, *89*(1), 117-139.

Beed, P., Hawkins, E. M., & Roller, C. M. (1993). Moving learners toward independence: The power of scaffolded instruction. *The Reading Teacher*, *44*(9), 648-655.

Bell, P., & Linn, M. C. (2000). Scientific arguments as learning artifacts: Designing for learning from the Web with KIE. *International Journal of Science Education*, *22*(8), 797-817.

Belland, B., Glazewski, K., & Richardson, J. (2008). A scaffolding framework to support the construction of evidence-based arguments among middle school students. *Educational Technology Research and Development*, *56*(4), 401-422.

Blumenfeld, P., Soloway, E., Marx, R., Krajcik, J., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist*, *26*(3&4), 369-398.

Blumenfeld, P. C., Kempler, T. M., & Krajcik, J. S. (2006). Motivation and cognitive engagement in learning environments. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 475-488). New York, NY: Cambridge University Press.

Bruner, J. (1985). Vygotsky: A historical and conceptual perspective. In J. V. Wertsch (Ed.), *Culture, communication, and cognition: Vygotskian perspectives* (pp. 1-34). Cambridge: Cambridge University Press.

Brush, T. & Saye, J. (2001). The use of embedded scaffolds with hypermedia-supported student-centered learning. *Journal of Educational Multimedia and Hypermedia*, *10*, 333-356.

Butler, K. A., & Lumpe, A. (2008). Student use of scaffolding software: Relationships with motivation and conceptual understanding. *Journal of Science Education and Technology*, *17*(5), 427-436.

Cagiltay, K. (2006). Scaffolding strategies in electronic performance support systems: Types and challenges. *Innovations in Education and Teaching International*, *43*(1), 93-103.

Chang, K. E., Sung, Y. T., & Chen, S. F. (2001). Learning through computer-based concept mapping with scaffolding aid. *Journal of Computer Assisted Learning*, *17*(1), 21-33.

Chen, Y. S., Kao, T. C., & Sheu, J. P. (2003). A mobile learning system for scaffolding bird watching learning. *Journal of Computer Assisted Learning*, *19*(3), 347-359.

Chin, C. (2007).Teacher questioning in science classrooms: Approaches that stimulate productive thinking. *Journal of Research in Science Teaching*, *44*(6), 815-843.

Choi, I., Land, S., & Turgeon, A. (2005). Scaffolding peer-questioning strategies to facilitate metacognition during online small group discussion. *Instructional Science*, *33*, 483-511.

Clark, D. B., & Slotta, J. D. (2000). Evaluating media-enhancement and source authority on the Internet: The Knowledge Integration Environment. *International Journal of Science Education*, *22*(8), 859-871.

Clark, D. B., & Sampson, V. D. (2007). Personally-seeded discussions to scaffold online argumentation. *International Journal of Science Education*, *29*(3), 253-277.

Collins, A., Brown, J. S., & Newman, S. (1989). Cognitive apprentice-ship: Teaching students the craft of reading, writing, and mathematics. In L. B. Resnick (Ed.), *Knowing, learning, and instruction: Essays in honor of Robert Glaser* (pp. 453-494). Hillsdale, NJ: Lawrence Erlbaum Associates.

Davis, E. A., & Linn, M. C. (2000). Scaffolding students' knowledge integration: Prompts for reflection in KIE. *International Journal of Science Education*, *22*(8), 819-837.

Davis, E. A. (2003a). Prompting middle school science students for productive reflection: Generic and directed prompts. *The Journal of the Learning Sciences*, *12*, 91–142.

Davis, E. A. (2003b). Untangling dimensions of students' beliefs about scientific knowledge and science learning. *International Journal of Science Education*, *25*, 439–468.

Dennen, V. (2004). Cognitive apprenticeship in educational practice: Research on scaffolding, modeling, mentoring, and coaching as instructional strategies. In D. Jonassen (Ed.), *Handbook of research on educational communications and technology* (pp. 813–828). Mahwah, NJ: Lawrence Erlbaum.

Dickson, S.V., Chard, D.J., & Simmons, D.C. (1993). An integrated reading/writing curriculum: A focus on scaffolding. *LD Forum*, *18*(4), 12-16.

Ertmer, P. & Simons, K. (2006). Jumping the PBL implantation hurdle: Supporting the efforts of K-12 teachers. *The Interdisciplinary Journal of Problem-based Learning*, *1*(1), 40-54.

Eslinger, E., White, B., Frederiksen, J., & Brobst, J. (2008). Supporting inquiry processes with an interactive learning environment: Inquiry Island. *Journal of Science Education and Technology*, *17*(6), 610-617.

Fawcett, L. & Garton, A. (2005). The effect of peer collaboration on children's problem-solving ability. *British Journal of Educational Psychology*, *75*, 157-169.

Fosnot, C. (1984). Media and technology in education: A constructivist view. *Educational Communications and Technology Journal*, *32*, 195-205.

Forman, E. (1989). The role of peer interaction in the social construction of mathematical knowledge. *International Journal of Educational Research*, *13*, 55-70.

Fox-Wasylyshyn, S. & El-Masri, M. (2005). Handling missing data in self-report measures. *Research in Nursing & Health*, *28*, 488-495.

Fretz, E. B., Wu, H.-K., Zhang, B., Davis, E. A., Krajcik, J. S., & Soloway, E. (2002). An investigation of software scaffolds supporting modeling practices. *Research in Science Education*, *32*(4), 567-589.

Fund, Z.(2007). The effects of scaffolded computerized science problem-solving on achievement outcomes: A comparative study of support programs. *Journal of Computer Assisted Learning*, *23*, 410-424.

Ge, X. & Land, S. (2004). A conceptual framework for scaffolding ill-structured problem-solving processes using question prompts and peer interactions. *Educational Research Technology and Development*, *52*(2), 1042-1629.

Ge, X., Chen, C., & Davis, K. (2005). Scaffolding novice instructional designers' problem-solving processes using question prompts in a web-based learning environment. *Journal of Educational Computing Research*, *33*(2), 219-248.

Glass, G. & Stanley, J. (1995). *Statistical methods in education and psychology*. Prentice-Hall: Englewood Cliffs, NJ.

Greene, B. A., & Land, S. M. (2000). A qualitative analysis of scaffolding use in a resource-based learning environment involving the World Wide Web. *Journal of Educational Computing Research*, *23*(2), 151–179.

Greening, T. (1998). Scaffolding for success in PBL. *Medical Education Online*, *3*(4). Retrieved from http://www.med-ed-online.org/f0000012.htm.

Grover, R., & Vriens, M. (2006). *The handbook of marketing research: Uses, misuses, and future advances*. Thousand Oaks, CA: Sage Publications.

Guzdial, M. (1994). Software-realized scaffolding to facilitate programming for science learning. *Interactive Learning Environments*, *4*(1), 1-44.

Hannafin, M.J., Land, S., & Oliver, K. (1999). Open learning environments: Foundations, methods, and models. In C. Reigeluth (Ed.), *Instructional-design theories and models (Volume II)* (pp.115-140). Mahwah, NJ: Erlbaum.

Hannafin, M.J., Kim, M., & Kim, H. (2004). Reconciling research, theory, and practice in web-based teaching and learning: The case for grounded design. *Journal of Computing in Higher Education*, *15*(2), 3-20.

Hill, J. & Hannafin, M. (2001). Teaching and learning in digital environments: The resurgence of resource-based learning. *Educational Technology Research and Development*, *49*(3), 37-52.

Hmelo, C., Holton, D., & Kolodner, J. (2000). Designing to learn about complex systems. *The Journal of the Learning Sciences*, *9*(3), 247-298.

Hoadley, C. M., & Linn, M. C. (2000). Teaching science through online, peer discussions: SpeakEasy in the Knowledge Integration Environment. *International Journal of Science Education*, *22*, 839–857.

Hoffman, J. L., Wu, H.-K., Krajcik, J. S., & Soloway, E. (2003). The nature of middle school learners' science content understandings with the use of on-line resources. *Journal of Research in Science Teaching*, *40*(3), 323-346.

Hogan, D. M., & Tudge, J. (1999). Implications of Vygotsky's theory for peer learning. In A. M. O' Donnell & A. King (Eds.), *Cognitive perspectives on peer learning* (pp. 39–65). Mahwah: NJ: Lawrence Erlbaum Associates, Inc.

Hsu, Y. S. (2004). Using the internet to develop students' capacity for scientific inquiry. *Journal of Educational Computing Research*, *31*(2) 137-161.

Huitema, B.E. (1980). *The analysis of covariance and alternatives*. New York: Wiley.

Jackson, S. L., Krajcik, J. S., Soloway, E. (1998). The design of guided learner-adaptable scaffolding in interactive learning environments. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 187–194.

Jacobson, M. J., & Archodidou, A. (2000). The design of hypermedia tools for learning: Fostering conceptual change and transfer of complex scientific knowledge.

Journal of the Learning Sciences, *9*(2), 145-199.

Jacobson, M. (2008). A design framework for educational hypermedia systems: Theory, research, and learning emerging scientific conceptual perspectives. *Educational Technology Research*, *56*, 5-28.

Jamaludin, A., & Lang, Q. C. (2006). Using asynchronous online discussions in primary school project work. *Australasian Journal of Educational Technology*, *22*(1), 64-87.

King, A., Staffieri, A., & Adelgais, A. (1998). Mutual peer tutoring: Effects of structuring tutorial interaction to scaffold peer learning. *Journal of Educational Psychology*, *90*(1), 134-452

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., & Holbrook, J., et al. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: Putting Learning by Design™ into practice. *The Journal of the Learning Sciences*, *12*, 495–547.

Kovalainen, M., Kumpulainen, K., & Vasama, S. (2001). Orchestrating classroom interaction in a community of inquiry: Modes of teacher participation. *Journal of Classroom Interaction*, *36*(2)-*37(*1), 17-28.

Krajcik, J., Blumenfeld, P.C., Marx, R.W., Bass, K.M., & Fredricks, J. (1998). Inquiry in project-based science classrooms: Initial attempts by middle school students. *The Journal of the Learning Sciences*, *7*(3-4), 313-350.

Krupa, M. P., Selman, R. L., & Jaquette, D. S. (1985). The development of science explanations in children and adolescents: A structural approach. In S. F.

Chipman, J. W. Segal & R. Glaser (Eds.), *Thinking and learning skills, Vol. 2: Research and open questions* (pp. 427-456). Hillsdale, NJ: Lawrence Erlbaum Associates.

Kyza, E. A., & Edelson, D. C. (2005). Scaffolding middle school students' coordination of theory and evidence. *Educational Research and Evaluation*, *11*(6), 545-560.

Lajoie, S. P., Lavigne, N. C., Guerrera, C., & Munsie, S. D. (2001). Constructing knowledge in the context of BioWorld. *Instructional Science*, *29*(2), 155-186.

Lakkala, M. Muukkonen, H., & Hakkarainen, K. (2005). Patterns of scaffolding in computer-mediated collaborative inquiry. *Mentoring and Tutoring*, *13*(2), 281-300.

Lee, H. S., & Songer, N. B. (2003). Making authentic science accessible to students. *International Journal of Science Education, 25*(8), 923-948.

Lee, E. Y. C., Chan, C. K. K., & van Aalst, J. (2006). Students assessing their own collaborative knowledge building. *International Journal of Computer Supported Collaborative Learning*, *1*(2), 277-307.

Lim, B. R. (2004). Challenges and issues in designing inquiry on the Web. *British Journal of Educational Technology, 35*(5), 627-643.

Lim, C. P., Nonis, D., & Hedberg, J. (2006). Gaming in a 3D multiuser virtual environment: Engaging students in Science lessons. *British Journal of Educational Technology*, *37*(2), 211–231.

Lin, X., Hmelo, C., Kinzer, C.K., Secules, T.J. (1999). Designing technology to support reflection. *Educational Technology Research and Development, 47*(3), 43-62.

Liu, M. (2004). Examining the performance and attitudes of sixth graders during their use of a problem-based hypermedia learning environment. *Computers in Human Behavior, 20*(3), 357-379.

Liu, M. & Bera, S. (2005). An analysis of cognitive tool use patterns in a hypermedia learning environment. *Educational Technology Research and Development*, *53*(1), 5-21.

Lizotte, D. J., McNeill, K. L., & Krajcik, J. (2004). Teacher practices that support students' construction of scientific explanations in middle school classrooms. *Proceedings of the Sixth International Conference of the Learning Sciences*, 310-317.

Luke, C. L. (2006). Fostering learner autonomy in a technology-enhanced, inquiry-based foreign language classroom. *Foreign Language Annals, 39*(1), 71-86.

Lumpe, A. T., & Butler, K. (2002). The information seeking strategies of high school science students. *Research in Science Education*, *32*(4), 549-566.

MacGregor, S. K., & Lou, Y. (2004). Web-based learning: How task scaffolding and web site design support knowledge acquisition. *Journal of Research on Technology in Education*, *37*(2), 161-175.

Manlove, S., Lazonder, A. W., & de Jong, T. (2007). Software scaffolds to promote regulation during scientific inquiry learning. *Metacognition and Learning*, *2*(2-3), 141-155.

Manlove, S., Lazonder, A., & de Jong, T.(2009). Collaborative versus individual use of regulative software scaffolds during scientific inquiry learning. *Interactive Learning Environment*, *17*(2), 105-117.

National Research Council (1996). *National science education standards*. Washington, DC: National Academy Press.

Maybin, J., Mercer, N, & Stierer, B. (1992). “Scaffolding” learning in the classroom. In K. Norman (Ed.) *Thinking voices: The work of the national oracy project* (pp. 186-195). London: Hodder & Stoughton.

McCleary, L. (2002). Using multiple imputation for analysis of incomplete data in clinical research. *Nursing Research*, *51*(5), 339-343.

Mercer, N. & Fisher, E.(1992). How do teachers help children to learn? An analysis of teacher’s interventions in computer-based activities. *Learning and Instruction*, *2*, 339-355.

Meyer, D.K. (1993). What is scaffolded instruction? Definitions, distinguishing features, and misnomers. In D.J. Leu & C.K. Kinzer (Eds.), *Examining central issues in literacy research theory, and practice* (pp.41-53). Chicago, IL: National Reading Conference.

McCormack, B. & Hill, E. (1997). *Conducting a survey: The SPSS workbook*. Boston, MA: International Thomson Business Press.

McNeill, K.L. & Krajcik, J. (2006, April). Supporting students’ construction of scientific explanation through generic versus context-specific written scaffolds. *2006*

Annual Meeting of the American Educational Research Association, San Francisco, CA.

McNeill, K. L., Lizotte, D. J., Krajcik, J., & Marx, R. W. (2006). Supporting students' construction of scientific explanations by fading scaffolds in instructional materials. *Journal of the Learning Sciences, 15*(2), 153-191.

Meyer, D. K. & Turner, J. C. (2002). Using instructional discourse analysis to study the scaffolding of student self-regulation. *Educational Psychologist*, *37*(1), 17-25.

Novak, A. & Krajcik, J. (2006). Using technology to support inquiry in middle school science. In L.B. Flick & N.G. Lederman (Eds.), *Scientific inquiry and nature of science* (pp.75-101). Netherlands: Springer.

Oliver, K. & Hannafin, M. (2000). Student management of web-based hypermedia resources during open-ended problem solving. *The Journal of Educational Researc*h, *94*(2), 75-92.

Oliver, K., & Hannafin, M. (2001). Developing and refining mental models in open-ended learning environments: A case study. *Educational Technology Research and Developmen*t, *49*(4), 5 – 32.

Paris, S. & Paris, A. (2001). Classroom applications of research on self-regulated learning. *Educational Psychologist*, *36*(2), 89-101.

Pata, K., Sarapuu, T., & Lehtinen, E. (2005). Tutor scaffolding styles of dilemma solving in network-based role-play. *Learning and Instructio*n, *15*(6), 571-587.

Pata, K., Lehtinen, E., & Sarapuu, T. (2006). Inter-relations of tutor's and peers' scaffolding and decision-making discourse acts. *Instructional Science: An International Journal of Learning and Cognition*, *34*(4), 313-341.

Pea, R. (2004). The social and technological dimensions of scaffolding and related theoretical concepts for learning, education, and human activity. *Journal of the Learning Sciences*, *13*(3), 423-451.

Pedaste, M., & Sarapuu, T. (2006). Developing an effective support system for inquiry learning in a web-based environment. *Journal of Computer Assisted Learning*, *22*(1), 47–62.

Pedersen, S., & Liu, M. (2002). The effects of modeling expert cognitive strategies during problem-based learning. *Journal of Educational Computing Research*, *26*(4), 353-380.

Perkins, D. N. (1992). What constructivism demands of the learner. In T. M. Duffy & D. H. Jonassen (Eds.), *Constructivism and the technology of instruction* (pp. 161-166). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Pressley, M., Hogan, K., & Wharton-McDonald (1996). The challenges of instructional scaffolding: The challenges of instruction that supports student thinking. *Learning Disabilities Research & Practice*, *11*(3), 138-146.

Puntambekar, S. & Hübscher, R. (2005). Tools for scaffolding students in a complex learning environment: What have we gained and what have we missed? *Educational Psychologist*, *40*(1), 1-12.

Puntambekar, S. & Kolodner, J. (2005). Toward implementing distributed scaffolding:

Helping students learn science from design. *Journal of Research in Science Teaching*, *42*(2), 185-217.

Quintana, C. & Frishman, B.J. (2006). Supporting science learning and teaching with software-based scaffolding. *2006 Annual Meeting of American Educational Research Association*, San Francisco, CA.

Reid-Griffin, A., & Carter, G. (2004). Technology as a tool: Applying an instructional model to teach middle school students to use technology as a mediator of learning. *Journal of Science Education and Technology*, *13*(4), 495-504.

Reiser, B. J. (2004). Scaffolding complex learning: The mechanisms of structuring and problematizing student work. *Journal of the Learning Sciences*, *13*(3), 273-304.

Revelle, G., Druin, A., Platner, M., Bederson, B., Hourcade, J. P., & Sherman, L. (2002). A visual search tool for early elementary science students. *Journal of Science Education and Technology*, *11*(1), 49-57.

Rimor, R., Reingold, R., & Heiman, T. (2008). Instructor's scaffolding in support of students' metacognition through online course. In J. Zumbach, N. Schwartz, T. Seufert, & L. Kester (Eds.). *Beyond knowledge: The legacy of competence* (pp. 43-54). Netherlands: Springer.

Rogoff, B. & Gardner, J. (1984). Adult guidance of cognitive development. In B, Rogoff & J. Lave's (Eds.) *Everyday cognition: Its development in social context* (pp 95–112). Harvard University Press, Cambridge.

Roth, W.-M. (1993). Metaphors and conversational analysis as tools in reflection on teaching practice: Two perspectives on teacher-student interactions in open-inquiry science. *Science Education*, *77*(4), 351-373.

Rubin, D.B. (1987). *Multiple imputation for nonresponse in surveys*. New York: Wiley & Sons.

Sandoval, W. A. (2003). Conceptual and epistemic aspects of students' scientific explanations. *The Journal of the Learning Sciences*, *12*, 5–52.

Sandoval, W. A. & Reiser, B. J. (2004). Explanation-driven inquiry: Integrating conceptual and epistemic scaffolds for scientific inquiry. *Science Education*, *88*(3), 345-372.

Sandoval, W. A. & Millwood, K. A. (2005). The quality of students' use of evidence in written scientific explanations. *Cognition and Instruction*, *23*(1), 23–55.

Seethaler, S. & Linn, M. (2004). Genetically modified food in perspective: An inquiry-based curriculum to help middle school students make sense of tradeoffs. *International Journal of Science Education*, *26*(14), 1765-1785.

Sharma, P. & Hannafin, M. (2007). Scaffolding in technology-enhanced learning environments. *Interactive Learning Environment*, *15*(1), 27-46.

Siegel, M. A. (2006). High school students' decision making about sustainability. *Environmental Education Research*, *12*(2), 201-215.

Simons, K. D. & Klein, J. D. (2007). The impact of scaffolding and student achievement levels in a problem-based learning environment. *Instructional Science*, *35*(1), 41-72.

Smith, B. K., & Reiser, B. J. (2005). Explaining behavior through observational investigation and theory articulation. *Journal of the Learning Sciences*, *14*(3), 315-360.

Squire, K. D., & Jan, M. (2007). Mad city mystery: Developing scientific argumentation skills with a place-based augmented reality game on handheld computers. *Journal of Science Education and Technology*, *16*(1), 5-29.

Stone, A. (1998). The metaphor of scaffolding: Its utility for the field of learning disabilities. *Journal of Learning Disabilities*, *31*(4), 344-364.

Stone, C. A. (2002). Promises and pitfalls of scaffolded instruction for students with language learning disabilities. In K. G. Butler & E. R. Silliman (Eds.), *Speaking, reading and writing in children with language learning disabilities: New paradigms in research and practice* (pp. 175–198). Mahwah, NJ : Erlbaum.

Sungur, S. (2007). Modeling the relationships among students' motivational beliefs, metacognitive strategy use, and effort regulation. *Scandinavian Journal of Educational Research*, *51*(3), 315-326.

Tabak, I., Smith, B.K., Sandoval, W.A., & Reiser, B.J. (1996). Combining general and domain-specific strategic support for biological inquiry. In C. Frasson, G. Gauthier, & A. Lesgold (Eds.), *Intelligent tutoring systems* (p. 288-297). Berlin, Germany: Springer-Verlag.

Tabak, I. (2004). Synergy: A complement to emerging patterns of distributed scaffolding. *Journal of the Learning Sciences*, *13*(3), 305-335.

Tudge, J. & Rogoff, B. (1989) Peer influences on cognitive development: Piagetian and Vygotskian perspectives. In M. Bornstein & J. Bruner (Eds.), *Interaction in Human Development* (pp.17-40). Hillsdale, NJ: Lawrence

Erlbaum Associates.

Toth, E. E., Suthers, D. D., & Lesgold, A. M. (2002). “Mapping to know”: The effects of representational guidance and reflective assessment on scientific inquiry. *Science Education*, *86*, 264–286.

Valanides, N., & Angeli, C. (2008). Distributed cognition in a sixth-grade classroom: An attempt to overcome alternative conceptions about light and color. *Journal of Research on Technology in Educatio*n, *40*(3), 309-336.

van den Boom, G., Pass, F., van Merrienboer, J., & van Gog, T. (2004). Reflection prompts and tutor feedback in a web-based learning environment: Effects on students’ self-regulated learning competence. *Computer in Human Behavior, 20*, 551-567.

van Aalst, J. (2006). Rethinking the nature of online work in asynchronous learning networks. *British Journal of Educational Technology*, *37*(2), 279-288.

Vattam, S. S., & Kolodner, J. L. (2008). On foundations of technological support for addressing challenges facing design-based science learning. *Pragmatics & Cognition*, *16*(2), 406-437.

Veermans, M. & Tapola, A. (2004). Primary schools students’ motivational profiles in longitudinal settings. *Scandinavian Journal of Educational Research*, *48*(4), 373-395.

Verenikina, I. (2003). Understanding scaffolding in the ZPD in educational research. *2003 Australian Association for Research in Education (AARE) Annual Conference*. Auckland, NZ.

Vreman-de Olde, C., & de Jong, T. (2006). Scaffolding learners in designing investigation assignments for a computer simulation. *Journal of Computer Assisted Learning*, *22*(1), 63-73.

Vygotsky, L.S. (1978). Mind in society: The development of higher psychological processes. Cambridge, MA: Harvard University Press.

Wang, F. & Hannafin, M. (2008). Integrating WebQuests in preservice teacher education. *Educational Media International*, *45*(1), 59-73.

White, B.Y., & Frederiksen, J. R. (1998). Inquiry, modeling, and metacognition: Making science accessible to all students. *Cognition and Instruction*, *1*6(1), 3-118.

Whitman, N. (1993). A review of constructivism: Understanding and using a relatively new theory. *Family Medicine*, *25*(8), 517-521.

Winn, J. (1994). Promises and challenges of scaffolded instruction. *Learning Disability Quarterly*, *17*, 89-104.

Winters, F. I., & Azevedo, R. (2005). High-school students' regulation of learning during computer-based science inquiry. *Journal of Educational Computing Research*, *33*(2), 189-217.

Wood, D., Bruner, J.S., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology & Psychiatry & Allied Disciplines*, *17*, 89-100.

Wu, H. K., Krajcik, J. S., & Soloway, E. (2001). Promoting understanding of chemical representations: Students’ use of a visualization tool in the classroom. *Journal of Research in Science Teaching*, *38*(7), 821 – 842.

Wu, H.-K. (2003). Linking the microscopic view of chemistry to real life experiences:

Intertextuality in a high school science classroom. *Science Education*, *87*, 868–891.

Wu, H. K. & Hsieh, C. E. (2006). Developing sixth graders' inquiry skills to construct explanations in inquiry-based learning environments. *International Journal of Science Education*, *28*(11), 1289-1313.

Wu, H.-K. & Krajcik, J. S. (2006a). Exploring middle school students' use of inscriptions in project-based science classrooms. *Science Education*, *90*(5), 852-873.

Wu, H.-K., & Krajcik, J. S. (2006b). Inscriptional practices in two inquiry-based classrooms: A case study of seventh graders' use of data tables and graphs. *Journal of Research in Science Teaching*, *43*(1), 63-95.

Zumbach, J., Schmitt, S., Reimann, P., & Starkloff, P. (2006). Learning life sciences: Design and development of a virtual molecular biology learning lab. *Journal of Computers in Mathematics and Science Teaching*, *25*(3), 281-300.

Zydney, J. M. (2005). Eighth-grade students defining complex problems: The effectiveness of scaffolding in a multimedia program. *Journal of Educational Multimedia and Hypermedia*, *14*(1), 61-90.

Zydney, J. (2010). The effect of multiple scaffolding tools on students' understanding, consideration of different perspectives, and misconceptions of a complex problem. *Computers & Education*, *54*, 360-370.

APPENDIX A

ARTICLES INCLUDED IN THE LITERATURE REVIEW

Table A.1 Included Articles in the Review

	Authors / Year	N / Grade	Scaffolding forms	Scaffolding purposes
1	Azevedo (2004)	49 Grade 11-12	Teacher	• Enhance students understanding • Monitor progress • Scaffold strategies o Help students evaluate content (*Cognitive scaffolding*) o Understand procedures
2	Azevedo (2005)	111 Grade 7 &10	• Adaptive scaffold o Instruction o Tutor • Fixed scaffold o Instruction o Sub-goals • No scaffold o Instruction	• Adaptive scaffold o Plan learning o Monitor o Use strategies • Fixed scaffold o Promote qualitative shifts in student's mental model
3	Azevedo (2008)	128 Middle school	Tutor	Self-regulatory skills • Activate students' prior knowledge • Prompt students to use effective strategies • Plan students' time and effort • Monitor and assess learning progress toward goals
4	Barab (2007)	28 G4	Non-player characters	Help students access resources

Table A.1 Continued

	First author / Year	N / Grade	Scaffolding forms	Scaffolding purposes
5	Bell (2000)	172 Middle school	1. KIE • Sentence starters • Hints o Activity hint o Evidence hint o Claim hint • Focusing question 2. Debate-based instruction	Scaffold student explanations 1. • Metacognitive • Highlight salient aspects of the project 2. Scaffold the process of considering the views of others
6	Butler (2008)	27 G5	Web interface in software	Provide a digital library for students to search and sort science information related to project-based investigations • Search • Save & View • Maintain • Organize • Collaborative
7	Chang (2001)	48 G8	Concept mapping	Concept mapping

Table A.1 Continued

	First author / Year	N / Grade	Scaffolding forms	Scaffolding purposes
8	Chen (2003)	86 Elementary school	The mobile bird-watching system • Hierarchical component skills • Decreasing support levels • Ongoing assessment • Repetitive authentic practice	• Hierarchical component skills o Easily search for the knowledge • Decreasing support levels o Provide different levels of assistance • Ongoing assessment • Repetitive authentic practice o Assist the students in accordance with their learning efficiency
9	Clark (2000)	240 Second year of high school	Knowledge Integration Environment	Scaffold students' use of internet resources, as well as other complimentary activities including authoring, electronic conversations and argument organization
10	Clark (2007)	84 Grade 8	Personally-seeded discussions	Scaffold high levels of scientific argumentation

Table A.1 Continued

	First author / Year	N / Grade	Scaffolding forms	Scaffolding purposes
11	Davis (2000)	N/A Grade 8	• Reflection prompts o Activity prompts o Self-monitor prompts	o *Activity prompts* ▪ Encourage students to reflect on their progress in the activity and specifically about whether they have devoted attention to each aspect of their project ▪ Guide students to identify appropriate, detailed considerations as they work on individual activities ▪ Include the prompts for all the steps necessary for the accomplishment of the project o *Self-monitor prompts* ▪ Planning and monitoring prompts designed to help students map out their strategies for an activity and then, reflect back on that activity and identify their work's strengths and weakness
12	Davis (2003a)	178 Grade 8	• Activity prompts • Reflection prompts o Generic prompts o Directed prompts	• *Activity prompts* Focus on sense-making and help students complete KIE projects • *Reflection prompts* o Ask students to "stop and think" for reflection o Indicate potentially productive directions for their reflection
13	Davis (2003b)	178 Grade 8	KIE project	Make sense of complex information from the world wide web

Table A.1 Continued

	First author / Year	N / Grade	Scaffolding forms	Scaffolding purposes
14	Eslinger (2008)	24 Grade 6-8	• Inquiry Cycle • Software • Teacher	• Inquiry Cycle o Question o Hypothesize o Investigate o Model o Evaluate • Software o Support the creation and assessment of inquiry projects o Scaffold the use of the Inquiry Cycle model • Lead students to understand why assessment values needed to be changed

Table A.1 Continued

	First author / Year	N / Grade	Scaffolding forms	Scaffolding purposes
15	Fretz (2002)	31 Grade 7	In Model-It software • Tool • Teacher • Peer	• Tool o Process map o Articulation text boxes o Dynamic testing o Others (e.g., Making context personally relevant: personalize, hiding complexity) • Teacher o Conceptual (e.g., critiquing structure of model) o Utility (e.g., how to use certain software function) o Task (e.g., refer students to textbook, notebooks) o Content (e.g., explain pH range/scale) o Strategy (e.g., suggest need for more planning) • Peer Same as teacher scaffolding
16	Hmelo (2000)	42 Grade 6	• Teacher o Use PBL's whiteboards o Questions o Dramatic opening o Questioning during presentations o Reflective activities	o Help students generate questions and investigate to answer them using available written resources as well as through experimentation; Help students plan and monitor their activities o Prompt the thinking o Help students understand that learning is incremental and that each new answer helps to light the way to new questions o Help students engage in the discourse of science o Help students pull together what they had done and extract things they had learned.

Table A.1 Continued

	First author / Year	N / Grade	Scaffolding forms	Scaffolding purposes
17	Hoadley (2000)	180 Grade 8	Online discussion forum (*SpeakEasy*)	Scaffold student discussion by providing multiple representations of discourse and emphasizing social information in the interface
18	Hoffman (2003)	16 Grade 6	1. Online learning materials • Interface to the Digital Library • The Middle Years Digital Library (MYDL) o *What to Do* page o *Share* page 2. Offline learning materials • Tactics and Strategies for Leading On-Line Investigations o Activity sheets 3. Teacher	Support students' information-seeking activities 1. • Allow students to focus on the contents of the resource, evaluate its usefulness, and synthesize information rather than spending the majority of time simply locating appropriate sites on the WWW • Web pages o Give a brief introduction to the science unit and the inquiry process o Allow students to click individual icons to reach on-line forms for sharing driving questions, sites pertinent to their questions, and comments or questions to other students 2. • Activity sheets o Use and provide a process model o Inquiry strategies (i.e., asking, planning, searching, assessing, writing, creating)

Table A.1 Continued

	First author / Year	N / Grade	Scaffolding forms	Scaffolding purposes
19	Jacobson (2000)	Study 1: 8 Year 14-16 Study 2: 13 High school	Knowledge mediator framework	• Provide conceptual scaffolding to support learners in problem-solving activities that require an appreciation of the relation of abstract conceptual knowledge both within specific cases and across multiple cases
20	Jamaludin (2000)	20 Primary school	Built-in notes in online discussions	• Articulate thoughts • Communicate ideas • Elaborate notes

Table A.1 Continued

	First author / Year	N / Grade	Scaffolding forms	Scaffolding purposes
21	Kyza (2005)	12 Grade 7	• Software-based o Data camera o Data boxes o Prompts accompany the text or data boxes o Articulation boxes or tables o Prompts in articulation boxes o Data page o Explanation page o Prompts in explanation pages o Evidence box in explanation pages • Paper-based	• Software-based o capture investigation data o paste and store the captured information o remind students of the task they are asked to do o serve as repositories for students' written articulations o help students reflect on the data o provide space for students to record data o record hypothesis, construct an explanation about what happened, and provide evidence for it o serve as a reminder of investigation-specific important concepts o support making the connections between theory and evidence more explicit
22	Lajoie (2001)	40 Grade 9	• Tools o Belief meter o Evidence palette • Human tutors o Teacher o Graduate students	• Scaffold metacognitive process • Modelling and fading assistance o The teacher was more directive

Table A.1 Continued

	First author / Year	N / Grade	Scaffolding forms	Scaffolding purposes
23	Lee (2006)	119 Grade 9	1.Knowledge forum • Portfolio notes • Knowledge-building principles	• Portfolio notes o Metacognitive prompts o Conceptual prompts • Knowledge-building principles o Note writing o Note selection o Explain how the selected notes illustrate the principles
24	Lim (2006)	8 Age 8 -12	• Template-based response documents o Guiding questions o Web links o Keywords	Direct students' attention to key variables, concepts, and visual cues, facilitate their cognitive thinking and metacognitive skills, promote their knowledge integration, and guide them to generate questions and elaborate upon their thinking
25	Liu (2004)	155 G6	• Technology • Teacher	• Technology o Cognitive tools • Teacher

Table A.1 Continued

	First author / Year	N / Grade	Scaffolding forms	Scaffolding purposes
26	Liu (2005)	110 G6	• Technology • Teacher	• Technology o Cognitive tools • Teacher o Facilitator
27	Lumpe (2002)	43 G9-10	1. Features in Artemis web-based interface • Collaborative • Organizational • Maintenance • Search • Save and view	• Share information • Workspace • Maintain results of their search • Conduct web searches, view descriptions of websites, and visit interesting websites • Save and retrieve search results
28	MacGregor (2004)	52 G5	• Concept mapping template • Study guide	• Make connections from the information they acquired to the major relevant concepts • Find relevant information
29	Manlove (2007)	70 Age 16-18	Software	Regulation

Table A.1 Continued

	First author / Year	N / Grade	Scaffolding forms	Scaffolding purposes
30	Oliver (2000)	20 Middle school	• Knowledge integration environment o Details button o Advance organizer; Question prompt o Activity hints	• Knowledge integration environment o Procedural o Conceptual o Metacognitive
31	Oliver (2001)	12 Grade 8	1. KIE • Conceptual question prompts o Note-taking • Procedural prompts • Metacognitive hints • Online scaffolding • A solution evaluation form 2. Teacher • Procedural prompts • Metacognitive hints	1. • Help students focus on key concepts • Provide instructions for completing specific activities • Suggest appropriate strategies for working on a specific activity • Guided students to review resources to determine their relevance to hypotheses • Help students identify quality or limiting aspects in their initial ideas

Table A.1 Continued

	First author / Year	N / Grade	Scaffolding forms	Scaffolding purposes
32	Pata (2005)	62 Age 14-17	• Tutor • Peer	• Tutor o Process o Content o Collaboration • Peer o Process o Content
33	Pata (2006)	62 Age 14-17	• Tutor • Peer	• Tutor o Process o Content o Collaboration • Peer o Process o Content
34	Pedersen (2002)	62 Grade 6	Hypermedia-based tool	• Give learners ideas about useful activities to engage in • Model a variety of skills useful

Table A.1 Continued

	First author / Year	N / Grade	Scaffolding forms	Scaffolding purposes

35	Puntambekar (2005)	98
		Grade 8
			STUDY 1
			• Design diaries
			  o Hints
			  o Prompts
			  o Guidance
			STUDY 2
			• Design diaries
			  o Macro prompts
			  o Micro prompts
			  o Metacognitive prompts
			• Teacher and peers
				STUDY 1
				• *Design diaries*
				o Make clear the range of activities
				o Made thinking visible
				o Carry out design activities and reflecting on them
				STUDY 2
				• *Design diaries*
				o Reason about the phase of design
				o Carry out the activities within each design phase
				o Monitor learning; reason and justify as they were making their design decisions
				• *Teacher's social / situational scaffolds*
				o Clarify science understanding
				o Offer explanations
				o Ask questions

36	Reid-Griffin (2004)	23 Grade 7-8	Teacher	• Help the use of technology tools • Prevent frustration
37	Revelle (2002)	106 Grade 2-3	Search interface of the software	• Make it easy for students to see whether their queries have been formulated correctly or not • Allow students to first focus solely on identifying the proper parameters to conduct the search they have in mind

Table A.1 Continued

	First author / Year	N / Grade	Scaffolding forms	Scaffolding purposes
38	Sandoval (2003)	69 High school	1.ExplanationConstructor • Explanation Guides o Conceptual o Epistemic 2. Teacher	1. *ExplanationConstructor* • Frame the problem • Access the data • Highlight the causal components of important domain theories *2. Teacher* • Frame the problem
39	Sandoval (2004)	69 Grade 9 87 Grade 9	• ExplanationConstructor o Explanation Guide	Guide students' construction and evaluation of their explanations • Suggest specific investigative actions that students can take (Conceptual) • Provide a concrete means for students to monitor their progress (Conceptual) • Encourage students to think about theories as explanatory framework (Epistemic) • Strategic guidance
40	Sandoval (2005)	87 High school	• ExplanationConstructor o Explanation templates o Data linking	• *Explanation templates* o Help students to articulate explanations; Suggest students explain possible factors • *Data linking* o Enable students to supply needed and sufficient evidentiary warrants (or backing) for specific claims

Table A.1 Continued

	First author / Year	N / Grade	Scaffolding forms	Scaffolding purposes
41	Seethaler (2004)	173 Grade 8	1. WISE features • Form • Page for structure their papers o Sentence starter o Idea-organization pages	1. *WISE features* • *Form* Note taking • *Page for structure their papers* Organize argument and evidence for the position they chose in order to write their papers
42	Siegel (2006)	57 Grade 10	Interface in the computer program	• Make evidence-based decisions • Connect supporting and conflict statements into a web

Table A.1 Continued

	First author / Year	N / Grade	Scaffolding forms	Scaffolding purposes
43	Simons (2007)	111 Grade 7	1. Opening screen • Strategic scaffolds o Guiding questions o Expert suggestion 2. Balloon design • Strategic scaffolds o Text-based response • Conceptual scaffolds 3. Travel plan • Strategic scaffolds o Guiding questions • Conceptual scaffolds	1. Opening screen o Offer expert advice o Organize information 2. Balloon design • Strategic scaffolds o Offer expert advice • Conceptual scaffolds o Cue students' thinking to discriminate information 3. Travel plan • Finalize answers • Cue essential things to consider
44	Smith (2005)	44 Grade 9	• Curricular o Investigation model • Software tools o Animal Landlord	• *Investigation model* o Make the process of observing and explaining explicit • Animal Landlord o Scaffold observation tasks made explicit in the investigation model; Encourage expert scientific practices defined by our investigation model

Table A.1 Continued

	First author / Year	N / Grade	Scaffolding forms	Scaffolding purposes
45	Squire (2007)	28 Grade 4 – High school	• Multimodal representations • Non-play characters • Game mechanics o Challenges o Roles o Resources o Place o Collaboration/ Competition	Learning and thinking
46	Toth (2002)	73 Grade 9	• Representation guidance o Evidence mapping	• Assist the development of thinking with the main epistemological categories of data and hypotheses
47	Valanides (2008)	18 Grade 6	The design of computer tools • Stimulator • Notebook • Structure the process • Prompts and questions • Tools • A systematic inquiry process	• Enable students to make careful observations • Organize the results of students' investigations • Make the process of inquiry explicit to learners • Make learners' thinking explicit • Conduct investigations • Help engage in the process

Table A.1 Continued

	First author / Year	N / Grade	Scaffolding forms	Scaffolding purposes
48	Vattam (2008)	16 Grade 6	• Partially filled template Prediction	Explanation-construction
49	Vreman-de Olde (2006)	45 Age 17	Design Sheet • Examples • Instruction	Guide students through different steps in the design of assignments • Conceptual support • Procedural support
50	Winters (2005)	62 High school	• Teacher-constructed worksheet • High prior-knowledge peers	• Scaffold their answering of class questions by asking them to state o experimental question, o hypotheses, and o results • Regulate their cognition by seeking help in clarifying things they did not understand
51	Wu (2001)	71 Grade 11	*Help* function in the software	Support the learning processes
52	Wu (2003)	25 Grade 11	Teacher • Discursive strategies • Questions	• Build meaningful links on their prior knowledge and experiences • Support the meaning making process

Table A.1 Continued

	First author / Year	N / Grade	Scaffolding forms	Scaffolding purposes
53	Wu (2006a)	27 Grade 7	• Teacher • Peer	• For students’ enactment of inscriptional practices o questioning o modeling o elaboration o explaining • Support students in accomplishing inscriptional tasks
54	Wu (2006b)	27 Grade 7	• Teacher • Guideline sheet o Questions or guidelines	• Support inquiry process o suggesting possible questions o guiding students to design their investigations o providing guidelines for data collection and analysis o modeling the use of inscriptions • Structure and participate activities
55	Zumbach (2006)	43 High school	• Conceptual/procedural • Metacognitive/strategic • Exchange	• Acquire domain specific declarative/procedural knowledge • Explore and experiment • Exchange research questions and findings

Table A.1 Continued

	First author / Year	N / Grade	Scaffolding forms	Scaffolding purposes
56	Zydney (2005)	Grade 8	• Time management o Deadlines and reminders • Cognitive processing o Computer tools and templates • Supportive guidance o Modeling and coaching	• Help pace students during problem solving • Assist students in finding, organizing, and integrating knowledge of the problem; Support students' memory and metacognitive processes • Offer hints and advice to the students when they solve the problem

APPENDIX B

TEACHER’S MANUAL FOR EARLY METACOGNITIVE SCAFFOLDING

Table B.1 Introduction of Teacher’s Manual

Supervolcano Module

Teaching strategies in technology-enhanced classrooms

Description	This learning module will be utilized in an innovative educational software program called Virtual Environments for Learning (VELs). VELs are designed to engage students in learning tasks that require them to learn both science content knowledge and scientific inquiry skills.
Learning tasks	The main task of the students is to answer five questions related to the environmental effects of the volcanic eruption. Students will need to read scientists' reports and use instruments to test their predictions. Students need to use the Science Notebook feature embedded in the learning module to record their learning process. After students finish recording their inquiry process for all five tasks in the Science Notebook, they will be asked to submit their answers to the final report.
Teacher’s role	The teacher will act as a facilitator to guide and encourage students to articulate, reflect upon, and extend their learning. To achieve this purpose, you will lead discussions **only during the specified class periods**.
Time	1 class period of 25 minutes (survey + pre-test) 10 class periods of 45 minutes each (survey + learning module) 1 class period of 35 minutes (survey + post-test)
Technology requirement	Each student will require access to the Internet for all 12 class periods

Table B.2. Schedule for the Early Introduction of Metacognitive Scaffolding

Day	Student's tasks	Teacher's tasks	Materials
1	– Complete the online survey – Complete pre-test	– Introduce the objectives of learning module – Administer the survey for 5 minutes. – Administer the test for 20 minutes.	– **Online survey A** (http://volcano.cilat.org/surveyA23.html) – **Online pre-test** (http://volcano.cilat.org/pretest32.html)
2	– Start the first inquiry question – Use the hints given in the Science Notebook to answer the question and record each inquiry step in the notebook	– Direct students to read the Scientist Reports and use the Science Notebook feature to start their inquiry. – **During the last 8 minutes of the class, choose random students and have them share their inquiry experiences (see guidelines below).**	– Supervolcano Program (http://volcano.cilat.org)
3	– Continue work on the first inquiry question	– **During the last 8 minutes of the class, choose random students and have them share their inquiry experiences (see guidelines below).**	– Supervolcano Program
4	– Start the second inquiry question	– **During the last 8 minutes of the class, choose random students and have them share their inquiry experiences (see guidelines below).**	– Supervolcano Program

Table B.2. Continued

Day	Student's tasks	Teacher's tasks	Materials
5	– Continue work on the second inquiry question	– **During the last 8 minutes of the class, choose random students and have them share their inquiry experiences (see guidelines below).**	– Supervolcano Program
6	– Complete the online survey – Start the third inquiry question	– **At the beginning of class, administer the survey for 5 minutes.** – Only encourage students to do the tasks. Do not provide specific guidance. Do not hold a class discussion.	– **Online survey B** (http://volcano.cilat.org/surveyB45.html) – Supervolcano Program
7	– Continue work on the third inquiry question	– Only encourage students to do the tasks. Do not provide specific guidance. Do not hold a class discussion.	– Supervolcano Program
8	– Start the fourth inquiry question	– Only encourage students to do the tasks. Do not provide specific guidance. Do not hold a class discussion.	– Supervolcano Program

Table B.2. Continued

Day	Student's tasks	Teacher's tasks	Materials
9	– Continue work on the fourth inquiry question	– Only encourage students to do the tasks. Do not provide specific guidance. Do not hold a class discussion.	– Supervolcano Program
10	– Start the fifth inquiry question	– Only encourage students to do the tasks. Do not provide specific guidance. Do not hold a class discussion.	– Supervolcano Program
11	– Continue work on the fifth inquiry question	– Only encourage students to do the tasks. Do not provide specific guidance. Do not hold a class discussion.	– Supervolcano Program
12	– Complete the online survey – Complete post-test	– Administer the survey for 5 minutes. – Administer the test for 30 minutes.	– **Online survey C** (http://volcano.cilat.org/surveyC65.html) – **Online post-test** (http://volcano.cilat.org/posttest76.html)

Guidelines for asking questions:

- Only ask the questions listed in this teaching manual, and ask them in the order in which they are listed.
- Take no longer then 8 minutes per class period to ask questions, and hold the discussions only at the end of the class period.
- During each class, ask questions of only 2 or 3 students. Try to ask different students each day.
- When asking a student a question, do not allow interruptions from other students trying to answer that question.
- Accept and acknowledge student responses in a neutral, rather than evaluative, manner. Teacher's guidance should not provide any judgment about the accuracy or completeness of students' comments.

Procedure for asking questions:

- Ask a student the first question listed for the day.
- If a student fails to provide an answer to the question, rephrase the question in a way that you feel will elicit a response from that student. If the student still fails to provide a response, ask a different student the same question.
- If a student provides an answer to the question, ask the student to provide a rationale for his answer.
- After the student provides a rationale, ask another student to evaluate that answer ("Do you want to add anything?" "Do you agree / disagree?").
- Once a student has provided an evaluation, ask that student the next question on the list.
- Repeat the procedure above until you reach the last question for the day.

Questions for Day 2 Discussion:

1. How long do the scientists believe the aerosols will remain in the air?
2. What science information can be used to answer this question?
3. How long do you think the aerosols will stay in the air?

Questions for Day 3 Discussion:

1. What equipment did you use to gather information?
2. What were the results from using the equipment?
3. What science information did you find useful in answering the question?
4. What did you conclude from the data?

Questions for Day 4 Discussion:

1. The scientists believe the volcanic cloud will affect which hemisphere?
2. What science information can be used to answer this question?
3. Which hemisphere do you predict the volcanic cloud will affect?

Questions for Day 5 Discussion:

1. What equipment did you use to gather information?
2. What were the results from using the equipment?
3. What science information did you find useful in answering the question?
4. What did you conclude from the data?

APPENDIX C

RUBRIC FOR ASSESSING SCIENTIFIC INQUIRY

Table C. 1. Rubric

	Low	Medium	High
Explore background information	Notes some key concepts, but without providing details. Fails to report the scientists' disagreements. (0 points)	Notes some key concepts without details. (5 points) Reports the scientists' disagreements, though without much detail. (5 points)	Notes many or all key concepts and provides details. (10 points) Reports the scientists' disagreements, and provides details. (10 points)
Predict the results	No predictions are provided, or predictions are irrelevant to the task. (0 points)	Provides a prediction, but does not fully address the question.(10 points) Ex. Did not identify the reasons	Provided a prediction that fully addresses the question (i.e., providing a time span). (20 points) Ex. Identify the reasons
Collect and record data	Used no instruments or instruments unrelated to the task. (0 points) Did not record any observations. (0 points)	Used some instruments related to the task.(5 points) Recorded observations with some detail. (5 points)	Used all instruments related to the task.(10 points) Recorded observations with much detail.(10 points)

Table C. 1. Continued

	Low	Medium	High
Analyze results and make conclusions	Failed to draw a conclusion, no conclusion provided, or drew a conclusion unrelated to the task. (0 points)	Drew a conclusion based on minimal evidence, that does not fit the evidence cited, or that did not fully answer the question. (10 points) Ex1. Only estimated the time it would take for the gases to return to normal levels (5 points) Ex2. Provided reasons for the estimated period but lacked sufficient evidence (10 points)	Drew a conclusion that is both supported by sufficient evidence and fully answers the question. (20 points)

APPENDIX D

SATISFACTION SURVEY

Howdy! Thank you for participating in the *Supervolcano* project. I hope that you had a great learning experience. In order to help researchers improve the computer program and conduct related studies, please help us by filling out this survey. All your information will be confidential; your teacher will not be able to access the responses you provide. Furthermore, there will be no right or wrong answers for this survey. Please select the answer that best describes your learning experience. Thank you!

Use the scale below to answer the questions. If you strongly agree with the statement, circle 7; if you strongly disagree with the statement, circle 1. Circle the number between 1 and 7 that best describes you.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

I had no problems using the mouse or keyboards to use the computer program.	1	2	3	4	5	6	7
The teacher-led discussions helped me to think more clearly about how to answer the questions.	1	2	3	4	5	6	7
The teacher's assistance should extend beyond the discussion sessions.	1	2	3	4	5	6	7
The teacher's support helped me to understand science concepts.	1	2	3	4	5	6	7
Overall, the discussion led by the instructor was helpful.	1	2	3	4	5	6	7
The hints given in the Science Notebook were clear.	1	2	3	4	5	6	7
The hints given in the Science Notebook were sufficient.	1	2	3	4	5	6	7
The hints given in the Science Notebook helped me to think more clearly about how to answer the questions.	1	2	3	4	5	6	7

The hints given in the Science Notebook helped me to understand science concepts.	1	2	3	4	5	6	7
The questions were difficult to answer.	1	2	3	4	5	6	7
I had sufficient time to answer the questions.	1	2	3	4	5	6	7
I am satisfied with my overall learning experience in this learning module. (Explain your answers)	1	2	3	4	5	6	7
	[						]

VITA

Hui-Ling Wu received her Bachelor of Arts degree in history from National Cheng Kung University, Tainan, Taiwan, in 1998. She began studying Instructional Systems Technology at Indiana University, Bloomington, in 2000 and received her Master of Science degree in May 2002. Her research interests include technology-based instruction, adult learning, and game-based learning.

Dr. Wu may be reached at: Department of Educational Psychology, 704 Harrington Tower, MS 4225, College Station, TX 77843. Her email is: mysterykelly@gmail.com.