

**Investigating a Computerized Scaffolding Software for
Student Designed Science Investigations**

By

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Investigating a Computerized Scaffolding Software for
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Science standards call for students to develop skills in designing their own investigations. However, this is a complex task that is likely to overload the working memory capacities of students, therefore requiring scaffolding. This study investigated the effects of a computerized scaffold for student-designed experiments. Students ($N = 102$) used the computer program to individually design an experiment during the third week of their high school general chemistry course. Students were randomly assigned to one of four software versions to determine the effects and interaction effects of backwards-design scaffolding and reflective prompts on laboratory report scores. Scaffolding the students in a backwards-design process lead to significantly higher student performance scores for all students when they were not provided with reflective prompts ($p = 0.01$). For students labeled as academically advanced by their eighth grade science teacher, backwards design increased student performance scores with or without reflective prompts ($p = 0.002$). Using reflective prompts had no effect on advanced students. The use of multiple reflective prompts caused the effect of the backwards-design scaffolding to disappear with lower-level students.

Dedication

To my children, Shana and Caleb. May you always love to learn and pursue all your dreams and goals.

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Chapter 1: Introduction

Context of the Study

The National Science Education Standards, NSES (NRC, 1996), Benchmarks for Science Literacy (AAAS Project 2061, 1993) and the Atlas of Science Literacy (AAAS Project 2061, 2001) all discuss the importance of implementation of inquiry-based science education in our schools. Each document contains standards specifically addressing students designing their own scientific investigations. State standards have been developed based on these documents. Despite the inclusion of experiment design skills in all guiding standards documents, a survey of 571 high school chemistry teachers found only 55.5% of the participants included student-designed laboratory investigations in their courses (Deters, 2006).

There are many reasons that a teacher might give, in explanation for lack of student-designed investigations in their chemistry course. One reason teachers give is that students do not seem to be able to design and carry out a scientific investigation despite experience reading and following pre-designed investigations. Teachers are often frustrated with students that do not know where to begin, which direction to head, and do not seem to understand the science content any better for having participated in the time-consuming process. Why does a technique with such face validity and support from guiding organizations often work so poorly in the classroom?

Cognitive theory suggests that information processing takes place within working memory (Bruning, Schraw, Norby and Ronning , 2004). Working memory is limited in

capacity with approximately four slots available for active processing (Cowan, 2005). Because students are novices in scientific investigation design, they have little to no current schema in long-term memory relevant to the design process. They have little ability to chunk relevant information and therefore the design of scientific investigations places large burden on their working memory. To overcome a low level of chunking, scaffolding is needed for students in novel problem-solving tasks to decrease demand on working memory (Kirschner, Sweller & Clark, 2006; Shell & Brooks, 2007). However, the task of effectively scaffolding a room full of students with diverse motivation, ability levels, prior knowledge, etc., is a difficult one, to say the least.

Many teachers succeed in challenging their students with higher-order thinking, real-world problem-solving, and/or problem-based learning. However, students do not usually succeed in open learning environments without careful guidance and scaffolding appropriate to the students' levels. Some teachers inherently know this and provide the needed guidance. A great number of teachers that are currently in the classroom have not been trained in the use of inquiry with students, however. They may have participated in a short workshop. They may have been told that they should be using inquiry. All too often these teachers indicate a belief that, in order for a task to be inquiry, it must be a setting in which the students do not have guidance, but rather are left free to explore and discover. Teachers attempt this type of learning environment, experience frustration when their students are not successful, decide that inquiry learning is not viable, and return to predominately lecture and laboratory investigations with lower-level thinking requirements. This is certainly not the case in every situation. Some teachers discover

appropriate levels of scaffolding. Others seem to know it intuitively. There remain many teachers who view the technique of inquiry as involving *no* guidance at all.

The Student-Designed Labs Scaffolding and Assessment Tool

The Student-Designed Labs Scaffolding and Assessment Tool (SDL-SAT, Deters, 2007) is a computer software program with the goal of reducing working memory demand for students. The software shows only the portions of the task and instructions that are salient at any given time during the development of an experiment and guides students through the design process.

Thinking (processing information) occurs in working memory (Bruning et al. 2004). Therefore, the capacity of working memory limits our processing ability. There are three types of load placed on working memory: intrinsic, extraneous and germane (van Merriënboer, J., Kester, L., & Paas, F., 2006).

Intrinsic load refers to task difficulty. The intrinsic cognitive load of a task is changed when the task is broken into smaller tasks. While intrinsic load connected to a task might exceed a student's working memory capacity, the intrinsic load connected with each of several sub-tasks might be within that capacity. This might be done for a student-designed investigation by having students focus on the purpose and background information and then moving onto the safety and materials section, for example. The breaking down of the larger task of designing a scientific investigation into smaller tasks, such as focusing only on the materials list, decreases the difficulty for students. When working on a materials list, the purpose or problem and background information does not need to be held in the student's working memory as it has already written down. The

paper serves as external memory. Students working on a materials list to need to be aware of what equipment and materials are available to them as well as how and when they have used that equipment in the past. However, that is not all. They cannot begin to know what equipment to use if they have not yet planned what they are going to do. Table 1.1 displays the additional information that they must hold in working memory because it has not yet been written down.

Section student is working on (main task):	Additional information student must hold in working memory:
Materials & Safety	<ul style="list-style-type: none"> • What calculation, comparison or trend recognition will be needed to address the purpose or problem? • What data/observations will be needed? • What steps will need to be performed?
Procedure	<ul style="list-style-type: none"> • What calculation, comparison or trend recognition will be needed to address the purpose or problem? • What data/observations will be needed?
Data	<ul style="list-style-type: none"> • What calculation, comparison or trend recognition will be needed to address the purpose or problem?
Results/Analysis	

Table 1.1 Additional information a student must hold in working memory when designing a scientific investigation from the beginning.

Even though the task has been divided into sub-tasks, students must still hold information about the future sub-tasks in their working memory. Students need more process guidance than simply doing one or two sections at a time.

With the SDL-SAT, students are guided through the investigation design process in a *backwards-design* method. After first identifying the purpose/question and background information, students develop a results section. Table 1-2 displays the information that has already been written down, in addition to the purpose and background information. This written down information is now “stored” in external memory and thereby expands the quantities of information the student can process.

Section student is working on (main task):	Information now held in external memory (previously written):
Results/Analysis	
Data	<ul style="list-style-type: none"> • What calculation, comparison or trend recognition will be needed?
Procedure	<ul style="list-style-type: none"> • What data/observations will need to be gathered? • What calculation, comparison or trend recognition will be needed?
Materials & Safety	<ul style="list-style-type: none"> • What steps will be needed to gather the data/observations? • What data/observations will need to be gathered? • What calculation, comparison or trend recognition will be needed?

Table 1.2 Information held in external memory during backwards-design.

Table 1.1 shows a large amount of information needed in the students working memory in the early steps of a top-down design process, making the task very difficult in the beginning. Contrast this with backwards design, Table 1.2, which eliminates the need for non-subtask information in the students' working memory at every stage by placing prerequisite information in external memory.

The observations and comments of teachers and students using the SDL-SAT program during the 2007-2008 year helped refine the program and develop more

sophisticated capabilities (Figure 1.1). With a working, practical tool in place, this study quantitatively investigated the effects of the backwards-design process and the use of reflective prompts on student laboratory investigation reports.

Figure 1.1 Screenshot of SDL-SAT

Purpose of the Study

When working with a lab instruction sheet, a lab grading rubric and their own lab report paper, any or all of which may be double-sided, students experience the split attention effect. This occurs when students need to locate, use and integrate information from different locations (Clark, Nguyen & Sweller, 2006). The SDL-SAT decreases split-attention effects and supports the design process for students who are working with novel science content. The techniques of lowering split attention effects and scaffolding are well-documented as improving learning (Clark & Mayer, 2003; Clark, Nguyen &

Sweller, 2006; Quintana, Reiser, Davis, Krajcik, Fretz & Duncan, 2004; Quintana, Zhang, Krajcik, 2005).

The purpose of this study was to quantitatively determine how different methods of scaffolding the investigation design process and the use of reflective prompts affect student investigation report quality.

Research Questions

1. How does the backwards-design scaffolding affect the quality of the student investigation reports?
2. How do reflective prompts affect the quality of student investigation reports?

Research Hypotheses

1. The quality of student-designed investigation reports will improve when students are provided with a backwards-design computer scaffold for student-designed labs.
2. The quality of student-designed investigation reports will improve when students are provided with reflective prompts during student-designed labs.

Significance of the Study

Inquiry and the ability to design scientific investigations are included in all science standards—often as the first standard in the document. Yet almost half of the chemistry teachers are not using student-designed investigations. There are large gaps between what is in standards, what is done in the classroom, and what is assessed.

This computerized scaffolding and assessment tool for investigation design can provide teachers and students with the ability to have successful experiences with student-designed investigations. If this study provides evidence for effective components of the computerized scaffold, it can further be developed into a faded-scaffolding program that tracks student performance across years, allowing teachers, schools, districts and states to track a student's progress over time. This possibility has the potential to dramatically change the way science is assessed within a district and state. The current study is the first step in developing such an assessment tool.

Chapter 2: Literature Review

Introduction

The Student-Designed Laboratory Scaffolding and Assessment Tool (SDL-SAT) is a computerized scaffold. The software has been designed to minimize split-attention, encourage student use of the grading rubric while developing lab sections, guide students through the investigation design process in a backwards manner, and to encourage reflection throughout the process. This study was to determine the effects backwards-design scaffolding and reflective prompts have on the quality of student designed scientific investigations. The hypotheses are that both backwards-design and reflective prompts will increase the quality of student work.

Cognitive Load Theory

Bruning et al. describe cognitive processing in their textbook *Cognitive Psychology and Instruction* (2004). Incoming information is initially processed in sensory memory. Once the sensory system perceives the stimulus, it is processed within working memory. Working memory activates information stored in long-term memory that is associated with the current information processing task. Our ability to process information, therefore, is constrained by the capacity of working memory. However, as information is grouped together through "chunking," or processes become automatic through large amounts of practice, they require less working memory. This allows people to overcome the limited capacity of working memory for the pieces of information we can process at any given time.

There are three types of load placed on working memory: intrinsic, extraneous and germane (van Merriënboer, J., Kester, L., & Paas, F., 2006). Intrinsic load refers to task difficulty. Although intrinsic load cannot be changed without changing the task itself, the expertise and knowledge of the person undertaking the task and the person's ability to chunk the information will affect the intrinsic load placed on that person's working memory. For example, a stoichiometry calculation (i.e., a chemical bookkeeping calculation) presents a large intrinsic load to a beginning chemistry student. However, the same stoichiometry problem carries a much lower intrinsic load for a senior chemistry major with more chunked knowledge and, therefore, an increased capacity for solving the problem.

Extraneous load is not necessary for the task to be completed—the elements causing extraneous load can be removed and the task is still possible. It can be due to unclear directions, poor instructional design, distractions present during the task, personal emotions and thoughts, etc.

Germane load refers to the load placed on working memory to learn (create or alter schema), and to encode information in a meaningful manner.

The types of load are thought to be additive. If the intrinsic and extraneous load on an individual is greater than their working memory capacity, there is no room for germane load—no room for processing to work towards meaningful learning.

Consider the cognitive load placed on an experienced teacher versus a student when designing an investigation. A teacher experienced at designing laboratory investigations for her students has chunks of information concerning the science content, the process of investigation design, the availability of tools and equipment, common

laboratory techniques that are applicable, prior experiences with similar laboratory investigations, an awareness of what background knowledge her students will or will not have, where students are likely to misunderstand instructions or make a mistake, etc. Perhaps her process of designing an investigation for her students has become automatic through years of practice. These chunks of information and automaticity of processing allow the teacher to process information concerning the results section, what will be needed in the data table, and the steps needed to gather the data while she is creating the materials list near the beginning of the investigation.

Consider the same scientific investigation design from the point of view of a student. She would not have the automaticity of design process. She likely would not have information concerning the science concepts, lab techniques, or common requirements of an investigation. The design of the same scientific investigation would put a much greater demand on her working memory than her teacher's.

Complexity of Student-Designed Investigations

Kirschner, Sweller and Clark (2006) discuss the assertion that scientific investigation design presents high cognitive demand. They present a discussion of the prevalence of various incarnations of minimally guided instruction and the lack of evidence supporting such methodologies. Their arguments are based on cognitive load theory and include extensive literature reviews. They begin with a description of the common attributes of minimally guided instruction: (1) presenting students with authentic problems requiring the formation of understanding in information-rich environments, (2) a belief that knowledge is best acquired through experiences in the process of the

discipline and that instructional guidance disrupts the natural process of students drawing their own conclusions, and (3) *minimal* guidance may be given in the form of task-relevant information *if* a student chooses to use it. Proponents of minimally guided settings believe that guidance during practice may result in increased performance during the practice, but that it will harm performance later (transfer tasks). Kirschner et al. present a review of cognitive theory (including that problem solving places a large burden on working memory) as theoretical evidence for the lack of appropriateness of minimally guided instruction for novel content.

The following terms have all been used to describe minimally guided instruction: discovery learning, problem based learning, inquiry learning, experiential learning, and constructivist learning. There are various incarnations that include more scaffolding or guidance (guided inquiry learning, for example), but those more structured inquiry experiences are not the type being criticized by Kirschner et al. (2006). The literature showing greater learning gains through minimally guided instruction reveal case studies in which effective teachers seamlessly added support for students when they failed to make progress in the open (minimally guided) discovery setting. In effect, teachers were scaffolding for their students. The positive effects shown in those case studies cannot be accurately attributed to unguided discovery learning. Ironically, rather than supporting the minimally guided instruction that the case studies sought to support, the studies provided evidence of the need for scaffolding and guidance (which is not the *minimally guided* instruction as critiqued by Kirschner et al). Studies carefully controlling for impromptu teacher scaffolding consistently show that minimally guided instruction is not successful when learners are dealing with novel information. Kirschner et al. conclude

that students should be explicitly shown what to do, when to do it, and how to do it. One technique they suggest is the use of process worksheets. These worksheets provide students with a guiding list of questions or instructions to lead them through a complex task. Evidence demonstrates how students, with guidance through the process sheets, outperformed those left to discover the process on their own, again showing that scaffolded or guided inquiry is necessary for novices.

Scaffolding

Scaffolding is “the precise help that enables a learner to achieve a specific goal that would not be possible without some kind of support” (Sharpe, 2006, p. 212).

Although Wood, Bruner and Ross (1976) did not use the term *zone of proximal development* in their presentation of scaffolding, many authors have since made those connections (for example: Bruner, 1985; Holton & Clarke, 2006; McNiell, Lizotte & Krajcik, 2006; Sharpe, 2006; Shepard, 2005). Vygotsky described the zone of proximal development in 1930 as “the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem-solving under adult guidance or in collaboration with more capable peers. The zone represents the potential for a child’s development when aided by others” (Vygotsky, 1978, p. 86).

Scaffolding can be seen as the assistance that is needed for the learner to succeed in the zone of proximal development. For scaffolding to be effective, it must place the learner within their zone of proximal development. Too much support results in

the task becoming less challenging; not giving enough support results in anxiety and frustration for the learner (McNeill et al., 2006).

The categories, features, characteristics and current meaning of scaffolding are described in various works. Four schema of scaffolding have been presented: conceptual, metacognitive, procedural, and strategic (Azevedo, Cromley & Seibert, 2004; Cagiltay, 2006). Holton and Clarke (2006) discuss scaffolding in terms of conceptual or heuristic (encompassing the metacognitive, procedural, and strategic categories of Azevedo et al., and Cagiltay) and indicate that a learner can be scaffolded by an expert, by peers as a reciprocal process, or within oneself (which they define as self-regulation).

The features and characteristics of scaffolding vary slightly depending on who is the author of a paper. Puntambekar and Kolodner (2005) described the central features of scaffolding as common goals, ongoing diagnosis, dynamic and adaptive support, dialogues and interactions, and fading for transfer of responsibility. Scaffolding can also be characterized as helping the learner with the more difficult or extraneous portion of the task allowing the learner to complete the primary learning objectives, the *real task*, of the activity (Shepard, 2005). Shepard links scaffolding with formative assessment through the shared characteristics: eliciting prior knowledge, providing feedback, teaching for transfer, and teaching students to self-assess.

Puntambekar and Hubscher (2005) present an examination of how the construct of scaffolding has changed over time. Scaffolding has shifted from the human interactions between adult and child that is hallmarked by continual, dynamic assessment and support, with fading (or the slow removing of) support as chunking takes place, to a more modern use in the literature that encompasses all forms of support, including non-

human supports such as written guides or computer software. However, not all supports provided to students are scaffolding. Some supports are used by both novices and experts (McNeill et al., 2006). For example, both experts and novices might use a calculator with scientific notation to support complex calculations. The novice may need extra support to use the scientific notation function on their calculator, however. The support of the calculator is not scaffolding; any instruction related to using the scientific notation functions of the calculator may be scaffolding.

In 1991, Norman described cognitive artifacts, or artificial devices that change the task in a way that allows the system (human, task, and artifact) to achieve more than the human and the task alone. This can be done by distributing actions across time (precomputation) or people (distributed cognition), or changing actions required to complete the task. He discusses how, with practice and mental effort, people can make a leap from acting on the artifact as a means of acting on the object to viewing their work as acting on the object itself. To use the example of calculator use by expert and novice, the calculator is a cognitive artifact. The expert views his actions with the calculator as acting on the object itself (in this case the virtual object of performing mathematic operations to reach a solution), rather than acting on the calculator.

Specific Techniques for Scaffolding

Various studies have investigated different specific techniques or tools for the purposes of scaffolding or supporting students both for conceptual as well as heuristic gains. Sharpe (2006) suggests that one way to scaffold students is to reduce the degrees of freedom of carrying out a task. This enables students to concentrate on acquiring

knowledge and reduces the cognitive load of following unproductive paths without a plan or purpose. Quintana et al. (2005) give more details to this end in their proposal of a framework for scaffolding tools. The suggestions include:

- Providing a work space for what's required
- Providing progress displays (on computerized scaffolding)
- Displaying information important to a process each time that specific information is important to a specific task
- Displaying the “big picture focal point” (such as the research question) on each screen, page or work space.

In an attempt to scaffold students throughout the very complex process of designing a solution while learning science content and processes, Puntambekar and Kolodner (2005) implemented a “Design Diary” within a unit of the Learning By Design curriculum. Through their two studies, which were separated by modifications in the supports after analyzing results of the initial study, they determined that different types of supports are needed for different processes (such as carrying out tasks of the project versus reflection) and they saw the need for students to be interrupted “when in the flow of work” in order to be prompted to reflect. Norman (1991) also discusses the need to interrupt automatic behavior to call conscious attention to some aspect of the task. He gives an example of a pilot's checklist and procedures breaking the flow of automated task performance to ensure safety procedures are followed. If students need to be prompted to reflect, what is the most effective way to promote the reflection?

In 2003, Davis published a study of prompting middle school science students for reflection throughout inquiry activities. Davis' paper discussed the importance of using

metacognitive prompts to promote student reflection, and the different timings for prompts depending on their purpose (prior to the activity for planning, within the activity and at the end of the activity for reflection). Specific and contextualized prompts are often used to promote specific reflection or knowledge acquisition, however they can confuse students (especially if the specific prompts are not appropriate for the student's zone of proximal development). The problem with these specific prompts is that human scaffolding is not "one size fits all" as is attempted by these singular prompts within the instructional materials. Davis studied reflective prompts in a generic format (such as "Stop and think" or sentence prompts like "Right now we're thinking...") and directed prompts ("Claims we didn't understand include..." etc.). Unlike the directed prompts which only made sense within their current placement and were not interchangeable with other prompts throughout the activity, the generic prompts were indistinguishable from one another as they were not contextualized for a specific placement within the task or process. The two types of prompts gave significantly different results.

Davis (2003) found students with generic prompts cited more ideas for a claim, used multiple pieces of evidence more frequently, were consistently more likely to show greater coherence, gave "no problem" responses less frequently, and the quality of their responses were less dependent on the placement of the prompt. Students experiencing directed prompts frequently answered "no problem." For example, answering "we understood all the claims" when given a sentence prompt of "Claims we didn't understand include..." The frequency of "no problem" responses was negatively correlated with overall project score and accounted for 23% of variance in students' scores. Data were disaggregated between students classified as poor reflectors and better

reflectors. Poor reflectors with directed reflection prompts scored significantly lower than both poor reflectors with generic prompts and better reflectors with directed prompts. Within the group of better reflectors, there was little difference between the directed or generic prompts. Davis's analysis showed generic prompts may especially help students with mid-levels of autonomy by increasing their level of coherence (by 0.6 standard deviations as compared to 0.31 sigma for high-autonomy students and 0.03 sigma for low-autonomy students). Why would such open-ended prompts result in more meaningful reflection when explicit scaffolding is being recommended for complex tasks?

Davis (2003) gave two possible explanations for generic prompts being a greater contributor to student performance than directed prompts. First, when students cannot interpret directed prompts, likely because they are not in the student's zone of proximal development, they may flounder or ignore the prompt. "No problem" responses may be indicative of this problem. In addition, wording the prompts in a negative fashion ("Claims we didn't understand include...") may have had an effect on students. Positively worded planning stage prompts, however, did not change findings. She suggested directed prompts may be better in a one-on-one situation, as the prompt can be tailored to the student. The students themselves determined the scaffolding provided to them, based on what they could or could not handle within their zone of proximal development. She also suggested a follow-up system for "no problem" responses to try to elicit an actual response from students if they indicated having no problems or questions.

Cooper (1998) discusses the cognitive load demands of means-end and goal free problem-solving: "If problems are 'goal free,' then a problem solver has little option but

to focus on the information provided (the given data) and to use it wherever possible. This automatically induces a forward working solution path similar to that generated by expert problem solvers. Such forward working solutions impose very low levels of cognitive load and facilitate learning.” Although his discussion concerned problems, it is reasonable to apply the same reasoning to reflections—that giving goal-free requests for reflections would reduce cognitive load compared to specific reflection prompts.

Reflection is one component of self-regulated learning. In 2007, Manlove, Lazonder and deJong studied the effect of scaffolding on reflection as well as other self-regulation indicators during scientific inquiry. High school students often fail to recognize when they do not know something. Software can help scaffold self-regulation of students by incorporating pop-up cues encouraging them to reflect and take notes, self-explanation prompts, or reason-justification prompts. The Manlove et al. study used an inquiry task where students were to discover which factors affected the time to empty a water tank. Students worked through a computer simulation and could test understandings by creating models that can be run by a computer. The students were scaffolded with Process Coordinator software. The PC+ group received a process model, goal hierarchy, hints, cues, and prompts as well as a separate computer template for their final report containing structure and suggestions for content. The hints were available through passive scaffolding. Cues and prompts were user-controlled; students were not required to take notes or respond to prompts when they appeared. The cues appeared when students had not taken notes for ten minutes or switched activities. The PC- group had options to set their own goals and take notes. The PC- group had no template for their final report.

Manlove et al. (2007) found students in the PC+ group gave better-structured reports and accounts of their activities. Students in the PC- group who were classified as low-achieving in the course gave better mental models than those low-achieving students in the PC+ group. The authors proposed that the low-achieving PC+ students may have used too much time interacting with supports and did not have adequate time for mental model formation. As an alternative explanation, the PC- groups used the help-files (which had information designed to aid in mental model formation) because they lacked the other supports available to the PC+ group. Manlove et al. proposed that students need to be guided as to which supports they should use for which components of the task. The findings suggest that scaffolding should include information about when to use which scaffolds.

Winne (1995) presents a discussion supporting Manlove et al.'s (2007) explanation that lower level students were overloaded with the cognitive demands of the task, and the use of supports, to form models. He discusses the demand on working memory of self-regulation, and suggests that the use of working memory for monitoring or reflection is not always a wise use of mental resources. This problem can be amplified in low achieving students as they make errors more frequently, as well as having non-automated, often ineffective, self-monitoring strategies. Winne suggests that self-monitoring should be encouraged after students have begun to acquire underlying declarative knowledge and begin making rules automatic.

Scaffolding with Humans versus Computers

Human tutor scaffolding may be more valuable than computerized or written scaffolding because of a human tutor's ability to pick up on subtle cues from the student (Holton & Clarke, 2006). However, several authors acknowledge that one-to-one scaffolding cannot readily occur in a classroom with many students and one instructor (for example, see Cagiltay, 2006; Davis, 2003; McNeill et al., 2006; Puntambekar & Kolodner, 2005). Even group activities with teachers attempting to respond to what might be described as a group's zone of proximal development can cause a teacher to juggle too many different zones. Peer scaffolding can be effective—but only if one of the peers has the necessary knowledge, skills, and ability to articulate them to their peers in an effective manner. Therefore, the construct of scaffolding has shifted from being a human-to-human experience as first introduced by Wood et al. (1976) and Vygotsky (1978) to utilizing artifacts, instructional materials, tools, or computer technologies. Adaptive support gives better results but is difficult to attain. Therefore many computer systems implement user-faded supports, such as a “Stop reminding me” function, or passive supports that can be chosen by the user (Cagiltay, 2006). These supports are not as effective as one-on-one dynamic adjustment of scaffolding by a human tutor.

Designing Effective Computerized Scaffolding

In 2004, Quintana et al. hoped to de-emphasize the idea of using supports within a program as scaffolding, but rather envisioning the software itself as being the scaffolding. The authors present obstacles for learners within the process management domain as: being overwhelmed by the complexity of available options, a lack of strategic knowledge,

and being distracted by less important managerial “chores.” Their suggestions for overcoming these obstacles with scaffolding software include: providing students with “what next” for complex tasks, embedding expert guidance in scientific process (“why do it”), and automaticity handling non-salient tasks.

Cagiltay (2006) presented many challenges in creating an effective computerized scaffolding program. A computerized performance system must support performance and learning simultaneously and must also support both well-defined tasks and loosely defined, complex activities. Computerized scaffolds should be designed to include fading, which often occurs as passive or user-controlled supports due to programming complexities. Supports must be flexible enough to allow the user to utilize it when necessary (such as the ability to re-implement a scaffold after using a “Stop reminding me” function). Software user interfaces ought to adhere to research results describing cognitive load demand and efficient ways of presenting information to learners (Clark & Mayer, 2003).

Puntambekar and Hubscher (2005) discuss the design of user-controlled and passive forms of scaffolding. They present these options as less than optimal forms of dynamic scaffolding as they depend on the student’s ability to determine when and if they need help (although some evidence has shown that high school students do use the “stop reminding me” function as expertise is gained in a task). They suggest a combination of such fading with a function that returns the supports if students fail to successfully complete a portion of the task, or “backslide” in their quality of work.

Aleven, Stahl, Schworm, Fisher and Wallace (2003) summarized their meta-analysis of help system and help-seeking literature. They found that a large number of the

studies showed students either ignored help systems or used them ineffectively, but that if they were used correctly learning can increase. They found a number of instances where the design of the help system, such as abstractness, and learner-related factors, such as prior knowledge or cognitive development, interacted. Therefore, effective help systems are often not simply a “one size fits all” solution. They also found that learners with lower prior knowledge sought help less often. Students with lower self-regulatory skill levels had lower levels of help-seeking. The students that need help most do not have the self-regulatory skills to know that they need help. This is yet another example of the challenge to create computerized scaffolding that is as sensitive to student needs as human scaffolding (Holton & Clarke, 2006).

The Quintana et al. (2005) analysis of many computer scaffolding tools led them to propose a framework for creating such tools. Their guidelines for software scaffolding of online inquiry include:

- Provide explicit description of the task structure
- Make the task structure visible
- Incorporate planning tools
- Make the process, working history and information common to multiple activities explicit
- Provide reflection opportunities through prompts.

Making working history explicit and providing reflection prompts could help with the problem of “gaming the system” that Joolingen, Jong and Dimitrakopoulou described in 2007, where students complete tasks in the software while thinking of each one at a time.

Students often complete the tasks just to be completing them, without connecting why they are completing that task with the overall problem-solving process.

Summary

The human mind can process a limited amount of information at a given time. When the learner is a novice in either the science content involved or the processes of investigation design, the intrinsic load of the task of designing their own scientific investigation can easily overload his or her working memory. Overwhelming intrinsic load leads to decreased available working memory, if any at all, for thoughtful processing (germane load). Students may struggle through the task, but the likelihood of them learning anything is low. The educational trend pendulum has swung in many instances to open inquiry and authentic problem settings in which students are overwhelmed and do not possess the requisite background knowledge and level of chunking to solve the problem and learn the intended content as well. This study tests a strategy that moves away from open-inquiry toward finding an effective way to scaffold the scientific investigation design process for novice learners. The SDL-SAT lowers intrinsic load by dividing the design process into sub-tasks.

Extraneous cognitive load also competes for working memory slots, pushing out germane load. The SDL-SAT attempts to lower extraneous load by showing only the relevant investigation report sections, instructions, and grading rubric at any given time. The software addresses the split-attention effect by not requiring scrolling for a student to compare their work with the instructions or grading rubric.

The SDL-SAT incorporates findings from literature on providing computerized scaffolding for inquiry. The SDL-SAT program incorporates Quintana et al.'s (2004, 2005) suggestions for scaffolding in general by:

- providing a work space for what is required
- displaying only information relevant to the task at hand, but displaying information each time it is relevant
- displaying the “big picture focal point” (the question, problem, or purpose) on each screen
- making the task structure visible
- making the process and working history explicit
- providing reflection opportunities through prompts
- making non-salient tasks automatic.

It is expected that the SDL-SAT program will lead to increased quality of student performance similar to those reported by Manlove et al. (2007). However the program attempts to avoid the findings of Manlove et al. that students did not know when to use which scaffold. The SDL-SAT, in contrast to the software used by Manlove et al., contains one program rather than multiple components and contains all scaffolds within the program itself rather than having separate help files.

If findings of this study indicate the SDL-SAT is successful at increasing student performance, future studies can begin to investigate how that scaffolding can be faded. How do teachers and computerized scaffolding start from this base scaffold where students are successful and back off the scaffolding, raising the load, to an appropriately challenging level for individual students? This series of study could lead to the

development of an individually faded scaffolding program that tracks a student's progress across their educational experience.

Chapter 3: Methods and Procedures

Population and Sample

The study took place in a public suburban/rural high school in the Midwest. The school's enrollment is 1112 freshman through seniors. Eighth grade science teachers place their students into appropriate freshman year high school science courses. The top students are placed in biology from which many proceed to chemistry their sophomore year. The mid-level students are placed in empirical science, a pre-chemistry course that uses lab experiences and data analysis to develop concepts. The empirical science students generally take biology as sophomores and chemistry as juniors or seniors. The low-average to low-level students are placed in a semester of physical science and a semester of earth/space science. They typically take chemistry their junior or senior year.

Participants were 102 students in high school general chemistry courses. Table 3-1 displays student demographics.

Gender	Year in school	Freshman year course
Male – 48	Sophomores – 7	Physical science / Earth science – 58
Female – 54	Juniors – 82	Biology – 13
	Seniors – 13	Empirical Science - 30

Table 3.1 Participant demographics, number of students.

Treatments

The research questions for this study sought to determine the impact of (1) backwards-design scaffolding and (2) reflective prompts on the quality of student-designed laboratory reports. A 2x2 design was used to determine main effects of each independent variable as well as any interaction effects. The treatment design is shown in Table 3.2.

Backwards-designed process	Student-determined design process
Reflective prompts	Reflective prompts
Backwards-designed process	Student-determined design process
No Reflective prompts	No Reflective prompts

Table 3.2 Treatment design.

Of the 138 general chemistry students in the school, 118 returned signed consent and assent forms. All 118 students were randomly assigned a username and password as well as a random assignment of software version. The information was stored in an *Excel* file along with student names and class period for the purposes of providing students login information. The *Excel* file was deleted once students no longer needed to login on the software, making connection between an individual data set and the individual's identity impossible. The username, password and software version were stored in the *MySQL* database.

Only 103 of the 118 students were present the first day of the investigation. The treatment groups included 22, 29, 28 and 23 students in the four software versions.

Classrooms remained intact, and students accessed the software through individual desktops in one of the school's computer labs.

The participant task was to design an investigation to determine which of two brands of paper towel absorbed the most water per dollar cost. Each student was presented with the same investigation instructions (Appendix A) and grading rubric (Appendix B) through the computer software.

Help from the teacher was limited to help navigating the software (for example: which button to click next, how to save their information, etc.). Although teacher support would likely be present in most classrooms, the limiting of support to software-specific questions provided a picture for how effective the computerized scaffolding tool is with the minimum of support and reduced the chances of variance in student scores based on their willingness to ask for help or the quality of help given to various students. Despite the usual setting of working in partners or small groups on laboratories, students worked individually on this task to minimize uncontrollable variables involved with partners or small groups,

Variables, Measures, and Instruments

An investigation report rubric was developed by examining the author's current rubric for scientific investigations, the National Science Education Standards, (NRC, 1996), Benchmarks for Science Literacy (AAAS Project 2061, 1993) and the Atlas of Science Literacy (AAAS Project 2061, 2001) for appropriate performance levels on investigation design for high school students. The rubric has been validated and modified by colleagues and field test teachers during the previous five years. Rubric scoring

reliability was determined with a random sample of 20% of the reports being graded by another chemistry teacher in the school. Student performance was determined by scoring the students' investigation reports with the rubric (Appendix B). Students were shown the rubric throughout the task within the software (Appendix C).

Content Validity

The paper towel lab appears in the *Kendall/Hunt Chemistry: Discovering Chemistry You Need to Know* high school textbook (Deters, 2008). It has been field and pilot tested by at least 25 teachers as well as being used in the author's classroom for the past five years. Modifications have been made to increase clarity of directions and instructions over the years as a result of feedback from these field and pilot tests. Each year the task presents a challenge to students despite their prior experiences with paper towels absorbing water in everyday life. The task of designing the investigation, even with low science content, is sufficiently challenging to produce cognitive overload without scaffolding in general chemistry students.

Data Analysis

Each lab report was assessed according to the rubric (Appendix B). The report categories had different possible scores, relative to the complexity of the report section. Table 3.3 summarizes the report section maximum scores.

Section	Maximum Score
Title	3
Purpose	3
Background	9
Materials	3
Procedure	9
Safety	2
Data/Observations	8
Results/Calculations	7
Conclusion	8
Overall	52

Table 3.3 Maximum scores for investigation report sections.

The two research questions were addressed as follows:

1. How does backwards design affect the quality of student investigation reports?
ANOVA calculations were performed to determine main effect of experimental design order on student performance scores.
2. How do reflective prompts affect the quality of student investigation reports? The ANOVA calculations also included main effect of reflective prompts on student performance scores.

The ANOVA calculations were also used to determine any interaction effects between design order and the presence of reflective prompts.

Prior Development of the SDL-SAT

The original tool utilized a web-based interface created with *php* (a programming language for the dynamic web pages, www.php.net). The web pages accessed a *MySQL* database (an open-source relational database, www.mysql.com) storing instructions from the teacher as well as the student lab reports. Within months, a new user interface was programmed using *Runtime Revolution* (a programming tool for creating interactive interfaces, www.runrev.com) to support more sophisticated functionality. The revised interface also connected to the *MySQL* database but allowed greater programming flexibility.

This tool was presented to science educators by Deters at the *ChemEd 2007* conference (August 2007 at the University of North Texas), the Kansas Association of Chemistry Teacher's annual conference (October 2007), a workshop on Making Labs Meaningful at the *Jones Institute for Excellence in Education (JIEE)* at Emporia State University (October 2007), the regional conference of the National Science Teacher's Association (Denver, November 2007), and several workshops on preparing for the science state assessment at JIEE (November 2007 – February 2008).

Throughout the 2007-2008 school year, teachers field-tested the program, offering suggestions and commenting both on functionalities currently within the program as well as others that might be made available. Changes were also made as a result of experiences Deters had using the tool within her own high school chemistry courses. Some components were successful; students struggled or made similar errors with others. Changes included allowing text formatting, adding spell-check, simplifying the layout,

and changing the programming to allow schools with blocked internet ports to access to the online database.

SDL-SAT User Interface

The student interface (Appendix C) allows each student to log into his or her class. Once logged in, they choose which lab they are working on and where in the process they are (the beginning, entering data, or viewing their final report). Students enter text into lab section boxes on the left of the screen while specific instructions and grading rubric information are displayed on the right of the screen. Each screen shows only the information necessary for that step of the lab design and does not require scrolling to see related information (Clark and Mayer, 2003).

Teachers create and edit lab assignments with specific instructions and tailor a grading rubric. Teachers view student reports within the software and enter scores and comments while viewing student work and the rubric side-by-side.

During the initial development school year, eight teachers (one elementary, one middle school, and six high school teachers) actively used the program for a total of over 750 student investigation reports created for 24 different student-designed investigations. Teachers utilizing the tool reported students preferred to use the computerized tool over designing labs on paper, displayed increased follow-through in report requirements, and produced higher quality work.

SDL-SAT Scripting

The *MySQL* database contains four tables:

1. Teachers: Contains teacher name, school name and teacher password.
2. Students: Contains student name, teacher name, student password and the hour that the student is in the teacher's class.
3. Labs: Contains the teacher name, task ID, and all instructions and rubric information from the teacher to the student.
4. StudentLabs: Contains the student name, task ID and the student laboratory report and any comments the teacher makes on that report through the teacher interface.

See Appendix D for examples of scripting from the SDL-SAT.

Students and teachers log into the system by selecting their information from lists to prevent errors when typing in username information. The lists are populated using a *Runtime Revolution (RunRev)* script that posts the previously selected information to a *php* script hosted on a server. The *php* scripts were necessary rather than simply using the *MySQL* functions built into *RunRev* in order to allow schools to access the *MySQL* database even if the *MySQL* port is blocked. A script was required in *RunRev* to accommodate schools that require proxy authentication each time a program accesses the internet. The *php* scripts returns information which is then parsed, formatted and displayed in the user interface.

Once logged in, the student selects a task from a list populated in a similar manner as the login information. After the task is selected, a *RunRev* scripts posts the student name, teacher name and task ID to a *php* script to query both the information in the "labs" table for that teacher name and task ID and the information in the "studentlabs"

table for that student name and task ID. The information is stored in invisible fields on a card in the *RunRev* stack that is not seen by the user.

Each time a student opens a “step” the information from the unseen fields that stored the teacher instructions and student report is placed into the appropriate fields on the screen for student use. Buttons at the top right corner of the screen allow students to move to the next step, previous step, save their information, go to the main menu or logout. Pressing any of the buttons updates the information in the unseen storage fields to reflect recent changes. The save, main menu and logout buttons also post the information from the unseen storage fields to a *php* script to update the *MySQL* database for that lab report record.

The teacher interface required similar scripting to the student interface. Teachers can input information such as a new task ID or a new student user that is posted to a *PHP* script to create new records in the database. Scripting was also necessary to display and edit information in the “labs” table as well as viewing the student lab report and adding comments that are stored in the “studentlab” table.

Other scripting includes *RunRev* scripting for a spell-check button, text formatting buttons as well as a *php* script to display the final lab report for printing.

SDL-SAT Computer Program Used in This Study

The login process was simplified from that described above. Students entered their assigned username and password and were sent to the lab task in the version they had been assigned. There was no need for the step of choosing a task in this study.

Screen images of the SDL-SAT program are in Appendix C. There were four versions of the software:

1. Backwards-design process with reflective prompts (BDP-R)

The backwards-design process progressed in the following order: title, purpose, background information, results section set-up, data table design, procedure development, materials and then safety. The SDL-SAT program was as described in the above section on the development of the software, with the addition of the reflective prompt feature.

The students were asked to reflect on their progress at various points throughout the process. Students were prompted with a text entry box on the right side of the screen below the instructions to reflect on the progress they made towards their lab goal up to that point. Responses were recorded in the database.

2. Backwards-design process without reflective prompts (BDP)

This version was the same as the BDP-R except there were no reflective prompts.

3. Student-determined process with reflective prompts (SDP-R)

This version more closely matched the experience of designing a lab with paper and pencil or a simple word processor. The program allowed students to progress in any order they wished. The left side of the screen contained the textboxes for students to develop their investigation while the right side presented the specific information and rubric information for each section, just as with the backwards-design process versions.

However, in this student-determined process version, all the textboxes were available on one screen (causing scrolling to be necessary to move between all the lab report sections) and students were able to work on them in any order.

When students were done with the development phase and pressed the button indicating they were ready to gather data, they were prompted to reflect on their work.

4. Student-determined process without reflective prompts (SDP)

This version was the same as the SDP-R version except that it did not utilize any reflective prompts.

Institutional Review Board Procedures

The author had approval from the Institutional Review Board at the University of Nebraska-Lincoln (IRB 2008058948 EX). Students were given a letter to take home to their parents on the first day of school, 15 days before the study was to begin (Appendix E). The letter explained the project, indicated that there were no known risks with the research task, and provided contact information for further questions.

All chemistry students participated in the student-designed investigation task as it is a course activity. Grades were determined by student effort rather than report quality, to prevent student grades being affected by the treatment group to which they were randomly assigned. Students not returning a signed consent form were required to design the investigation on paper without any computer software. These students were given the instructions and rubric on paper. The practice of all students completing the task and receiving a grade was designed to prevent students from failing to return a signed consent form in order to have free-time during the task, and to encourage students to put forth effort (a non-graded assignment is rarely taken seriously).

Procedural Steps

The author, one of the chemistry teachers in the school, met with the other chemistry teacher prior to the start of the school year to discuss the study. The chemistry teachers follow the same curriculum, minimizing the effects of curricular differences on the results of this study.

Prior to the task, students were randomly assigned usernames and each was assigned a random number from one through four. The number assigned to the student indicating the version of the computer software he/she received in the *MySQL* database. The usual log-in system of the SDL-SAT was modified to direct the student to the appropriate version of the software at the time of log-in.

Students were presented with the overall task goal of finding the most absorbent paper towel per dollar between two brands. The students were given two block periods (a total of 200 minutes) to complete the task. The classes stayed in the computer lab until all students were ready to gather their data (less than 100 minutes). The remainder of the time was spent performing the lab to gather data and enter data, results, and conclusions into the computer software in the regular classroom. Students finished gathering data at different times, and were able to rotate through the six classroom computers one at a time rather than all going to the computer lab at the same time.

The specific instructions for each component of the investigation report (Appendix A) and the grading rubric for each section (Appendix B) were provided within the SDL-SAT program (Appendix C).

The author scored each investigation report through the teacher interface in SDL-SAT. This interface displays the students' work on the left, the rubric on the right and an

area to record the score for that section (Appendix C). The second chemistry teacher independently scored a random sample of 20% of reports.

Chapter 4: Results

Student Scores

Only 83 of the 102 students completed the entire assignment within the 200 minute time-frame. Others were called out of class during the second session for various reasons such as meetings with administrators, medical appointments, or extra-curricular activities. The 19 students that did not complete the task within the 200 minute time period did finish the activity, but some did not finish until a week after this study period.

This prompted the analysis of the correlation between planning scores and total scores. Planning scores are the scores awarded from the rubric for title, purpose, all background information, materials, safety and all procedure categories. These sections were completed by all 102 students within the first class period. The rubric allows for a total of 30 points for these laboratory report sections. The total grade takes into account the entire report and involves a maximum of 52 points.

For the 83 students that did complete the entire activity within the 200 minutes, their planning grade (score for the components completed before performing the experiment) was compared to their total grade (score for all components) with a Pearson correlation of $r = 0.872$ ($p = 0.00$). The overall scores for the 83 students that completed the task within the 200 minutes were highly correlated with their plan score. In other words, if students were going to have a high total grade, they also had a high plan grade. This prompted the use of all 102 students' plan grade rather than the use of only the 83 students' total grade, allowing for a greater sample size.

Scoring Validation

A random sample of 20 reports was chosen from the pool of 102. The second chemistry teacher was provided the scoring rubric and asked to score each of the 20 reports. The Pearson correlation between the planning scores awarded by the two chemistry teacher on the 20 labs was $r = 0.872$ ($p = 0.000$). This strong correlation between raters for the sample of 20 labs suggests consistency in the use of the scoring rubric.

Another random sample of 20 reports was chosen. These reports were rescored by the author approximately three months after the initial scoring. The first and second scorings of the 20 reports were strongly correlated with $r = 0.900$ ($p = 0.000$).

Summary of Data

Bartlett's test of variance was performed to ensure equal variances. The variances for student planning score resulted in a non-significant finding, $p = 0.997$. Therefore, the variances were equal for all treatment groups.

Table 4.1 displays mean and standard deviation for planning score for each version of the scaffolding software.

Student Planning Scores

	No Reflective Prompts	Reflective Prompts
Backwards Design Scaffolding	M = 22.45 s = 4.056 n = 22	M = 20.48 s = 4.128 n = 29
Student-Determined Design Order	M = 19.09 s = 4.133 n = 23	M = 20.50 s = 4.350 n = 28

Table 4.1 Summary of student planning scores. Maximum score possible: 30 points.

When analyzing student planning scores with ANOVA, a significant interaction effect was found, $F(1,98) = 4.127$, $p = 0.045$. Simple main effects were analyzed following the interaction effect.

When comparing the two versions without reflective prompts, scores increased from 19.09 (the lowest of the four versions) with student-determined design order to 22.45 (the highest mean score) when students were provided with backwards-design scaffolding. This finding is significant, $F(1,43) = 7.26$, $p = 0.010$, with a Cohen's d effect size of 0.82, a large effect (Cohen, 1977). For the two program versions without reflective prompts, backwards scaffolding resulted in significantly higher levels of student performance. This was the only significant finding between the four versions of the program.

This finding is in stark contrast to students prompted to reflect, where there was virtually no difference in student scores for backwards and student-determined design order (20.48 and 20.50), an effect size of 0.0045, no effect. When students were prompted to reflect, the presence of scaffolding had no effect on student performance.

Chapter 5: Discussion

Backwards-Design Scaffolding

The design of an experiment certainly presents a high cognitive load for students as discussed by Kirschner et al. (2006). As seen in this example, even when given an experimental design task with very low science content (simply absorbing water with a paper towel), students averaged 68.7% on the task without peer or teacher help.

The backwards-design versions of the software provided similar scaffolding to that described by Kirschner et al. as “process worksheets.” Process worksheets are a guided list of question or instructions to guide a student through a complex task. That scaffolding technique has been found to help students outperform those without the worksheets. The scaffolding in this study acted similar to a process worksheet, guiding students through the process rather than leaving students to determine in which order to proceed. This study, as those summarized by Kirschner et al., provided evidence for the positive effect of this type of scaffolding as scaffolded students without reflective prompts outperformed those without the scaffolding by a large effect size of 0.82.

Reflective Prompts

Another form of scaffolding involves scaffolding of self-regulation techniques for students. Reflection is one component of self-regulation. Puntambekar and Koladner (2005) and Norman (1991) discussed the need to break the automaticity of work to prompt for reflection. Davis (2003) found generic prompts were more effective for poor

reflectors than directed prompts. There was no difference found in the Davis study for students classified as good reflectors.

This study employed generic reflective prompts in two of the four versions in an attempt to provide scaffolding for students for regulatory tasks. The presence of these reflective prompts provided seemingly inconsistent effects. A dramatic effect was seen between backwards-scaffolding and no design process scaffolding when reflective prompts were not used ($p = 0.01$, $d = 0.82$). However, when reflective prompts were employed, the positive effect of the scaffolding vanished ($p = 0.988$, $d = 0.0045$).

One factor that may have played a role in this is that the students provided with design scaffolding were asked to reflect three times: after they designed the results section, then again after the data table, and finally after the procedure. The students without backwards-scaffolding were prompted to reflect one time as they only used one screen to design all investigation components. It is a possibility that being prompted to reflect several times had a different effect than being prompted to reflect only one time. Manlove et al. (2006) suggested that too much time interacting with supports, such as reflective prompts, does not allow students adequate time for mental model formation. Winne (1995) also presented similar arguments concerning the use of working memory for regulatory processes such as monitoring or reflection. Both Manlove et al. and Winne suggested this effect may be more of a concern in low-level students. Perhaps the demand for three reflections interfered with the design process for lower-level students in this study as well.

To investigate the claim that multiple reflective prompts hindered lower-level students, the performance scores must be grouped by student level. The only measure of

overall student achievement in this study was the course taken during the freshman year. Students taking either biology or empirical science as a freshman were considered advanced students by their eighth grade teacher. See Table 5.1 for scores for advanced students.

Plan Scores for Advanced Students

	No Reflective Prompts	Reflective Prompts
Backwards Design Scaffolding	M = 24.18 s = 2.04 n = 11	M = 23.71 s = 3.039 n = 7
Student-Determined Design Order	M = 19.23 s = 4.456 n = 13	M = 20.92 s = 4.582 n = 12

Table 5.1 Summary of student planning scores for advanced students only. Maximum score possible: 30 points.

When analyzing the planning scores of only the advanced students, the interaction effect between reflective prompts and design order scaffolding disappears, $F(1,39) = 0.811$, $p = 0.373$. At the same time, a main effect for design order scaffolding is present, $F(1,39) = 10.494$, $p = 0.002$. This is a very large effect ($d = 1.5$). The effect of scaffolding

does not depend on the presence of reflective prompts for advanced students. Backwards scaffolding has a significant positive effect for all advanced students.

No effect was found for reflective prompts in the upper-level students, $F(1,39) = 0.259$, $p = 0.613$.

This analysis of higher-achieving students, when compared to the analysis of all students, as summarized in Table 5.2, shows a disappearance of the interaction effect and the strengthening of the design scaffolding main effect. These findings support the suggestion that prompting lower-level students to reflect multiple times may interfere with other task processes.

	Interaction Effect	Backwards Scaffolding	Reflective Prompts
All students	Significant effect.	Significant effect, positive large effect size ($p = 0.010$, $d = 0.82$) for no-reflective prompts only.	No significant effect.
Advanced students	No significant effect.	Significant positive large effect ($p = 0.002$, $d = 1.5$).	No effect.

Table 5.2 Comparison of effects for all students and advanced students.

When comparing the findings for all students to the findings for advanced students, this study presents similar results to those of Manlove et al. (2006) and Davis (2003). Manlove et al. found that lower-level students performed better without supports than lower-level students having access to the help systems. Davis found that poor reflectors' performances were affected by the type of reflective prompts while students classified as good reflectors exhibited no such effect. In this study, the effect of the backwards scaffolding was dependent on the presence of reflective prompts. However, this only held true when analyzing all student scores. When advanced student scores were analyzed, the presence of reflective prompts had no effect as the backwards scaffolding significantly increased student performance with and without the reflective prompts.

In the Manlove et al. (2006) study, students either did or did not have access to the help systems. In the Davis (2003) study, students either had generic or directed reflective prompts. In this study, students either had one reflective prompt (in the student determined design order version) or three reflective prompts (with the backwards scaffolding version). Each of these studies showed the type, presence and frequency of reflective prompts affected on lower-level students but not for more advanced students. Winne (1995) suggested these forms of self-regulatory scaffolding be reserved for students that have begun to create schema and understand underlying rules as they require working memory resources which would then not be available for the main task.

In their meta-analysis of help system and help-seeking literature, Aleven et al. (2003) discussed the need for the help system to match the learner-related factors. It is clear from the findings in this study that the reflective prompt support was not a "one size

fits all” support and needs further study to determine when and how to implement such self-regulatory support for different levels of students

.

Chapter 6: Summary and Conclusions

This study sought to determine the effects of backwards-design scaffolding and reflective prompts during a student designed scientific investigation on student lab report scores. A 2x2 experimental design was used with the two independent variables (backwards-design scaffolding and the presence of reflective prompts). Students were randomly assigned to a program version and asked to design an investigation to compare brands of paper towels to determine the best value.

Limitations of the Study

There were several factors potentially limiting the ability of this study to find meaningful effects. First, students knew they would not be graded on the quality of their lab report, but only on their participation during class time. This was done to ensure that no course grades suffered simply by being assigned one version or another. However, this can have the effect of lowering student effort. Several times throughout the study, students clarified that they indeed were not being graded on the lab report itself. This study would be strengthened by ensuring that all students took their lab report quality seriously while not penalizing course grade for random assignment to version.

Although the individual seating in the computer lab provided a good environment for monitoring that students worked individually, it was difficult to maintain the individual nature of the task when students entered the regular classroom to carry out their procedures. Students executed their procedures with three or four people at each lab

table and observed others as well as discussed the task, despite frequent reminders that this was an individual task.

During the previous school year, the average score on this task was 84.55% with a standard deviation of 8.15%. The students worked with a partner or in a group of 3, had access to help from the instructor and knew the report counted as a course grade. During the current individual task, with no help from the instructor and the quality of the report not affecting the students' course grade, students scored an average of 68.7% with a standard deviation of 14.2%. In order to eliminate the uncontrollable variable of being influenced by others while in the classroom performing the procedures, and to increase sample size, the planning score was used for data analysis in this study. The study would be strengthened by a setting in which individual work could be assured.

Another limitation of the study was the smaller sample sizes when data were disaggregated for low-level and advanced students. A greater pool of advanced students was available in the honors chemistry course at the school. However the use of students in a different course could have introduced more uncontrollable variables and therefore it was decided to not include those students. The study would be strengthened by a larger sample of an academically diverse group of students.

Recommendations

Backwards-design scaffolding was found to be a way to improve student performance when students were asked to design their own experiments. Three out of the four suggestions by Quintana et al. (2005) for computerized scaffolding were included in this software: providing a work space for what's required, displaying information

important to a process each time that specific information is important, and displaying the “big picture focal point” on each screen. The only recommendation that was not included in this study was providing a progress indicator on the screen to display the number of steps completed and the number remaining. During the study, several students were questioning how many screens they had to complete each time they pressed “next step” on a screen to be presented with another step to complete. The students that were not scaffolded in design order did not display this reaction as they had one screen with all report sections on it rather than moving through multiple screens to plan the investigation. The progress display was implemented for the remainder of the school year.

The presence of multiple reflective prompts had a detrimental effect on student performance scores when used frequently with lower-level students. This effect, however, was not present in upper-level students or when lower-level students were asked to reflect only one time. It is therefore recommended that the reflection process be adjusted to lower the cognitive load of monitoring and reflection while encourage self-regulatory processes and schema change.

Future Research

This study opened a large possibility for future study. It is desirable to determine reliable measures of cognitive load, such as performance on transfer tasks, for all future studies. Also, reflective prompts can be studied and refined further as discussed previously.

The scaffolding software can be used to watch scores over time with science-neutral tasks such as the paper towel tasks. By keeping the science content low, scores may show evidence of student progress in the design and lab writing aspect. For tasks targeting specific science content, correlations between laboratory scores and content knowledge gains can be studied. These types of studies may be used to identify components of scaffolding that encourage germane cognitive load.

Wider groups of students, such as multiple grade levels, could be studied, providing insight on how laboratory design skills progress over large time-spans. This would provide data for creating a bottom-up system where the tasks start where the students are and gradually progress rather than starting with what we want them to be able to do and backing it down until they are capable of completing a task. This longitudinal type of study may also provide data to determine when and how to fade scaffolding, as is suggested by the scaffolding literature.

Conclusions

Unguided experiences often overload most students' cognitive capabilities, yet a student learning how to design her/his own experiments is a component of every set of science education standards. In order to meet these goals, students must be scaffolded in a way that supports the formation and change of schema concerning the design process. Backwards-design scaffolding has been shown to increase student performance scores. However, in its current form, it does not include the type of individualized, faded scaffolding a human, either teacher or peer, can provide as demonstrated by the lower scores during this year than previous years where human scaffolding was employed.

The use of reflective prompts has been shown to increase students' self-regulatory functions in previous work. The effect of reflective prompts in this study, as with previous work, depended on the overall academic ability of the student. These results are an example of the need for varied scaffolding techniques for students of various levels.

This study serves as the foundation for a scaffolding and assessment software that can be studied in the future to increase its ability to support students, increase germane cognitive load and track student progress towards inquiry goals set in place by standards. Future research is needed to determine appropriate levels of scaffolding for a wide range of students, including much younger students. This can be accomplished in a bottom-up approach by starting with what students are capable of doing and increasing their zones of proximal development through appropriate scaffolding. Suggestions for future use and research include building a system that begins at the elementary school level at the students' ability level and acts as a cohesive, vertically aligned scaffolding and assessment tool. With a vertical record keeping system, scaffolding and self-regulation prompts can be tailored to a students' past performance. Such a system would provide a readily accessible formative assessment system for student skill-level on investigation design tasks.

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Appendix A: Student Investigation Instructions

The following task instructions were provided to the student. The overall goal was present at the top of every screen of the SDL-SAT. The instructions for each section appeared on the left half of the screen (see Appendix C) when a student entered into the textbox for that section.

Lab Instructions—The Most Absorbent Paper Towel

Purpose: To determine which paper towel is most absorbent for its price.

Safety: No chemicals other than water are being used, and there is no heating of any chemicals. Use caution with glassware.

Instructions:

1. You need to further define your purpose/problem. You know you're going to be comparing differently priced paper towels, but how will you define "absorbent"—by mass of water absorbed or volume? (Don't write this down now...just decide. You'll write it in a minute)
2. Begin writing your lab report:
 - Restate the **purpose/problem**. Remember to clearly state your variables in the purpose/problem—don't leave it the generic one written above.
 - Write **background information**
 - What information do you already know about your variables and how paper towels absorb water?

- Which sample do you believe will perform the best based on your variables and why?
 - List your variables (specify dependent and independent) and as many important constants as you can.
- For the **calculations/results**, you will need to compare your dependent and independent variables in some way. For this lab, the most appropriate way is to find a ratio of dependent to independent measurement. Be sure to specify how you're going to measure "amount of water"—either "mass of water" or "volume of water." You'll also need to average the multiple trials for each paper towel. Set these calculations up (you'll plug in the numbers after performing the experiment, but get them set up now).
 - Make sure everything needed in your calculations is included in your **data table**. Keep in mind when making your data table and procedure that you should not put wet paper towels directly on the balance. The data table contains no calculations (not even subtracting out the mass of a beaker).
 - Take each quantity that you need to measure in the data table and write a **procedure** step to either set it up or to measure it. Include steps specifying how you will know when to stop adding the water to the paper towel. There are many ways that you can do this—just pick one and be consistent! Make sure to use clear, concise language and to number your steps. Include 3 trials of each type of paper towel.
 - Make a detailed **materials** list. Write down each thing you need in your procedure, and exactly how much you need of it.

- Write down any **safety concerns** about materials.
3. Only after your lab is planned and written-up, perform your experiment. If you need to make any adjustments to any section of your report, do so in writing. For example, if you realize you forgot a step in the procedure, write it in as you do it. When you are finished with the experiment, the report should accurately state exactly what you did.
 4. Complete your **calculations/results** section by performing the calculations you set up earlier. After your calculations, write a general statement that states any trends or patterns in your results (such as “X brand absorbed a higher volume of water per mass of paper towel than Y brand”). Do not attempt to explain why you got these results, just state them in sentence form.
 5. Write your **conclusion**. It should include the purpose/problem and completely answer the purpose/problem. Use evidence to support your conclusions. Was your original hypothesis supported or not? Give an explanation as to why you think you got these results based on the chemistry you understand up to this point. Give at least two possible sources of error (remember, “human error” is too broad, and “calculations” don’t count). Possible sources of error do not mean that they are things you did—but places in the lab where error could occur in data gathering to throw off the results. Also write one additional investigation or one question that you now wonder about.

Appendix B: Investigation Report Rubric

The grading rubric for each section was displayed below the specific instructions for each section (see Appendix A) when a student entered into the textbox for that section (see Appendix C).

Lab Rubric—The Most Absorbent Paper Towel

CATEGORY	4	3	2	1
Title		Title directly relates to lab and clearly indicates variables.	Title indirectly relates to lab or does not clearly indicate variables.	Title is not appropriate for lab.
Purpose		The purpose of the lab is clearly identified and stated. Variables are clearly defined.	The purpose of the lab is identified, but is stated in a somewhat unclear manner. (such as: One variable may be un-defined.)	The purpose of the lab or the question to be answered during the lab is erroneous or irrelevant OR no variables are defined.

Background Information		Background includes information the students know about their variables and how paper towels absorb water in a logical, concise paragraph.	Background includes important information but not in a logical or concise paragraph.	Background is missing information about the variables or how paper towels absorb water.
Hypothesis		Hypothesis gives prediction and reason for prediction based on background information.	Hypothesis gives prediction and reason that is not directly based on background information.	Hypothesis gives prediction only.

Variables and constants		All variables are correctly identified. Important constants are identified.	One or more variable un-defined OR many important constants not addressed.	One or more variable un-defined AND many important constants not addressed.
Materials		All materials and setup used in the experiment are clearly and accurately described.	Most of the materials and the setup used in the experiment are accurately described.	Many materials are described inaccurately OR are not described at all.
Procedure: Format		Procedures are listed in clear steps. Each step is numbered and is a complete sentence.	Procedure steps are not numbered and/or are not in complete sentences.	Procedures do not accurately list the steps of the experiment.

<p>Procedure: Scientific Concepts</p>		<p>Procedure displays no errors in scientific concepts.</p>	<p>Procure displays errors in scientific concepts, but will still address the purpose.</p>	<p>Procedure displays large errors in scientific concepts and will not adequately address the purpose.</p>
<p>Procedure: Experiment Design</p>		<p>Enough detail is provided for experiment to be repeated. Procedure is logical and efficiently addresses the purpose. Following this procedure will likely result in</p>	<p>Missing ONE</p>	<p>Missing TWO</p>

		appropriate, valid, reliable data.		
Safety			Lab is carried out with full attention to relevant safety procedures.	Lab is carried out with some attention to relevant safety procedures.
Data	Units appropriate, Sig digs correct, Data taken is appropriate to the problem, Data taken is accurate, No calculations are used.	Missing ONE	Missing TWO	Missing THREE
Observation	Clear, accurate notes are taken regularly.	Clear, accurate notes are taken occasionally.	Notes are taken occasionally, but accuracy of notes might be	Notes rarely taken or of little use.

			questionable.	
Results		Summarizes data in word form, complete sentences, no conclusions are drawn.	Missing ONE	Missing TWO
Results: Calculations	Calculations are appropriate, Units and Sig digs are correct, Calculations are shown, Calculations are correct.	Missing ONE	Missing TWO	Missing THREE
Conclusion	Problem restated, answer given, evidence provided.	Missing ONE	Missing TWO	Conclusion is inappropriate

<p>Conclusion: Application</p>			<p>Future applications are different from original application and appropriate.</p>	<p>Future applications are very similar to original application.</p>
<p>Conclusion: Error Analysis</p>			<p>Sources (2) discussed, Sources are appropriate.</p>	<p>Missing ONE</p>

Appendix C: Screen-Images

Screen-image of the backwards-design process SDL-SAT

The screenshot shows a web application window titled "Student Designed Labs". The interface is divided into several sections:

- Top Right:** Contains buttons for "Next Step", "Log Out", "SPELL CHECK", and text formatting buttons (B, I, U).
- Left Side (Form Fields):**
 - Title:** A text box containing the text: "Which paper towel absorbs the most water per dollar? You may modify this question slightly, but stick with paper towels and absorbancy."
 - Purpose, Problem or Question:** A text box containing a single vertical bar "|".
 - Background Information:** An empty text box.
 - Analysis, Calculations, Trend Recognition, etc.:** An empty text box.
- Right Side (Purpose Information):**
 - Purpose Information:** A heading.
 - Be sure your problem or purpose is specific and clear.** A bold instruction.
 - Look below for specific information from your teacher** A bold instruction.
 - Remember to clearly state your variables in the purpose/problem don't leave it the generic one written above.** A reminder text.

Screen-image of the student-determined process SDL-SAT

Student Designed Labs

Which paper towel absorbs the most water per dollar? You may modify this question slightly, but stick with paper towels and absorbancy.

Title:

Purpose, Problem or Question

Background Information

Materials

Safety

Procedure

Next Step Log Out

SPELL CHECK B I U

Purpose Information

Be sure your problem or purpose is specific and clear.
Look below for specific information from your teacher

Remember to clearly state your variables in the purpose/problem don't leave it the generic one written above.

Scroll bar leads to other lab sections.

Screen image of teacher interface

Student Designed Labs

Click in the first cell or a cell with typing. Use the "TAB" key to move right and the enter key to start a new row.

Data Table

Towel #	Brand	Price	Trial #1	Trial #2
1	Sunrise recycled	1.81 cents/sheet	30mL	30mL
4	Viva	3.45 cents/sheet	75mL	75mL

Observations

The Viva will hold more water and be cheaper by the cost

Analysis, Calculations, Trend Recognition, etc.

volume of water/how much paper towel is=what it is worth

Results

Sunrise-16.6
Viva-22.2

Conclusion

Viva holds over double the amount of water as sunrise did. So therefore Viva is a better choice for a paper towel. It would be cheaper than the Sunrise.

Save

Keep in mind when making your data table and procedure that you should not put wet paper towels directly on the balance.

The data table contains no calculations (not even subtracting out the mass of a beaker).

-----Grading Rubric-----
4 points: Units appropriate, Sig digs correct, Data taken is appropriate to the problem, Data taken is accurate, No calculations are used.
3 points: Missing ONE
2 points: Missing TWO
1 point: Missing THREE

Overall 0 1 2 3 4
Application 0 1 2 Error 0 1 2

Appendix D: Examples of Scripting

***RunRev* script running when the program is opened:**

```

on preOpenStack
  global tCurrentVersion, CodeURL, gHeader
  set the cursor to watch

  --clear the first card
  set the visible of field "CodeURL" on card "Check" to false
  set the visible of field "Label1" on card "Check" to false
  set the visible of button "ProxySettings" on card "Check" to false
  set the visible of field "Label2" on card "Check" to false
  set the visible of button "SaveSettings" on card "Check" to false

  --set header for proxy
  put the selectedtext of button "ProxySettings" on card "Check" into
  tProxySettings
  if tProxySettings = "Halstead High School" then
    set the httpproxy to "172.16.2.11:3128"
    put science & ":" & dragons into tAuthString
    put base64Encode(tAuthString) into tEncString
    put "Proxy-Authorization: Basic" && tEncString into tHeader
    set the httpHeaders to tHeader
  else
    set the httpproxy to ""
    put "" & ":" & "" into tAuthString
    put base64Encode(tAuthString) into tEncString
    put "Proxy-Authorization: Basic" && tEncString into tHeader
    set the httpHeaders to tHeader
  end if

  --define URL for version check
  put field "CodeURL" of Card "Check" into CodeURL
  put CodeURL into tempURL
  set the itemdelimiter to "/"
  put the number of items in tempURL into x
  delete item x in tempURL
  put tempURL & "/SDLVersion.txt" into VersionURL

```

```

--check version online
put line 1 of URL VersionURL into tLatestVersion
put "2.0.0.0" into tCurrentVersion
if tLatestVersion="" then
  answer "You are not connecting to the internet. Do you need to change proxy
settings?" with "Yes" and "No"
  if it is yes then
    set the visible of button "ProxySettings" on card "Check" to true
    set the visible of field "Label2" on card "Check" to true
    set the visible of button "SaveSettings" on card "Check" to true
    go to card "Check"
  else
    answer warning "You're not connected to the internet. Check with your
firewall that this program is allowed to connect to the internet (via the same Port
as Internet Explorer, Firefox, etc., Port 80. It needs to"&&tempURL&")
    quit
  end if
else

  if tLatestVersion=tCurrentVersion then
    go to card "SpellCheck"
  else
    Answer Warning "<h3>You're not working with the most current version of
the program.</h3><p></p><p>You currently have version " & tcurrentVersion &
"<p></p><p>The latest version is " & tLatestVersion& "<p></p><p>Do you
want to download the latest version?</p>" with "No" or "Yes" titled "Get Latest
Version?"
    if it=yes then
      close stack "Student Designed Labs"
      put tempURL & "/SDLApplication.htm" into NewURL
      revGoURL NewURL
    else
      go to card "SpellCheck"

    end if
  end if
end if
reset the cursors
end preOpenStack

```

RunRev script to populate the field of school names on the login card:

```

on preOpenCard

  global CodeURL

  put "" into field "TeacherName"
  put "" into field "StudentName"

  put "Step=5" into myList
  post myList to URL CodeURL
  put it into field "School"
  sort field "School"

  pass preOpenCard
end preOpenCard

```

RunRev script to verify student password:

```

on mouseUp
  set the cursor to watch
  global gTeacherName, gStudentName, gLogin, CodeURL
  put selectedtext of field "StudentName" into gStudentName

  if gStudentName="" then
    answer "Choose a school, teacher, hour and student name first"
  else

    ask password clear "Password?"
    put it into gPassword

    put "Step=8&TeacherName=" &gTeacherName& "&StudentName="
    &gStudentName into myList
    post myList to URL CodeURL
    put it into gCorrectPassword

    if gPassword=gCorrectPassword then
      go to next card
    else
      go to card "Login"
    end if
  end if
end mouseUp

```

```

end if
end if

```

```

  reset cursors
end mouseUp

```

***RunRev* script to populate the field of student names on the student**

login card:

```

on mouseUp
  set cursor to watch
  global gTeacherName, gHour, CodeURL
  put selectedtext of field "NewHour" into gHour

  if gHour = "All" then
    put "" into gHour
  end if

  put "Step=7&TeacherName=" &gTeacherName &"&Hour=" &gHour into
myList
  post myList to CodeURL
  put it into field "StudentName"
  sort field "StudentName"

  reset cursors
end mouseUp

```

***RunRev* script to get, parse and put the student lab report information**

into an unseen “holder” card:

```

on preOpenCard
  set cursor to watch
  put "" into field "StudentPurpose"
  put "" into field "Data"
  put "" into field "AnalysisCalculations"
  put "" into field "Background"
  put "" into field "StudentTitle"
  put "" into field "LabMaterials"

```

```

put "" into field "LabSafety"
put "" into field "LabProcedure"
put "" into field "ImageFileName"

```

--global variables & header

```

global CodeURL, gStudentName, gTeacherName, gLabID

```

--Check to see if a record already exists. If not, create one.

```

put "Step=2&StudentName=" & gStudentName & "&TeacherName="
&gTeacherName& "&LabID=" &gLabID into myList
post myList to URL CodeURL
put it into IsRecord
replace "<return>" with "" in IsRecord
if IsRecord = "" then
  put "" into MakeRecord
  repeat until MakeRecord="1"
    put "Step=11&StudentName=" & gStudentName & "&TeacherName="
    &gTeacherName& "&LabID=" &gLabID into myList
    post myList to URL CodeURL
    put it into MakeRecord
  end repeat
end if

```

--get the student's record

```

put "" into GotRecord
Repeat until GotRecord<>""
  put "Step=2&StudentName=" & gStudentName & "&TeacherName="
  &gTeacherName& "&LabID=" &gLabID into myList
  post myList to URL CodeURL
  put it into tURLData
  replace return with "" in tURLData
  replace "<return>" with return in tURLData
  put line 1 of tURLData into GotRecord
end Repeat

```

--put the student lab report into the unseen fields

```

set the htmltext of field "GroupMembers" to line 2 of tURLData
set the htmltext of field "StudentTitle" to line 3 of tURLData
set the htmltext of field "StudentPurpose" to line 4 of tURLData
set the htmltext of field "Background" to line 5 of tURLData
set the htmltext of field "LabMaterials" to line 6 of tURLData
set the htmltext of field "LabSafety" to line 7 of tURLData
set the htmltext of field "LabProcedure" to line 8 of tURLData
put line 9 of tURLData into tData
replace "/r" with return in tData

```

```

put tData into field "Data"
set the htmltext of field "Observations" to line 10 of tURLData
set the htmltext of field "AnalysisCalculations" to line 11 of tURLData
set the htmltext of field "LabResults" to line 12 of tURLData
set the htmltext of field "Conclusion" to line 13 of tURLData
put line 14 of tURLData into field "ImageFileName"

```

```

go to next card

```

```

reset cursors
pass preOpenCard
end preOpenCard

```

***RunRev* scripting to populate a “step” card in the student interface**

```

on preOpenCard
  set cursor to watch

  set the traversalOn of button "Bold" to false
  set the traversalOn of button "Italic" to false
  set the traversalOn of button "Underline" to false

  put "" into field "TeacherName"
  put "" into field "LabID"
  put "" into field "StudentName"
  put "" into field "GroupMembers"
  put "" into field "StudentTitle"
  put "" into field "StudentPurpose"
  put "" into field "Background"
  put "" into field "AnalysisCalculations"
  put "" into field "Instructions"
  put "" into field "Info"
  put "Click a section to see instructions" into field "InfoTitle"
  put "" into field "Definition"

  global gStudentName, gTeacherName, gLabID, gLabName, gInstructions

  put gTeacherName into field "TeacherName"
  put gLabID into field "LabID"
  put gStudentName into field "StudentName"
  put gLabName into field "LabName"
  put gInstructions into field "Instructions"

```

```

    set the htmltext of field "GroupMembers" to the htmltext of field ID 3824 on
card "Holder"
    set the htmltext of field "StudentTitle" to the htmltext of field ID 3392 on card
"Holder"
    set the htmltext of field "StudentPurpose" to the htmltext of field ID 3394 on
card "Holder"
    set the htmltext of field "Background" to the htmltext of field ID 3397 on card
"Holder"
    set the htmltext of field "AnalysisCalculations" to the htmltext of field ID 3399
on card "Holder"

    reset cursors
    pass preOpenCard
end preOpenCard

```

***RunRev* scripting to save a student lab information**

```

on mouseUp
    set cursor to watch
    global gStudentName, CodeURL, gLabID, gTeacherName

    --reset the color in case spell check changed a word to red. Remove "&"
    put htmltext of field "GroupMembers" into tGroupMembers
    replace "&" with "and" in tGroupMembers
    replace "FF0000" with "000000" in tGroupMembers
    set the htmltext of field "GroupMembers" to tGroupMembers
    put htmltext of field "StudentTitle" into tStudentTitle
    replace "&" with "and" in tStudentTitle
    replace "FF0000" with "000000" in tStudentTitle
    set the htmltext of field "StudentTitle" to tStudentTitle
    put htmltext of field "StudentPurpose" into tStudentPurpose
    replace "&" with "and" in tStudentPurpose
    replace "FF0000" with "000000" in tStudentPurpose
    set the htmltext of field "StudentPurpose" to tStudentPurpose
    put htmltext of field "Background" into tBackground
    replace "&" with "and" in tBackground
    replace "FF0000" with "000000" in tBackground
    set the htmltext of field "Background" to tBackground
    put htmltext of field "AnalysisCalculations" into tAnalysis
    replace "&" with "and" in tAnalysis
    replace "FF0000" with "000000" in tAnalysis
    set the htmltext of field "AnalysisCalculations" to tAnalysis

```

```

--put the current information on the "Holder" card
set the htmltext of field "GroupMembers" on card "Holder" to the htmltext of
field "GroupMembers"
set the htmltext of field ID 3392 on card "Holder" to the htmltext of field
"StudentTitle"
set the htmltext of field ID 3394 on card "Holder" to the htmltext of field
"StudentPurpose"
set the htmltext of field ID 3397 on card "Holder" to the htmltext of field
"Background"
set the htmltext of field ID 3399 on card "Holder" to the htmltext of field
"AnalysisCalculations"

```

```

--save info from "Holder" card
put the htmltext of field ID 3824 on card "Holder" into tGroupMembers
put the htmltext of field ID 3392 on card "Holder" into tStudentTitle
put the htmltext of field ID 3394 on card "Holder" into tStudentPurpose
put the htmltext of field ID 3397 on card "Holder" into tBackground
put the htmltext of field ID 3403 on card "Holder" into tLabMaterials
put the htmltext of field ID 3406 on card "Holder" into tLabSafety
put the htmltext of field ID 3409 on card "Holder" into tLabProcedure
put field ID 3412 on card "Holder" into tData
replace return with "/r" in tData
put the htmltext of field ID 3423 on card "Holder" into tObservations
put the htmltext of field ID 3399 on card "Holder" into tAnalysisCalculations
put the htmltext of field ID 3417 on card "Holder" into tLabResults
put the htmltext of field ID 3419 on card "Holder" into tConclusion
put field "ImageFileName" on card "Holder" into tURL

```

```

put "" into SavedRecord
repeat until SavedRecord ="11"
  put "Step=3&StudentName=" &gStudentName& "&TeacherName="
  &gTeacherName& "&LabID=" &gLabID& "&GroupMembers="
  &tGroupMembers& "&StudentTitle=" &tStudentTitle& "&StudentPurpose="
  &tStudentPurpose& "&Background=" &tBackground& "&LabMaterials="
  &tLabMaterials& "&LabSafety=" &tLabSafety& "&LabProcedure="
  &tLabProcedure& "&Data=" &tData& "&Observations=" &tObservations&
  "&AnalysisCalculations=" &tAnalysisCalculations& "&LabResults="
  &tLabResults& "&Conclusion=" &tConclusion & "&Image="&tURL into myList
  post myList to url CodeURL
  put it into SavedRecord
end repeat

```

```

answer "Lab Saved"

```

```

reset cursors

```

end mouseUp

PHP scripting for student interface

```

<?PHP
# Connect to database
$cxn=MySQL_connect("98.172.113.5","root","jayhawks1") or die ("Couldn't
connect");
MySQL_select_db("reallif1_SDL") or die ("couldn't connect to db");

# Get list of schools
if ($_POST[Step]==1){
$sql = "SELECT Distinct School FROM Teacher";
$findname=MySQL_query($sql);

while($studentrow = MySQL_fetch_array( $findname ))
{
echo $studentrow['School']."\n";
}
}

# Get student record
elseif ($_POST[Step]==2) {

$sql = "SELECT * FROM StudentLab WHERE
StudentName='$_POST[StudentName]' and LabID='$_POST[LabID]' and
TeacherName='$_POST[TeacherName]";
$findname=MySQL_query($sql) or die ("die");
$studentrow=MySQL_fetch_assoc($findname);

    # Set variable names without the array name
$StudentTitle=$studentrow[StudentTitle];
$StudentPurpose=$studentrow[StudentPurpose];
$Background=$studentrow[Background];
$LabMaterials=$studentrow[LabMaterials];
$LabSafety=$studentrow[LabSafety];
$LabProcedure=$studentrow[LabProcedure];
$Data=$studentrow[Data];
$Observations=$studentrow[Observations];
$AnalysisCalculations=$studentrow[AnalysisCalculations];
$LabResults=$studentrow[LabResults];
$Conclusion=$studentrow[Conclusion];
$GotRecord=$studentrow[GotRecord];

```

```

$GroupMembers=$studentrow[GroupMembers];
$image=$studentrow[Image];

    # Display information
echo "$GotRecord<return>";
echo "$GroupMembers<return>";
echo "$StudentTitle<return>";
echo "$StudentPurpose<return>";
echo "$Background<return>";
echo "$LabMaterials<return>";
echo "$LabSafety<return>";
echo "$LabProcedure<return>";
echo "$Data<return>";
echo "$Observations<return>";
echo "$AnalysisCalculations<return>";
echo "$LabResults<return>";
echo "$Conclusion<return>";
echo "$Image<return>";
}

# Save student record
elseif ($_POST[Step]==3){
$sql = "UPDATE StudentLab SET GroupMembers='$_POST[GroupMembers]',
StudentTitle='$_POST[StudentTitle]',
StudentPurpose='$_POST[StudentPurpose]',
Background='$_POST[Background]', LabMaterials='$_POST[LabMaterials]',
LabSafety='$_POST[LabSafety]', LabProcedure='$_POST[LabProcedure]',
Data='$_POST[Data]', Observations='$_POST[Observations]',
AnalysisCalculations='$_POST[AnalysisCalculations]',
LabResults='$_POST[LabResults]', Conclusion='$_POST[Conclusion]',
Image='$_POST[Image]' WHERE StudentName='$_POST[StudentName]' and
LabID='$_POST[LabID]' and TeacherName='$_POST[TeacherName]";
$findname=MySQL_query($sql);
echo $findname;

MySQL_close($cxn);
$cxn=MySQL_connect("localhost","reallif1_detersk","jayhawks1") or die
("Couldn't connect");
MySQL_select_db("reallif1_SDL") or die ("couldn't connect to db");
$query = "Insert into studentlab (GroupMembers, StudentTitle, StudentPurpose,
Background, LabMaterials, LabSafety, LabProcedure, Data, Observations,
AnalysisCalculations, LabResults, Conclusion, StudentName, TeacherName,
LabID) Values
($_POST[GroupMembers],'$_POST[StudentTitle]','$_POST[StudentPurpose]','$
_POST[Background]','$_POST[LabMaterials]','$_POST[LabSafety]','$_POST[La

```

```

bProcedure'],'$_POST[Data'],'$_POST[Observations'],'$_POST[AnalysisCalculati
ons'],'$_POST[LabResults'],'$_POST[Conclusion'],'$_POST[StudentName'],'$_P
OST[TeacherName'],'$_POST[LabID]')";
$result = MySQL_query($query) or die ("can't update record");
echo $result;
}

```

```

#Get Lab Instructions
elseif ($_POST[Step]==4){
$sql = "SELECT * FROM Lab WHERE TeacherName='$_POST[TeacherName]'
AND LabID='$_POST[LabID]'";
$findname=MySQL_query($sql) or die ("die");
$studentrow=MySQL_fetch_assoc($findname);

```

```

    # Set variable names without the array name

```

```

$LabName=$studentrow[LabName];
$Instructions=$studentrow[Instructions];
$titleInfo=$studentrow[TitleInfo];
$PurposeInfo=$studentrow[PurposeInfo];
$BackgroundInfo=$studentrow[BackgroundInfo];
$MaterialsInfo=$studentrow[MaterialsInfo];
$SafetyInfo=$studentrow[SafetyInfo];
$ProcedureInfo=$studentrow[ProcedureInfo];
$DataInfo=$studentrow[DataInfo];
$ObservationsInfo=$studentrow[ObservationsInfo];
$AnalysisInfo=$studentrow[AnalysisInfo];
$ResultsInfo=$studentrow[ResultsInfo];
$ConclusionInfo=$studentrow[ConclusionInfo];

```

```

    # Display information

```

```

echo "$LabName<return>";
echo "$Instructions<return>";
echo "$TitleInfo<return>";
echo "$PurposeInfo<return>";
echo "$BackgroundInfo<return>";
echo "$ProcedureInfo<return>";
echo "$MaterialsInfo<return>";
echo "$SafetyInfo<return>";
echo "$DataInfo<return>";
echo "$ObservationsInfo<return>";
echo "$AnalysisInfo<return>";
echo "$ResultsInfo<return>";
echo "$ConclusionInfo<return>";
}

```

```

# Get list of schools
elseif ($_POST[Step]==5){
$sql = "SELECT Distinct School FROM Teacher";
$findname=MySQL_query($sql);

while($studentrow = MySQL_fetch_array( $findname ))
{
echo $studentrow['School']."\n";
}
}

#Get list of teachers for specific school
elseif ($_POST[Step]==6){
$sql = "SELECT TeacherName FROM Teacher WHERE
School='$_POST[School]'";
$findname=MySQL_query($sql);

while($studentrow = MySQL_fetch_array( $findname ))
{
echo $studentrow['TeacherName']."\n";
}
}

#Get list of students for teacher and hour
elseif ($_POST[Step]==7){
    if ($_POST[Hour]<1){
        $sql = "SELECT StudentName FROM Student WHERE
TeacherName='$_POST[TeacherName]'";
        $findname=MySQL_query($sql);

        while($studentrow = MySQL_fetch_array( $findname ))
        {
            echo $studentrow['StudentName']."\n";
        }
    }else{

        # Get student's row
        $sql = "SELECT StudentName FROM Student WHERE
TeacherName='$_POST[TeacherName]' and Hour='$_POST[Hour]'";
        $findname=MySQL_query($sql);

        while($studentrow = MySQL_fetch_array( $findname ))
        {
            echo $studentrow['StudentName']."\n";
        }
    }
}

```

```

    }
}

#Get student password
elseif ($_POST[Step]==8){
$sql = "SELECT Password FROM Student WHERE
TeacherName='$_POST[TeacherName]' and
StudentName='$_POST[StudentName]'";
$findname=MySQL_query($sql);
$studentrow=MySQL_fetch_assoc($findname);

# Set variable names without the array name
$Password=$studentrow[Password];
echo $Password;
}

# Get list of labs
elseif ($_POST[Step]==9){
$sql = "SELECT LabID FROM Lab WHERE
TeacherName='$_POST[TeacherName]'";
$findname=MySQL_query($sql);

while($studentrow = MySQL_fetch_array( $findname ))
{
echo $studentrow['LabID']."\n";
}
}

#Check to see if student lab exists
elseif ($_POST[Step]==10){
$query = "Select * From StudentLab WHERE
StudentName='$_POST[StudentName]' AND
TeacherName='$_POST[TeacherName]' AND LabID='$_POST[LabID]'";
$result = MySQL_query($query);
$studentrow=MySQL_fetch_assoc($findname);
$GotRecord=$studentrow[GotRecord];
echo $GotRecord;
}

#Add lab if not existing
elseif ($_POST[Step]=11){
$query2="INSERT INTO StudentLab (LabID, TeacherName, StudentName)
VALUES
('$_POST[LabID]','$_POST[TeacherName]','$_POST[StudentName]')";
$result2=MySQL_query($query2);

```

```

echo $result2;
}

?>

```

PHP scripting for teacher interface

```

<?PHP
# Connect to database

$cxn=MySQL_connect("98.172.113.5","root","jayhawks1") or die ("Couldn't
connect");
MySQL_select_db("reallif1_SDL") or die ("couldn't connect to db");

if ($_POST[Step]==1){
$query2="INSERT INTO Lab (LabID, TeacherName) VALUES
($_POST[LabID],$_POST[TeacherName])";
$result2=MySQL_query($query2) or die ("That LabID already exists for you");

echo $result2;

} elseif ($_POST[Step]==2){
$query2="DELETE FROM Lab WHERE LabID='$_POST[LabID]' AND
TeacherName='$_POST[TeacherName]";
$result2=MySQL_query($query2) or die ("can't delete lab row");

echo $result2;

} elseif ($_POST[Step]==3){
$query2="INSERT INTO StudentLab (LabID, StudentName, TeacherName)
VALUES
($_POST[LabID],$_POST[StudentName],$_POST[TeacherName])";
$result2=MySQL_query($query2) or die ("That LabID already exists for you");

echo $result2;

} elseif ($_POST[Step]==4){
$query2="INSERT INTO Student (StudentName, TeacherName, Password,
Hour) VALUES

```

```

($_POST[StudentName]','$_POST[TeacherName]','$_POST[Password]','$_POST[Hour]');
    $result2=MySQL_query($query2) or die ("That student already exists for you");

echo $result2;

}elseif ($_POST[Step]==5){
$query = "UPDATE Lab SET School='$_POST[School]',
Share='$_POST[Share]', LabName='$_POST[LabName]',
BackgroundInfo='$_POST[BackgroundInfo]',
Instructions='$_POST[Instructions]', TitleInfo='$_POST[TitleInfo]',
PurposeInfo='$_POST[PurposeInfo]', ProcedureInfo='$_POST[ProcedureInfo]',
MaterialsInfo='$_POST[MaterialsInfo]',
SafetyInfo='$_POST[SafetyInfo]',ResultsInfo='$_POST[ResultsInfo]',
DataInfo='$_POST[DataInfo]', AnalysisInfo='$_POST[AnalysisInfo]',
ConclusionInfo='$_POST[ConclusionInfo]' WHERE
TeacherName='$_POST[TeacherName]' AND LabID='$_POST[LabID]';
$result = MySQL_query($query) or die ("can't update record");

echo $result;

}elseif ($_POST[Step]==6){
$query2="DELETE FROM Student WHERE
StudentName='$_POST[StudentName]' AND
TeacherName='$_POST[TeacherName]";
    $result2=MySQL_query($query2) or die ("can't delete student record");

echo $result2;

}elseif ($_POST[Step]==7){
$query2="DELETE FROM StudentLab WHERE
StudentName='$_POST[StudentName]' AND
TeacherName='$_POST[TeacherName]' and LabID='$_POST[LabID]";
    $result2=MySQL_query($query2) or die ("can't delete lab row");

echo $result2;

}elseif ($_POST[Step]==8){
$query2="Update Student Set StudentName='$_POST[NewStudentName]',
Password='$_POST[Password]', Hour='$_POST[Hour]' WHERE
TeacherName='$_POST[TeacherName]' and
StudentName='$_POST[StudentName]";
    $result2=MySQL_query($query2) or die ("can't update record");

```

```
$query2="Update StudentLab Set StudentName='$_POST[NewStudentName]'
WHERE TeacherName='$_POST[TeacherName]' and
StudentName='$_POST[StudentName]";
    $result=MySQL_query($query2) or die ("can't update record");

echo $result2;
echo $result;

}elseif ($_POST[Step]==9){
$query = "UPDATE StudentLab SET
BackgroundComment='$_POST[BackgroundComment]',
OverallComment='$_POST[OverallComment]',
TitleComment='$_POST[TitleComment]',
PurposeComment='$_POST[PurposeComment]',
ProcedureComment='$_POST[ProcedureComment]',
MaterialsComment='$_POST[MaterialsComment]',
SafetyComment='$_POST[SafetyComment]',ResultsComment='$_POST[Results
Comment]', DataComment='$_POST[DataComment]',
AnalysisComment='$_POST[AnalysisComment]',
ObservationComment='$_POST[ObservationComment]',
ConclusionComment='$_POST[ConclusionComment]' WHERE
StudentName='$_POST[StudentName]' AND
TeacherName='$_POST[TeacherName]' AND LabID='$_POST[LabID]";
$result = MySQL_query($query) or die ("can't update record");

echo $result;

}
?>
```

Appendix E: Consent and Assent Forms



COLLEGE OF EDUCATION AND HUMAN SCIENCES
Department of Teaching, Learning and Teacher Education

INFORMED CONSENT FORM

IRB# (Labeled by IRB)

Identification of Project:

A Comparison of Student Designed Labs Scaffolding and Assessment Tools

Purpose of the Research:

Science inquiry is a part of the national and Kansas science education standards. Students must learn how to design their own scientific experiments. We hope to find an effective way to support students during the design process. Chemistry students will use one of four versions of a computer program intended to help them through the investigation design process.

Procedures:

Students will be asked to design an investigation. This is a task that is part of the normal chemistry curriculum and has been used for several years. Students will have two block periods (a total of 200 minutes) to design and conduct the experiment and write their conclusions.

Students will access the computer program. Their names will be kept secret. The finished lab reports will be graded in the same way as for the rest of the chemistry course. Their lab reports will be used to determine if there is a difference between the four different versions of the software program.

Because student names will not be associated with their final report, students will be given a grade for the activity based on their effort, participation and appropriate use of class time throughout the two class periods.

Risks and/or Discomforts:

There are no known risks associated with this research. Once the work is completed but before the researchers study that work, the identities will be removed – so that we won't be able to tie any student to his or her work.

Benefits:

Future students may benefit from this study as they will have access to the most effective supports while designing future scientific investigations. All current students will benefit from use of the current materials.

Confidentiality:

Students will be given random logon. Their name will not be connected in any way to the final lab report that is stored in a computer database. All data will be reported as a group (of approximately 38 students each) and no individual report scores will be reported or published.

Compensation:

There will be no compensation for participating in this research.

Opportunity to Ask Questions:

You may ask any questions concerning this research and have those questions answered before agreeing to participate in or during the study. Or you may call the investigator at any time, office phone, 379-5880, or email detersk@usd450.net. You may contact Dr. David Brooks at (402) 472-2018. If you have questions concerning your rights as a research subject that have not been answered by the investigator or to report any concerns about the study, you may contact the University of Nebraska-Lincoln Institutional Review Board, telephone (402) 472-6965.

Freedom to Withdraw:

You are free to decide not to allow your child to participate in this study or to withdraw at any time without adversely affecting your relationship or your child's relationship with the investigators, the University of Nebraska-Lincoln or USD 450. If you choose not to allow your child to participate, your child will still complete the paper towel investigation task for their effort/participation grade, but they will not use the computer program and their report scores will not be included in the data analysis and reporting.



UNIVERSITY OF
Nebraska
Lincoln

COLLEGE OF EDUCATION AND HUMAN SCIENCES
Department of Teaching, Learning and Teacher Education

Consent, Right to Receive a Copy:

You are voluntarily making a decision whether or not to allow your child to participate in this research study. Your signature certifies that you have decided to allow your child to participate having read and understood the information presented. You will be given a copy of this consent form to keep.

Name of student _____

Yes, I would like my student to participate in the study.
 No, I do not want my student to participate in the study.

Signature of Participant:

Signature of Research Participant Parent/Guardian

Date

Name and Phone number of investigator(s)

*Kelly Deters, Ph.D student, Principal Investigator
David Brooks, Ph.D., Secondary Investigator*

*detersk@usd450.net (785) 579-5880
(402) 472-2018*



COLLEGE OF EDUCATION AND HUMAN SCIENCES
Department of Teaching, Learning and Teacher Education

YOUTH ASSENT FORM

IRB# (Labeled by IRB)

A Comparison of Student Designed Labs Scaffolding and Assessment Tools

One of the tasks students are asked to do in some science classes is to design their own scientific investigation. This is a difficult task. We're conducting this research study to find out if one of the four versions of a computer program is better at supporting you while you design investigations.

You'll have two block periods to design, conduct and write a conclusion about which paper towels absorbs the most water per dollar. Everyone will do the task and receive a grade for their effort, participation and use of class time. Those not participating in this research will do the task on paper. Those that return signed student and parent forms will use one of the four versions of the computer program.

You will log into the system with a random username, so your name will not be connected with the final lab report that is produced by using the computer program. The scores on those lab reports will be used to determine if one of the computer program versions is better than the other.

Because there is random username assignment, no names connected with the final report, and you are graded on effort/participation, there is no risk to you in participating in this study. All findings from this research project will be reported or published as group data—no individual lab report scores will ever be published.

We will also ask your parents for their permission for you to do this study. Please talk this over with them before you decide whether or not to participate.

If you have any questions at any time, please ask one of the researchers (contact information below).

If you check "yes," it means that you have decided to participate and have read everything that is on this form. You and your parents will be given a copy of this form to keep.

Yes, I would like to participate in the study.

No, I do not want to participate in the study.

Signature of Participant

Date

Signature of Investigator

Date

Name and Phone number of investigator(s)

Kelly Deters, Ph.D student, Principal Investigator
David Brooks, Ph.D. Secondary Investigator

detersk@usd450.net (785) 579-5880
(402) 472-2018