Exploring the Role of Showing Design Intent in Supporting Curriculum Modifications

by

Hsien-Ta Lin

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
(Education)
in The University of Michigan
2008

Doctoral Committee:
- Associate Professor Barry J. Fishman, Chair
- Professor Joseph S. Krajcik.
- Associate Professor Priti Shah
- Assistant Professor Christopher L. Quintana

ACKNOWLEDGEMENTS

I am fortunate to work with the members of my dissertation committee who shared their constructive comments and suggestions that helped me develop my ideas. I am particularly grateful to my advisor, Barry Fishman, for giving me sustained guidance and encouragement with patience and understanding throughout the years of my study. He encouraged exploration and helped me envision the broader picture of the field of learning sciences. I am thankful to Joe Krajcik who has provided insights and rich resources during my investigation of innovative curriculum design practices. I would like to thank Chris Quintana for his thoughtful comments on design and implementation of software scaffolding strategies. I want to thank Priti Shah for her inspiring suggestions on design of visualizations.

This dissertation could not have been completed without the participation of science teachers who carved out precious time and energy to work with me and gave me invaluable feedback. I am thankful to my colleagues at hi-ce and friends at the University of Michigan. I would also like to thank the Fulbright Program and the Chiang Ching-kuo Foundation for International Scholarly Exchange for providing generous financial support.

To my father, mother, and my sister: thank you for unconditional love, support, and encouragement to pursue my passion for life-long learning. My dissertation, I dedicate to you.

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CHAPTER 1

INTRODUCTION

1.1. Problem statement

Coherent curriculum materials are critical for helping students develop integrated understanding of science concepts. Recent standards-based reform movements have encouraged curriculum researchers and developers to address content standards and benchmarks using more complex designs that weave scientific ideas together across multiple lessons and activities (Kali, Linn, & Roseman, in press). However, creating materials where lessons are linked to standards does not guarantee quality learning experiences (Schmidt, Wang, & McKnight, 2005). The parts of coherent curricula need to be connected together in a manner that helps students develop deep understanding of important ideas in a subject domain (Newmann, Smith, Allensworth, & Bryk, 2001). Without coherent connections between various parts of curricula, students may develop fragmented understanding of important science concepts (Kesidou & Roseman, 2002; Stern & Roseman, 2004). With more coherent understanding of scientific subject matter, students will be able to apply what they know to make sense of everyday scientific phenomena using strategies that are closer to those used by domain experts (Chi, Feltovich, & Glaser, 1981; Roseman, Linn, & Koppal, in press). This goal is at the core of modern conceptions of scientific literacy.

Coherent curricula usually have complex connections between and across lessons. Coherent curricula contain deliberate connections and coordination between the important concepts in each subject within a grade and between grades (Newmann et al., 2001). To construct coherent curricula, curriculum designers must carefully analyze the science standards and benchmarks and organize sequences of topics around big ideas in order to achieve the goal of integrated understanding (Krajcik, Slotta, McNeill, & Reiser, in press). The Atlas of Science Literacy (American Association for the Advancement of Science, 2001, 2007) lays out detailed sequences and connections among science concepts for K-12 science education.

Curriculum designers also arrange these big ideas so that the units introduce more fundamental concepts with observable phenomena before introducing deeper or abstract concepts. Appropriate phenomena not only engage students by creating a sense of purpose for science concepts, but can also help them view scientific concepts as relevant to daily life (Smith, Wiser, Anderson, & Krajcik, 2006). For example, the developers of the Investigating and Questioning our World through Science and Technology (IQWST) project have sequenced their units (which serve as the basis for this dissertation) so that students explore visible chemical reactions in physical systems in the 6th grade before they study less observable chemical reactions in living systems in the 7th grade (Shwartz, Weizman, Fortus, Krajcik, & Reiser, in press).

Coherent curricula also guide students to revisit the same or similar concepts and scientific practices in different grade levels and across disciplines (Roseman et al., in press). An explicit demonstration of the relationship between fundamental principles and phenomena enables learners to integrate new ideas into what they already know (Chi et al., 1981).

Teachers need help in interpreting and adapting coherent curricula such as that developed by IQWST, since curriculum units designed for coherence have become more complex due to the deliberate connections among elements. Teachers need to understand these types of connections between elements of coherent curricula in order to create meaningful learning environments for students and to avoid making adaptations that inadvertently alter the core ideas of these curricula in ways that are inconsistent with their developers' intentions (Collopy, 2003; Davis & Krajcik, 2005). Knowledge of the connections between elements of coherent curricula is related to lateral and vertical curriculum knowledge (Shulman 1986). Lateral curriculum knowledge refers to a teacher's ability to relate the content of a lesson to topics being discussed in other units in the same grade level. Vertical curriculum knowledge refers to understanding how topics fit together across different grade levels in a particular subject.

Before teachers can use and modify curriculum in a way that is congruent with designers' intent, they need to understand the knowledge embedded in the design of these materials and ways to use them in various contexts without creating interpretations that can cause "lethal mutations" (Brown & Campione, 1996). When modifying curriculum materials, teachers need to possess coherent content knowledge, understand strategies for effective student learning, and hold modification strategies compatible with the reform ideas embedded in curriculum materials (D. K. Cohen & Ball, 1990; Putnam & Borko, 2000; Shulman, 1987). They also need to recognize the strengths and weaknesses of using the curriculum materials in their own classrooms (Ben-Peretz, 1990), making modifications to suit their local context where needed.

If we accept the claim that helping teachers understand the design of coherent curriculum materials is a critical issue for successful curriculum implementation, especially as curriculum developers attempt to "scale up" or spread the use of their materials to broad audiences of teachers, a practical problem becomes how we might design a supportive environment that allows teachers to make decisions about curriculum implementation in their local context that are coherent with respect to designers' intentions. Below I describe findings from previous studies related to this issue and identify gaps in the research to date.

1.2. Research problem

Prior studies have employed three major strategies to help teachers understand curriculum materials: software tools, educative curriculum materials, and professional development. Software programs have been used to demonstrate design rationale, show examples of enactment, and provide opportunities for social support (Davis & Varma, in press). First, information about design rationale helps teachers make informed decisions about adapting lessons while still supporting the learning goals addressed in those lessons. For example, the Technology Enhanced Learning in Science (TELS) Center provides annotated teachers' modules that include information about the curriculum designers' rationale behind specific activities (Davis & Varma, in press; Linn, Husic, Slotta, & Tinker, 2006) . Second, examples of enactment demonstrate what inquiry lessons look like in classrooms. For example, the online environment called Knowledge Networks On the Web (KNOW) provides two types of video to support teachers learning about materials: “Images of practice” and "How to" videos. The first type of video shows how a teaching strategy is used in classrooms. The second type of video gives step-by-step instruction on how to use equipment and materials in science inquiry (Fishman, 2003). Third, online learning communities provide teachers and curriculum designers with opportunities to share ideas about enacting curricula. For example, the Curriculum Access System for Elementary Science (CASES) provides a broad range of cases and prompts for discussion among pre-service teachers (Davis, 2006).

Recently, educative curriculum materials have been used to provide situated learning opportunities for teachers to develop learning-promoting strategies (Ball & Cohen, 1996; Davis & Krajcik, 2005) and to help teachers reflect on the relationship between the current lesson and other curriculum units by presenting a list of learning objectives (Wang & Paine, 2004). Some curriculum materials clearly demonstrate learning goals, the scope and sequence of learning activities, and strategies to deal with student prior knowledge, and connections between units (Krajcik et al., in press; Remillard, 2005). For example, all of the activities the “Investigations in Environmental Science” curriculum are labeled by the role that they play in the learning-for-use learning cycle (Edelson & Reiser, 2006), a pedagogical model that underlies the design of the Investigations curriculum. The goal is to highlight the role of particular activities for teachers in the context of the larger curriculum.

Although the aforementioned efforts all attempted to improve teachers’ understanding of curriculum design in order to facilitate enactment, these efforts focused more on helping teachers improve their understanding of coherence related to a specific lesson and less on helping teachers to be aware of deeper curriculum design intent, such as how lessons work together to address learning goals across an entire unit. Professional development activities often overlook the need for helping teachers learn to adapt curriculum units for local contexts (Clandinin & Connelly, 1992; Randi & Corno, 1997). Most educative curriculum materials address how to manipulate elements of curriculum units for adaptations (e.g., substitute an instructional strategy with another one in a lesson), but do not instruct teachers to observe how their adaptations or modifications affect the overall structure of a curriculum unit (Remillard, 2005).

Helping teachers understand underlying curriculum design intentions is a challenge (Spillane, Reiser, & Reimer, 2002), since it takes about three years for experienced teachers to develop and engage in classroom enactments that are congruent with the conceptual foundation of project-based science *with* the support of the curriculum designers (Marx, Freeman, Krajcik, & Blumenfeld, 1998). What happens when the curriculum is used apart from the influence of its original developers? This is a key challenge for the scalability and sustainability of inquiry-oriented curriculum materials. One possibility is to devise tools that can work together with curriculum materials in order to support or scaffold teachers' understanding of the underlying rationale behind curriculum materials' design. Previously, researchers have argued that scaffolding can help people to understand the relationships among components in a system (Edelson, Gordin, & Pea, 1999; Quintana et al., 2004). However, few studies have addressed the role of scaffolds in helping teachers understand curriculum design intent or how to teach units with fidelity or congruence to designers' intentions. There is a need for further research (explored in the literature review in Chapter Two) on scaffolds for helping teachers to understand the overall organization of a unit and learning goals to help them keep the essence of a coherent curriculum unit intact as they modify it to fit their local contexts.

1.3. The current research study

In this dissertation, I explore the effectiveness of software-based scaffolds as a way to help teachers make decisions about curriculum modification that are more congruent with designers' intentions. As part of the study, I developed a software tool called the Planning, Enactment, and Reflection Tool (PERT) that employs specific scaffolding to help teachers better see and reflect on how their curriculum modification decisions affect what I call "unit structures," which are the interconnections between content and inquiry standards within and across different lessons in a curriculum unit (I define these terms more specifically in Chapter Two). I observed twenty different teachers using PERT in order to answer the following three research questions: (1) How does the amount of teaching experience relate to teachers' understanding of curricular coherence? (2) What are the roles of software scaffolds in helping teachers consider more complex elements of curricular coherence when they modify curriculum units? (3)When teachers make changes in curriculum units with the assistance of the software scaffolds, how do they reflect on their understanding of curricular coherence and their curriculum modification strategies?

My hypotheses for these research questions are that software scaffolds can help teachers pay better attention to more complex elements of curricular coherence when they make changes to curriculum units, and thus make decisions that are more in line with the curriculum developers' intentions and support greater scalability for curriculum materials. I also hypothesize that, with the assistance of software scaffolds, teachers will reflect on their knowledge and practices of curriculum modification when they notice the difference between their understanding and provided unit structures information. The details of these research questions and hypotheses are presented in Chapter Two.

1.4. Overview of the dissertation

In Chapter Two I present a review of literature that informs the conceptual framework underlying this dissertation, including curriculum as a cultural tool, expert-novice differences in how teachers adapt curricula, and the specific scaffolds explored in this study. Chapter Two also contains definitions of key terms used in this work as well as a presentation of PERT as an embodiment of the scaffolds. In Chapter Three I describe the methods used in this study, including the setting, participants, procedures, data collection methods (such as think-aloud interview and screen capture tools), data analysis strategies (verbal analysis), and validity issues. Findings are presented in Chapter Four. In Chapter Five I discuss the findings and conclude by considering the implications of this research for the field of science education and curriculum development and implementation.

CHAPTER 2

LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

Inquiry-oriented science curricula is challenging for teachers to enact (Crawford, 2000), and there is a wealth of evidence that teachers' enactment of these materials can vary widely from what curriculum designers envision (Remillard, 2005; Spillane et al., 2002). From a socio-cultural perspective, it is natural for teachers to modify innovative curriculum units in response to the challenges they encounter when they enact inquiry-based curriculum units. Furthermore, experienced and novice teachers may have different modification strategies in terms of the breadth and depth of elements of curriculum units considered. It is not unreasonable to hypothesize that experienced teachers would take different elements into consideration when modifying curriculum units. For instance, they might consider the deeper structures of curriculum units, and therefore make modification decisions that do a better job of preserving the coherence of the materials.

In this study, I examine strategies used by teachers with a range of experience in modifying inquiry-oriented curricula in a scenario that is common to teaching practice: insufficient time to enact the unit as originally designed. I also examine the value of an intervention that uses scaffolds intended to help teachers compare lessons, examine the coverage rates of content and inquiry standards, and in general better understand how their modifications of curriculum relate to the intentions of the curriculum designers. In this chapter, I discuss the challenge of enacting inquiry-oriented curriculum materials. I examine our current understanding of teacher planning from the literature, and what that literature tells us about how best to support novices. These supports are then explored using scaffolding theory, and I present a set of scaffolds that I believe are particularly relevant to supporting curriculum modification. I then describe an intervention that is used to explore the value of these scaffolds, the Planning, Enactment, and Reflection Tool (PERT), and define the key terms used in this thesis to explore teacher decision making about curriculum modification. I conclude this chapter by presenting the specific research questions pursued in this study, along with hypotheses derived from my interpretation of the relevant literature.

2.1. Challenges in enacting inquiry-oriented curricula

When enacting inquiry-oriented curriculum units, teachers face many potential challenges, including (1) a shift of pedagogical paradigms, (2) a shortage of required resources, and (3) lack of knowledge, both about the content embodied in the curriculum and about the curriculum developers' intent, which is related to their ability to make wise choices when modifying the curriculum. First, in the current educational reform climate, instructional practices in science education are shifting significantly from traditional practice. For example, in the past, teachers' teaching practices followed a more linear flow of traditional information delivery. Now, teachers are being asked to adopt inquiry-based instructional practices, use coaching or modeling strategies, manage classroom dynamics, employ technologies to support learning, and use nontraditional assessments, all of which may be more challenging to enact (Marx et al., 1994).

Second, given the ideal pedagogical goals mentioned above, teachers often do not have sufficient resources (e.g., time, materials, technologies) to finish teaching an entire curriculum unit as designed (Blumenfeld, Fishman, Krajcik, Marx, & Soloway, 2000; Remillard, 2005). When a teacher notices that there is not much time left to teach a unit, they will often simply stop teaching in the middle of the unit and students will not be able to achieve the learning goals addressed at the end of the unit (Marx et al., 1994; Schneider, Krajcik, & Blumenfeld, 2005).

A third challenge comes from teachers' lack of required knowledge and skills related to curriculum modification. Without sufficient understanding of the deeper structures of curricula, teachers might modify the curriculum in a way that cuts the units inappropriately or alters the intent of original curriculum (A. L. Brown & Campione, 1996). Less knowledgeable teachers tend to emphasize superficial structures and stick to the details of activities and sometimes miss opportunities to focus on important ideas or connections among ideas (Grossman, Wilson, & Shulman, 1989). Even some experienced teachers may concentrate primarily on what to do and how to do it, rather than on the premises underlying project-based instruction (Blumenfeld et al., 2006). Inappropriate curriculum modification may prevent students from learning all of the key elements in the curriculum and getting a whole picture of the key ideas as intended by the curriculum designers (Shwartz, Weizman, Fortus, Krajcik, & Reiser, 2008).

2.2. Modification of curriculum units

In this section, I will first describe typical teachers' modification practices that can result from the challenges they encounter during implementation of inquiry-oriented curricula. I will also describe the differences between experienced and novice teachers in terms of the modification strategies and factors they considered.

In the American education system, curriculum materials are usually designed by curriculum design experts or science education researchers, and then enacted by teachers. Curriculum designers embed reform ideas in the curriculum materials and organize the lessons according to a particular design theory and the expectation that, if the materials are enacted as designed, students will develop a deep understanding of major concepts and skills. But in reality, all curriculum developers understand that there will be variation at the classroom level as teachers modify curriculum materials to meet the needs of their local contexts. Sometimes these modifications may be made thoughtfully, such as when a teacher believes that students lack particular background knowledge or when access to resources such as computers or lab equipment is not possible. But sometimes these modifications are made less thoughtfully, such as when a teacher simply runs out of time and must stop teaching a curriculum unit to move on to another topic, or when a teacher does not understand that materials might have an iterative design and only address topics once, without later follow-up. Some researchers treat this as a problem of fidelity (Snyder, Bolin, & Zumwalt, 1992), others as a problem of congruence between the enactment and the designed materials (Blumenfeld et al., 2006).

In building a plan or design, designers usually examine parts of their plans and consider the advantages and disadvantages of using a part in the plan. Designers compare the advantages and disadvantages of including candidate parts in the final product. During the design process, designers check the partial or complete product to see if the relevant design specifications are satisfied. They also generate explanations about why something did not work as predicted. The difference between their expectations and the outcome creates opportunities for reflection on their understanding and strategies for modification. As a result of these processes, a solution is incorporated into the designer's repertoire of knowledge to be used in future design. These articulations and reflections in action can help designers identify weaknesses in their understanding and make better decisions for later modifications (Schon, 1983).

Similar to the steps used by experts in making design changes, teachers' ideal modification practices should include the following steps or elements: (1) Compare lessons; (2) Examine the coverage rates of standards and connections of a unit; (3) Examine change in the coverage rates of standards and connections of the modified units; and (4) Reflect on understanding and modification strategies. When comparing lessons, teachers identify the advantages and disadvantages of including or excluding individual lessons. When teachers examine coverage rates of standards and connections of a unit, they may point out standards that are covered more than others (I call it *strong coverage rates*) or less than others (I call it *weak coverage rates*). When teachers examine changes in the coverage rates of standards and connections in the modified units, they may identify the coverage rates of standards or connections that go up (I call it *improved coverage rates*) or go down (I call it *worsened coverage rates*). When teachers reflect on their understanding and modification strategies, they examine their understanding of curriculum units and decide whether they are satisfied with the modified units.

When they make changes, experienced teachers may focus more on the overall coverage rates of learning goals and the connections among lessons in a unit, and pay less attention to the details of individual lessons. They may be concerned with the flow of activities for an entire week or the whole unit, rather than with the fine details of each lesson. That is, experienced teachers' plans are explicit and rich in interconnections, because they can better predict what will happen as a result of a particular lesson (Clark & Yinger, 1987). For example, they know what types of prior knowledge their students are likely to bring to a lesson and the consequences of not dealing with or building upon this prior knowledge for the success of later lessons. On the other hand, the planning of novice teachers may consist primarily of daily lesson planning, and tend to provide simple descriptions of isolated events, instead of making inferences about the underlying structure of the teaching and student learning (Borko & Putnam, 1996; Clark & Yinger, 1987). Teachers without much experience with innovative curriculum units usually focus more on facts, rules, and procedures and stick closely to detailed lesson plans listed in the text. As a result, they are likely to miss the curriculum design principles that emphasize important ideas and connections among these ideas (Grossman et al., 1989; Spillane et al., 2002).

I found similar results in pilot studies for this dissertation. I investigated teachers' understanding of curriculum design principles and the role of teachers' experiences in their understanding of underlying connections between lessons. This pilot study showed that science teachers have a reasonable understanding of the relationships between individual lessons and learning goals, but have difficulties identifying connections among lessons, or the deeper structure of the curriculum (Lin & Fishman, 2004, 2006a, 2006b).

2.3. Elements of curricular coherence explored in this study

As described earlier, curriculum designed to be coherent emphasizes the interconnection between important concepts and science practices in order to create effective learning experiences. Coherent curricula have several important features (Roseman et al., in press). First, they focus on a set of interrelated ideas across grade levels and subject areas. Second, they emphasize important connections among these ideas. Third, they help students make connections among the ideas and use them to explain phenomena. For example, the IQWST curriculum relates ideas across life, earth, and physical sciences in 6-8th grade. IQWST developers sequence their units to ensure that students investigate observable phenomenon before they encounter less-observable phenomenon (Krajcik et al., in press). In this study, I explore some of the elements that constitute curriculum coherence and I call these elements unit structures. I will first present my definition of the types of unit structures and then the levels of unit structures.

2.3.1. Unit structures

Unit structures refer to: (1) the relationships between individual lessons and learning goals addressed in a unit; (2) the connections that exist between lessons; (3) the number of covered relationships and connections of a lesson; and (4) the rate of coverage of these relationships and connections in a modified unit. In this study, learning goals refer to the focused content and inquiry standards addressed in a unit or a set of units. Figure 1 shows a schematic diagram of the relationship between lessons and learning goals and the connections between lessons. In Figure 1, Lesson 2 addresses content standards B and inquiry standards A. Content standards A is addressed in both Lesson 1 and Lesson 3. Lesson 1 and Lesson 2 are connected because they both address inquiry standards A.

First, an individual lesson addresses content and inquiry standards. For example, a unit might address the following content standard for seventh grade science several times, “A substance has characteristic properties, such as density, a boiling point, and solubility, all of which are independent of the amount of the sample” (National Research Council, 2000). Second, one lesson may connect with another lesson through a common standard. These lessons are designed to connect in order to reinforce the learning goal or to work together to help students to acquire complete understanding of the learning goal. For example, a lesson may introduce the concept of “a substance has characteristic properties” and a later lesson may introduce ways to identify different substances by measuring their properties. These two lessons are connected through this common content standard and the former must be taught before the latter. Third, lessons in a coherent unit usually address several learning goals and are connected to other lessons. For the example shown in Figure 1, Lesson 1 addresses content standard A and inquiry standard A. It is also related to Lesson 2 and Lesson 3. Some lessons may address more learning goals and connect to more lessons than other lessons in a unit. Fourth, when a teacher removes a lesson from a unit, the total number of opportunities for addressing its related standards decreases. For example, if the *conservation of mass* content standard is addressed in ten lessons in a unit and a teacher removes two lessons that address this content standard from the unit, then the coverage rate of *conservation of mass* in the remaining lessons will drop to 80 percent. The removal of this lesson also breaks its connections with other lessons.

The first and second elements are the focus of previous studies on curriculum coherence (Newmann et al., 2001; Roseman et al., in press). In contrast, the third and forth elements have not received as much attention. The third and fourth elements of unit structures demonstrate the big picture of coverage of curricular coherence and consequences of changing parts of a curriculum unit. This type of overview information may be useful to teachers when they make decisions of whether to keep or remove parts of a curriculum unit.

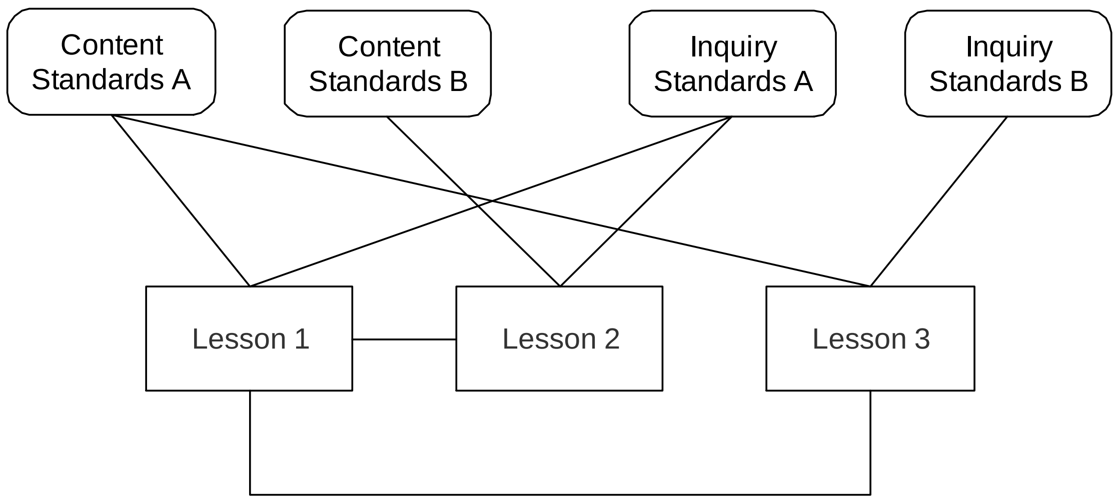

Figure 1. A schematic diagram of unit structures.

2.3.2. Levels of unit structures

In order to explore teachers' level of expertise in terms of the "depth" of unit structures, I developed a scheme to categorize the elements of unit structures into basic, intermediate, and advanced levels for the purposes of this study. The higher the level, the more a particular element of unit structures is related to the overall picture of coverage and connections between lessons. From my pilot studies (Lin & Fishman, 2004, 2006a), I also found that teachers were in general not familiar with these two deeper or "higher" level structures. The basic level of types of unit structures includes elements related to standards in a lesson and lessons related to a standard. The intermediate level includes elements related to lesson connections and overall coverage rates of standards. The advanced level of unit structures includes elements related to the connections through standards, the number of connections of a lesson, and the overall coverage rates of connections in a unit. Table 1 shows the elements of unit structures in the three levels. I will use this categorization to determine teachers' level of understanding of unit structures.

2.4. Scaffolding strategies for helping teachers consider deeper structures of units when they modify units

The goal of this study is to examine the role(s) of software scaffolds in helping teachers considering the deeper structures of curriculum units when they compare lessons, examine coverage, and examine consequences during modification. In this section, I will describe general scaffolding theories and how scaffolds can help teachers modify their units.

2.4.1. Scaffolding theories

Constructivist learning theories emphasize that understanding and learning involves active, constructive, and generative processes (Piaget, 1954; Vygotsky, 1978). Socio-constructivist theories emphasize that novices develop proficiency in a discipline through social interaction with other people or tools related to the discipline (Cole, 1996; Lave, 1988; Wertsch, 1998). Novices start participating in an activity by referring to their personal meanings, negotiate new meanings with others, and gradually become able to use the relevant cultural tools in the discipline in manner consistent with experts in the discipline (J. S. Brown, Collins, & Duguid, 1989; Rogoff, 2003).

Table 1. The three levels of unit structures examined in this study.

Level	Types of unit structures	Code
Basic	• Content standards covered by a lesson	1.1
	• Inquiry standards covered by a lesson	1.2
	• Lessons related to a content standard	1.3
	• Lessons related to an inquiry standard	1.4
Intermediate	• Number of content standards related to a lesson	2.1
	• Number of inquiry standards related to a lesson	2.2
	• Content connections related to a lesson	2.3
	• Inquiry connection related to a lesson	2.4
	• Overall coverage rates of content standards	2.5
	• Overall coverage rates of inquiry standards	2.6
Advanced	• Number of content connections related to a lesson	3.1
	• Number of inquiry connections related to a lesson	3.2
	• Connections related to a content standard	3.3
	• Connections related to an inquiry standard	3.4
	• Overall coverage rates of content connections	3.5
	• Overall coverage rates of inquiry connections	3.6

From this perspective on learning and development, learners develop their understanding in a personal zone of proximal development (ZPD), which is defined as "the distance between the learner's actual developmental level as determined by independent problem solving and the higher level of potential development as determined through problem solving under adult guidance and in collaboration with more capable peers" (Vygotsky, 1978, p. 86). In addition to assistance from more capable peers, learners are also exposed to cultural tools that provide affordance and constraints for tasks (Wertsch, 1998). Experienced others and tools could provide a range of assistance for task accomplishment and reflection (Palincsar & Brown, 1984; Wood, Bruner, & Ross, 1976). This assistance is called scaffolding, and it assists learners within their ZPD and is gradually changed and reduced (or faded) as the learner takes more ownership of their roles in problem solving and engages in more advanced thinking (Collins, Brown, & Newman, 1989).

Software tools have been used to provide scaffolding in interactive learning environments that foster the development of understanding (Cognition and Technology Group at Vanderbilt, 1990; Jonassen, 1995; Krajcik, Blumenfeld, Marx, & Soloway, 2000; Papert, 1993; White, 1993). Software tools can help structure the task of problem solving and can encourage learners to examine their understanding and identify what they don't know well. (Reiser, 2004). Software tools and handheld devices can help people examine their understanding and make sense of complex concepts (Quintana et al., 2004; Squire & Klopfer, 2007). In addition, Software tools can rapidly calculate complex data and present results as visualized representations. Such speed and flexibility is difficult to achieve with traditional paper-based curriculum materials (Bailenson et al., 2008). Several software scaffolding design principles have been developed for supporting science learning (Linn, Davis, & Eylon, 2004; Quintana et al., 2004) These software scaffolds were designed based on learning theories such as cognitive apprenticeship and situated cognition (J. S. Brown et al., 1989). In this study, I focused on three of the scaffolding strategies derived from those design principles. Although these software scaffolding design principles were designed to describe scaffolds to support students learning science, I believe that they are also relevant for understanding potential scaffolds to support science *teachers* as learners, in this case learning how to modify science curriculum materials with better understanding of their underlying design intent. In the following sections, I describe the three scaffolding strategies used to support teachers' understanding of the complex idea of curricular coherence.

2.4.2. Scaffolding strategy #1: Providing visualization to help teachers inspect multiple aspects of unit structures

By exploring cases of an ill-structured domain from multiple perspectives, people can increase their ability to make sense of complex concepts and their flexibility of dealing with new sets of events (Spiro & Jehng, 1990). Since no single representation can easily support detailed consideration of every perspective in examining the complex connections among elements in a system (Shah & Hoeffner, 2002), one way to demonstrate such complexity is to use multiple representations that help people examine data from multiple perspectives (Leinhardt, Zaslavsky, & Stein, 1990; Mayer, 2001). When people make comparisons across different aspects of the same data, they can identify the implicit properties of elements more easily (Reiser et al., 2001; Schwartz & Bransford, 1998). For example, the software tool eChem includes a range of visualizations providing different views of molecules that students build so they can automatically generate correspondences between various molecular representations (Wu, Krajcik, & Soloway, 2001).

Scaffolding can simplify the task for learners by hiding parts of the task, allowing them to focus their attention on the main tasks to be learned. For example, it would be time-consuming and tedious to calculate all of the content and inquiry standards in modified lessons by hand while teachers make changes to a unit. Software tools can offload part of the cognitive process so that teachers can focus on the overall coherence of the unit when they modify lessons. This scaffolding strategy is related to Quintana et. al.'s scaffolding strategy, "3a: Provide representations that can be inspected to show underlying properties of data" (Quintana et al., 2004).

2.4.3. Scaffolding strategy #2: Demonstrating changes in coverage rates of unit structures as consequence of modification

Malleable representations allow learners to directly manipulate representations and get immediate feedback about the consequences of changes made (Kafai & Resnick, 1996; Papert, 1993; Sandoval, 2003). In math and science classrooms, software tools also afford learners the ability to construct, apply, and evaluate models (Penner, Lehrer, & Schauble, 1998; Roth, Woszcsyna, & Smith, 1996). For example, the software tool Model-It enables students to represent and explore relations between variables when students are building relationships in their model (Metcalf, Krajcik, & Soloway, 2000; Stratford, Krajcik, & Soloway, 1998).

Making changes in coverage rates for unit structures explicit to teachers may help them pay attention to structures neglected as a result of their proposed modifications. Since unit structures consist of the coverage of learning goals and the complex connections between lessons, teachers may not be able to track the influence of modifications on all aspects of unit structures. For example, a teacher may be aware that removing a lesson makes the coverage level of a content standard drop, but may not be able to notice the broken connections. In addition, making the consequences of changes explicit may help teachers evaluate the advantage and disadvantages of different modification options. For example, teachers may choose between two lessons by comparing the relative amount of increased coverage rate of adding either one of them.

2.4.4. Scaffolding strategy #3: Encouraging reflection

Experience alone does not lead to learning. Learners need support for reflection on their experiences (Collins et al., 1989; Scardamalia & Bereiter, 1991). Reflection involves examining one's experiences and considering principles used for thinking and action (Davis & Linn, 2000; Schon, 1987). The results of reflection can contribute to building new understandings to inform future actions in similar situations (A. L. Brown, Bransford, Ferrara, & Campione, 1983). Reflection helps make learners' thinking overt and allows gaps and disagreements in understanding to become visible (Schwartz, Brophy, Lin, & Bransford, 1999; Teasley & Roschelle, 1993).

In the process of attempting to accomplish tasks, failure also plays a central role in promoting reflection. Failure promotes a need to reflect on the outcome, explain unexpected results, and revise newly developing conceptions (Pintrich, Marx, & Boyle, 1993; Posner, Strike, Hewson, & Gertzog, 1982). The concept of scaffolding also emphasizes the importance of focusing learners' attention by highlighting discrepancies between what a learner might produce on their own and the target practice (Vygotsky, 1981; Wood et al., 1976). One related strategy is to have learners make a prediction before they see the results of their work. Unexpected results can often make people question their usual thinking process (White & Frederiksen, 1998).

Another scaffolding approach for encouraging reflection involves using prompts and text areas in the software interface. The process of responding to prompts enables learners to review their understanding of a concept or thinking process (Davis & Linn, 2000; Puntambekar & Kolodner, 2005). For example, text prompts can convey important ideas learners should think about regarding the products they generate and the information they analyze throughout their work (Jackson, Krajcik, & Soloway, 2000).

For teachers to make meaningful changes in their instructional practices, they must become more reflective about their practices in ways that make their knowledge and modification strategies about pedagogy and learners more explicit. They also need to reconsider their practices on the basis of these reflections to improve their understanding of teaching and learning (Munby, Russell, & Martin, 2001; Schon, 1987). This scaffolding strategy is related to Quintana et. al.'s scaffolding strategy "7c: Provide reminders and guidance to facilitate articulation during sense-making" (Quintana et al., 2004).

2.4.5. How scaffolds are examined in this dissertation

In order to test the roles of the scaffolds in helping teachers consider higher levels of unit structures, I have developed a software tool that supports teachers' unit modification process by addressing the three scaffolding strategies described above. In addition to the software tool, I also designed two unit modification activities in which teachers make changes to units with and without the scaffolding provided by the software tool. The goal is to see the differences between levels of unit structures considered by teachers in the two situations. I will describe the details of the software tool and the accompanying modification activities in the following sections.

According to scaffolding theories, one important characteristic is that scaffolds should “fade” as learners internalize the target performance, otherwise, they are only tools that support doing tasks (Pea, 2004). It is possible that the software scaffolds in this study are supports and not true scaffolds. In order to test this one would need a study with an iterative design where the scaffolds are not present in later iterations. This study is not designed to allow for that comparison. However, the results will demonstrate that the scaffolds explored in this study do alter teachers’ modification strategies, and therefore may provisionally be considered as scaffolds.

2.5. Description of PERT

In this section, I describe the design of PERT, a software tool designed to help teachers consider higher levels of unit structures by addressing the scaffolding strategies described above. PERT includes three modules: (1) *Select lesson*; (2) *See Coverage of Standards*; and (3) *See Coverage of Connections*. I describe the specific features in each module and the scaffolding strategies related to these features. In the *Select Lesson* module (see Figure 2), PERT demonstrates the structure of lessons in a unit and the learning performance related to a lesson. In addition, it also shows teachers the target and current class periods selected for inclusion in the unit (the modification goal). In the *See Coverage of Standards* module (see Figure 3), PERT demonstrates the relative coverage rates of content and inquiry standards (the intermediate level of unit structures) and the details of the coverage in the unit (the basic level of unit structures). In the *See Coverage of Connections* module (see Figure 4), PERT demonstrates the relative coverage rates of content and inquiry connections (the advanced level of unit structures) and the details of the connections in the unit (the intermediate level of unit structures).

2.5.1. Features addressing scaffolding strategy #1: Providing visualization to help teachers inspect multiple aspects of unit structures

PERT shows teachers different aspects of the coverage and details of the coverage rates of unit structures in a curriculum unit. The different aspects include: (1) the relative coverage rates of standards; (2) the lessons addressing a standard; (3) the standards addressed in a lesson; (4) the relative coverage rates of connections; (5) the lesson connections related to a standard; (6) the connections related to a lesson; and (6) the number of connections related to a lesson. In this section, I will describe how these features address scaffolding strategy #1: Providing visualizations to help teachers inspect multiple aspects of unit structures. The purpose of using this scaffolding strategy is to show multiple types of unit structures to teachers to make it easier for teachers to make sense of higher levels of unit structures.

In the *Select Lesson* module, teachers can see the structure of the current unit, including the lessons and corresponding page numbers in the curriculum materials and the number of class periods designed to be used by each lesson (see #1 in Figure 2). By clicking on the “See Details” buttons along the column of “learning performance”, teachers can see description of related learning performance (see #2 in Figure 2).

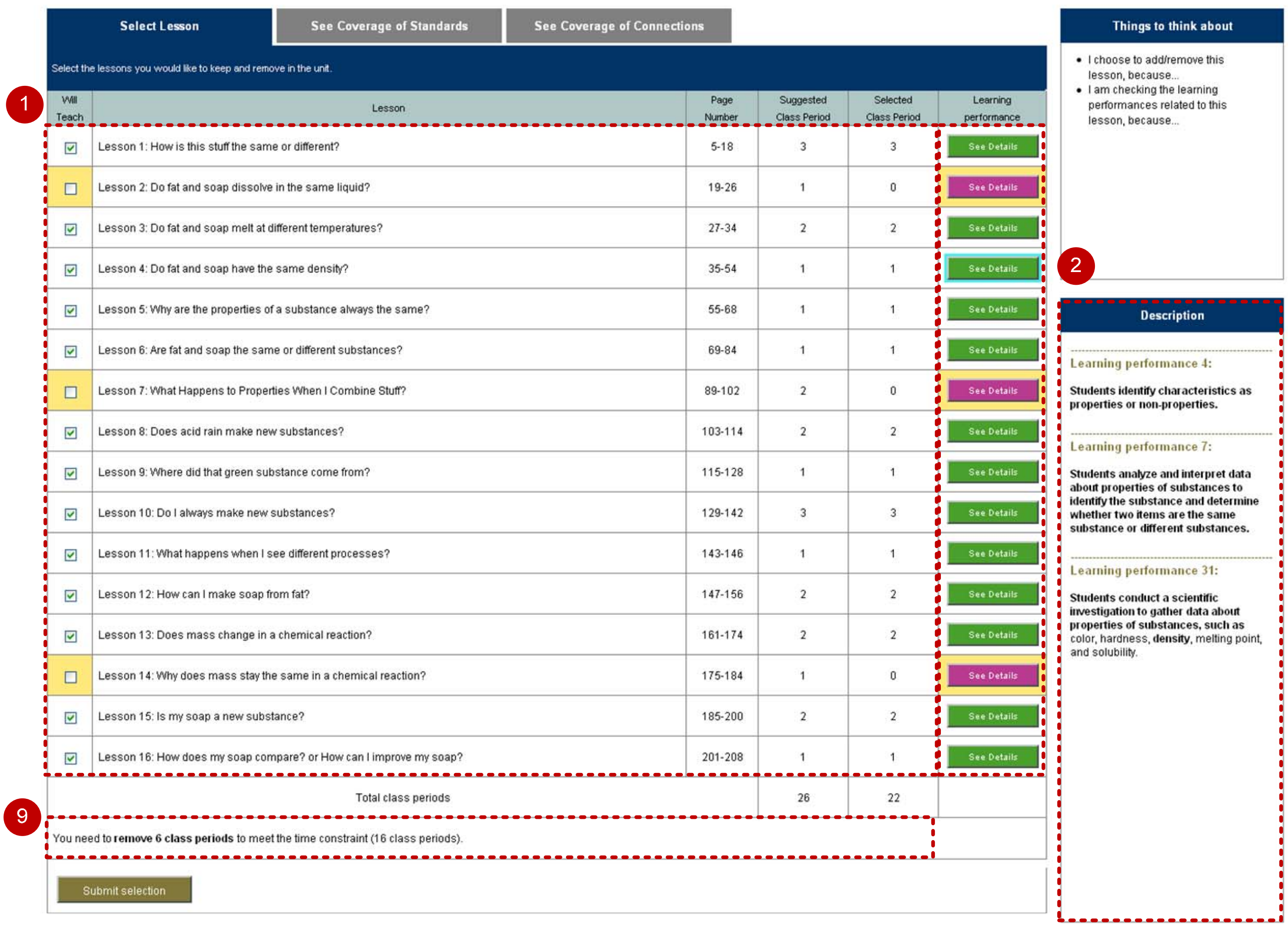

Figure 2. The Select Lesson module of PERT

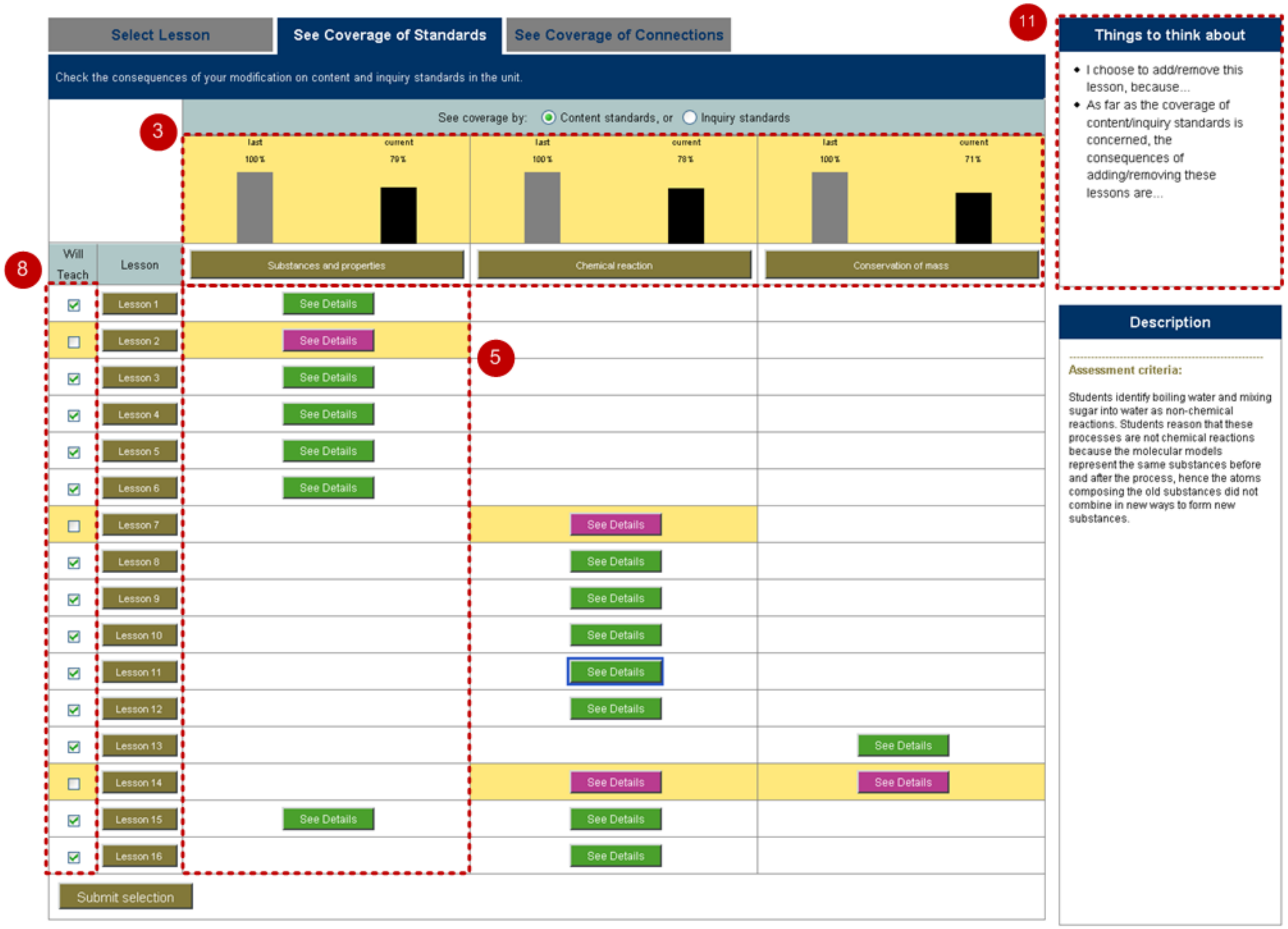

Figure 3. The See Coverage of Standards module of PERT

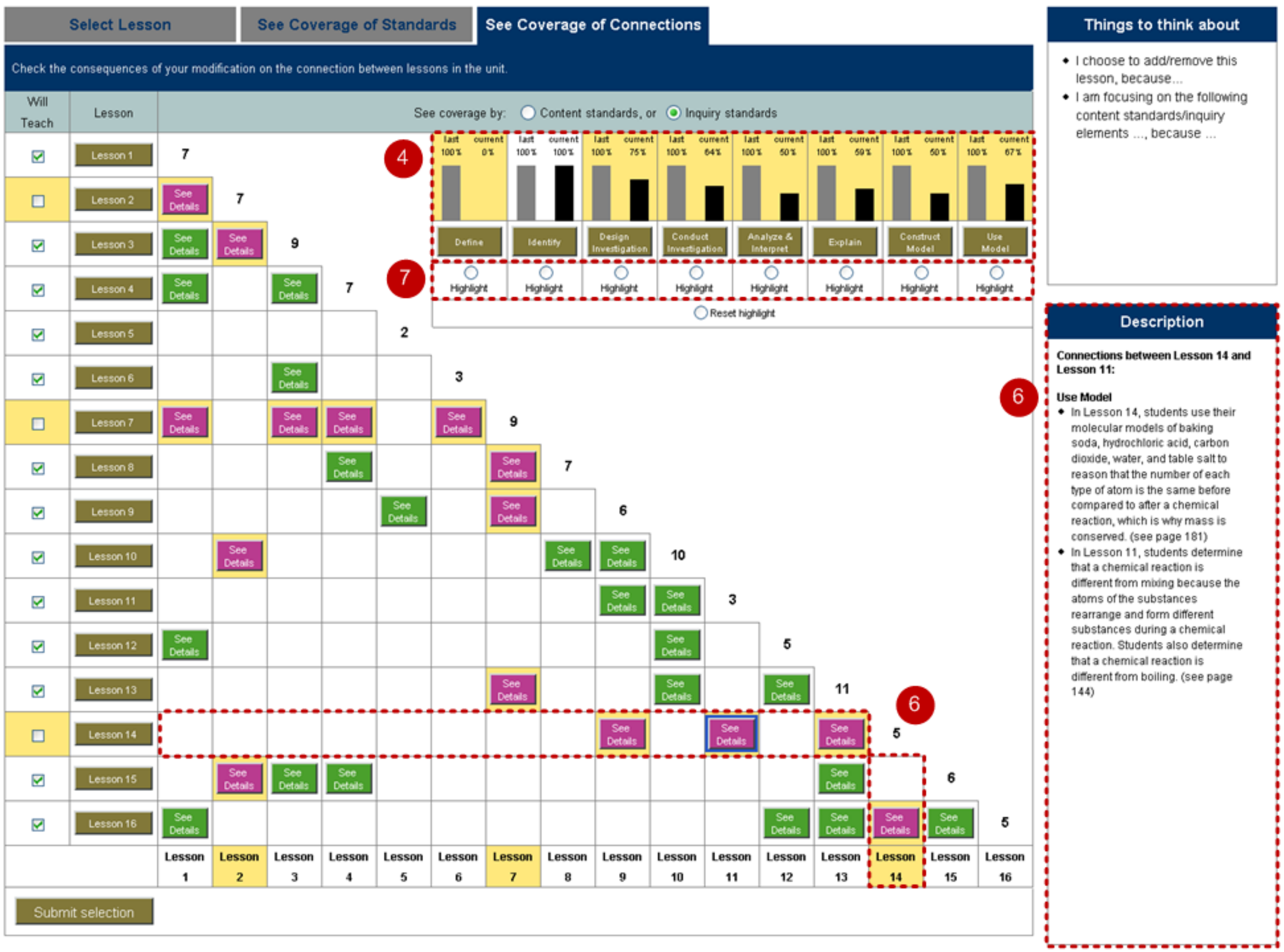

Figure 4. The See Connections module of PERT

In the *See Coverage of Standards* and *See Coverage of Connections* modules, the relative coverage rates of standards and connections are represented by a set of bar graphs that show the coverage rates of each standard in the modified unit (see #3 in Figure 3, and #4 in Figure 4). Graphs and other visual displays can be helpful in demonstrating quantitative data (Larkin & Simon, 1987). Among them, bar graphs are often used to help viewers compare the relative value of discrete data (Zacks & Tversky, 1999). In the example shown in Figure 3, the similar heights of the black bar graphs show that the coverage rates of the three content standards is about the same.

I used color codes in PERT to help teachers identify covered and missing coverage of standards and connections. Colors can be used to group elements in a display. For example, color can help viewers quickly scan and group data in a temperature map (Edelson et al., 1999). Another potential benefit of using colors is that it reduces the difficulty viewers face in keeping track of graphic referents because of the demands imposed on working memory (Kosslyn, 1994). I used green buttons to show covered standards or connections and red buttons to show missing standards or connections. This representation addresses scaffolding strategy #1, since it aims to help teachers focus on either the covered or missing elements by glancing at the distribution of colored buttons.

In the *See Coverage of Standards* and *See Coverage of Connections* modules, the details of the coverage in the unit are represented by buttons in a table where the rows are the lessons and the columns are the standards. Table or matrix representations make the big picture or overarching relationships apparent. When a matrix is examined both vertically and horizontally, the big picture can emerge and help students discover implicit overarching relationships (Larkin & Simon, 1987). Tables can be useful for representing the complex inter-connections among elements of a complex system (Ulrich & Eppinger, 2004). A button in a table cell indicates that the elements in the corresponding row and column are related. Teachers can look down along the column representing a standard to see the lessons that address this standard. Similarly, they can also look along the row of a lesson to see related standards. Take the substance and properties content standard shown in Figure 3 (see #5 in Figure 3) as an example, the buttons along the column show that six of the seven opportunities (lessons 1, 3, 4, 5, 6, 15) addressing this standard are included in the currently selected lessons.

Connections are displayed in a triangle-like table. The buttons in the cells indicate the connections between two lessons of corresponding row and column. In addition, the numbers along the diagonal of the table represent the number of connections of the lesson in each corresponding row. For example (see #6 in Figure 4), Lesson 14 has connections with lessons 9, 11, 13, and 16 through inquiry standards, as indicated by the four buttons. The number "5" at the end of the row of Lesson 14 indicates that Lesson 14 has five connections with the four lessons. Lesson 14 has two connections with Lesson 11 through inquiry standards, shown in the Description text box.

The highlight feature in the *See Coverage of Connections* tab (see Figure 4) enables teachers to focus on just the connections related to a specific standard. When a teacher clicks on the radio button of the highlight feature, they will see the buttons related to this standard become highlighted (see #7 in Figure 4). This representation addresses scaffolding strategy #1, since it aims to help teachers focus on only one aspect of connections.

PERT enables teachers to examine information on unit structures at four levels of detail. The most abstract level refers to the tab representation that lets teachers focus on the coverage rates of either standards or connections of a unit. The second level refers to the bar graphs for the coverage rates of standards and connections. The third level refers to the table with buttons that show the details of the coverage rates of standards and connections. The most detailed level is the content displayed in the Description area. Teachers can also refer to curriculum materials for further information about learning activities.

2.5.2. Features addressing scaffolding strategy #2: Demonstrating changes in the coverage rates of unit structures as consequence of modification

In all of the three modules of PERT, teachers can select the lessons to be included in the enactment by checking or deselecting the boxes before lessons. Checked boxes represent selected lessons, and empty boxes represent the ones not selected (see #8 in Figure 3). This feature enables teachers to select the lessons they want to include in the modified unit and to see the consequences of the modification (described in later sections). By selecting different combinations of lessons, teachers do thought experiments on what kind of modification serves their needs for teaching and student learning.

In the *Select Lesson* module, teachers can also see the number of target class periods and currently used class periods. The number of target class periods is the amount of class periods available for doing this unit. PERT calculates the number of class periods of lessons currently selected and shows the difference between selected and target class periods. In the example shown in Figure 2, teachers need to shorten this unit by six more class periods. Scaffolding strategy #2 is addressed in the function that demonstrates the difference between the numbers of class periods of current selected lessons and the time constraint (see #9 in Figure 2). This information reminds teachers that they need to reconsider current lesson selections in order to meet the time constraints.

In the *See Coverage of Standards* and *See Coverage of Connections* modules, I used bar graphs to represent the change in coverage between the current lesson selection and the last lesson selection. For each standard, the gray bar represents the coverage rate of this standard based on last lesson selection. The black bar represents the coverage rate of this standard based on the current lesson selection. By comparing the heights of the bars, teachers can tell whether the coverage goes up or down as a consequence of different lesson selections. For example, the black bars are lower than the gray bars for all the standards in Figure 3, which means that removing lessons 2, 7, and 14 lowers the coverage rates of the three content standards (see #3 in Figure 3). This feature addresses scaffolding strategy #2 because it helps teachers identify improved and decreased coverage rates of standards

I used color codes in PERT to help teachers identify the changed coverage rates of standards and connections. For showing the changed coverage rates of standards and connections, I used an orange background for bar graphs or buttons to indicate that this element was influenced by the most recent change in lesson selection. For example, if a teacher removed Lesson 2, 7, and 14 (see #8 in Figure 3), the consequence is that all of the coverage for content standards is changed (see #3 in Figure 3) and one of the seven opportunities to address the substance and properties content standard is missed (see #5 in Figure 3). This type of representation addresses scaffolding strategy #2, since it aims to help teachers locate the parts influenced by changes in lesson selections.

2.5.3. Features addressing scaffolding strategy #3: Encouraging reflection

In this study, the major strategy for encouraging reflection is creating opportunities to identify conflicts in understanding and providing text prompts to help teachers identify the difference between their understandings of unit structures and those addressed in the units. Before teachers make changes to the organization of lessons in a unit, they make predictions about how their modifications will influence the coverage rates of standards in the unit. Then they test the modified unit and check whether their predictions are correct. If their predictions are wrong (an expectation failure), the prompts would encourage them to think about what aspects of the modification they needed to recognize. When teachers recognize the difference between their understanding and what is presented by the software tool, they might explore and consider more about the unit structure, therefore creating opportunities for improvement (Posner et al., 1982).

PERT also provides text prompts to remind teachers about issues related to different aspects of the coherence of the unit. For example, prompts are used to remind teachers where to find broken connections and changes in the coverage rates of inquiry standards. Examples of prompts include, “What are the problem requirements? Which criteria do your solutions meet? Why do you think these criteria are important? What are the positive features of each of the solutions? What are the limitations of each of the solutions? What are the criteria you are using to evaluate possible solutions?” (see #11 in Figure 3)

2.5.4. Summary of features and covered scaffolding strategies

In Table 2, I summarize the scaffolding design strategies and their corresponding features in PERT. For some features, I also list the corresponding level of unit structures as described in Table 1. For example, the corresponding level of unit structures for the feature, “Show relative heights of bars to represent relative coverage rates of standards and connections,” is “Intermediate (2.5, 2.6).” That means the information represented by this feature falls into the intermediate level of unit structures and the corresponding code in my analytic scheme (presented in Chapter 3) for the specific types of unit structures is 2.5 and 2.6 in Table 1.

2.6. Lesson selection activities

When people are involved in activities beyond their current understanding but within their zone of proximal development, they have opportunities to examine their understanding of a topic (J. S. Brown et al., 1989; Stone, 1998; Wood et al., 1976). Design activities are well-suited for helping people understand underlying principles by providing opportunities to use knowledge, making implicit beliefs explicit, and reflecting on the solutions (Perkins, 1986; Schwartz & Bransford, 1998). Design places learners in the process of constructing rather than receiving knowledge (Lehrer, 1993).

Table 2. Overview of scaffolding strategies, corresponding features, and addressed levels of unit structures.

Scaffolding strategy	Feature	Level of unit structures
Scaffolding strategy #1: Providing visualization to help teachers inspect multiple aspects of unit structures	Show structure of lessons	
	Show relative heights of bars to represent relative coverage rates of standards and connections	Intermediate (2.5, 2.6)
	Show buttons in a table to represent details of coverage rates of standards and connections	Intermediate (1.1, 1.2, 1.3, 1.4, 2.3, 2.4), Advanced (3.3, 3.4)
	Show number of connections related to a lesson	Advanced (3.1, 3.2)
	Show four levels of details of information about unit structures	
	Highlight connections related to a standard	Advanced (3.3,3.4)
	Colors of buttons that show covered and missing coverage of standards and connections	Intermediate (1.1, 1.2, 1.3, 1.4, 2.3, 2.4), Advanced (3.3, 3.4)
Scaffolding strategy #2: Demonstrating changes in coverage rates of unit structures as consequence of modification	Teachers can select different combinations of lessons and see consequence in terms of coverage rates of unit structures	
	Show difference between the number of current selected class periods and available class periods	
	Show two bars whose heights represent the rates of coverage for last and current selection of lessons	Intermediate (2.5, 2.6)
	Show orange background that marks recovered or missing coverage due to most current changes in lesson selection	Intermediate (1.1, 1.2, 1.3, 1.4, 2.3, 2.4, 2.5, 2.6), Advanced (3.3, 3.4)
Scaffolding strategy #3: Encouraging reflection	Prompts that encourage teachers to consider their strategies	
	Teachers compare their prediction and actual consequence of coverage	

In this study, teachers were recruited to participate in a lesson selection activity in which they are asked to shorten a unit, reflecting a real-life situation. Modifying units is a normal part of teachers' work in planning to teach that situates teacher learning in a meaningful context (Putnam & Borko, 2000). When teachers plan to adapt an innovative curriculum to their specific situation, they need to consider what to teach and how to teach, anticipate potential difficulties, and then make choices to solve these problems (Clark & Peterson, 1986). Teachers construct new knowledge by integrating new insights with prior knowledge and modification strategies, applying ideas to practices, and evaluating and reflecting on the results (Carter & Doyle, 1987). By observing these teachers' modification practices, I hope to identify their considerations and their levels of understanding of unit structures when modifying the curriculum units.

2.7. Research questions and hypotheses

My goal is that through participating in design challenges that address unit structures with support from software scaffolds, teachers will become aware of higher levels of unit structures when they modify curriculum units. In addition, the scaffolding will help teachers to reflect on their understanding about unit structures and modification strategies when they recognize the difference between their understanding and the provided unit structures information.

2.7.1. Research question 1: How does the amount of teaching experience relate to teachers' understanding of curricular coherence?

Experts can identify functions and deeper structures of a system, and solve problems by considering the big picture. Teachers' level of expertise is related to their understanding of deeper structures of curriculum units (Munby et al., 2001; Wilson, 2000). Therefore, my hypothesis for the first research question is that experienced teachers will be able to recognize higher levels of unit structures than novice teachers. For example, connections between lessons are more implicit than the content standards addressed in a lesson and would be more difficult to recognize. I also hypothesize that when teachers identify conflicts between their understanding of unit structures and the information provided by the software tools, they may try to clarify their understanding.

2.7.2. Research question 2: What are the roles of software scaffolds in helping teachers consider more complex elements of curricular coherence when they modify curriculum units?

The design of scaffolds used in this study follows the guideline of effective scaffolding design principles for helping people understand deeper structures of information. Two related scaffolding strategies are: #1: Providing visualization to help teachers inspect multiple aspects of unit structures; and #2: Demonstrating changes in coverage rates of unit structures as a consequence of modification. I hypothesize that these scaffolds should be able to help teachers consider higher levels of unit structures when they conduct unit modification, including comparing lessons, examining coverage rates of unit structures, and examining the change of coverage rates of unit structures.

2.7.3. Research question 3: When teachers make changes in curriculum units with the assistance of the software scaffolds, how do they reflect on their understanding of curricular coherence and their curriculum modification strategies?

Making modifications to curriculum units with information about multiple aspects of unit structures, teachers have rich opportunities to identify the weakness in their understanding of unit structures and modification strategies. Scaffolding strategy #3: Encouraging reflection, was used to help teachers examine their understanding of unit structures and modification strategies. I hypothesize that teachers will try to clarify their understanding of unit structures and make modification decisions based more on higher levels of types of unit structures.

2.8. Summary and overview of remaining chapters

In this chapter, I described challenges teachers face when they enact inquiry-based curriculum units and their likely unit modification practices. Then I introduced the idea of unit structures to represent deeper levels of curriculum units. I described scaffolding strategies that guided the design of a software tool used to evaluating the roles of software scaffolds in helping teachers understand higher levels of unit structures in unit modification activities.

In Chapter Three, I will describe the methods used in this study, including the setting for testing the scaffolds, teachers participating in this study, procedures for data collection, data analysis, and strategies used to enhance validity. In Chapter Four, I will present findings for answering the three research questions. In Chapter Five, I will compare the findings to the hypotheses and discuss the implications and directions for future studies.

CHAPTER 3

METHODS

This study aims to examine the roles of software scaffolds in helping teachers visualize the deeper design intent of curriculum units. In order to accomplish this purpose, multiple sources of data are collected. In this chapter, I first discuss the overall approach and rationale of the research design. I then describe the context of this study and provide a detailed account of data collection and analytical procedures.

3.1. Overview of study

The research questions addressed in this study are: (1) How does the amount of teaching experience relate to teachers' understanding of curricular coherence? (2) What are the roles of software scaffolds in helping teachers consider more complex elements of curricular coherence when they modify curriculum units? (3)When teachers make changes in curriculum units with the assistance of the software scaffolds, how do they reflect on their understanding of curricular coherence and their curriculum modification strategies? In order to answer these research questions, I designed activities in which teachers modified project-based science curriculum units without the software scaffolds and then with the software scaffolds. The purpose is to compare the difference between teachers' modification practices when the software scaffolds are and are not present. I observed twenty teachers engaged in the curriculum modification activities. Each teacher was teaching one of three project-based science units in middle schools (Krajcik, McNeill, & Reiser, 2006). These teachers had varying levels of experience teaching project-based science units, allowing me to examine how teachers with different individual characteristics use the software scaffolds in their modification practices.

3.1.1. Interview with teachers

The interview with teachers includes five parts: (1) survey; (2) lesson selection without the software scaffolds; (3) tutorial of PERT; (4) lesson selection with the software scaffolds; and (5) post-task interview. By filling out the survey, teachers provided information about the amount of experience teaching project-based science units. Next, teachers were told that they needed to shorten a unit because they had less time to teach the unit than was specified by the curriculum's designers. I observed their decisions about how to shorten the unit *without* the support of scaffolds beyond what is already available in the curriculum materials. At the end of their modification, they were asked to estimate the coverage rates of standards and connections addressed in the modified unit in comparison to the original unit. Next, teachers learned how to use PERT by following step-by-step instructions and conducting a few short practicing activities. Then they were asked to modify the curriculum unit again with PERT. Teachers had opportunities to examine the difference between their estimated coverage rates and the actual coverage rates of standards and connections, explore the details of unit structures, and make changes to their lesson selections to better meet their goals for teaching the unit. Finally, I debriefed teachers with questions about their experience in the curriculum modification activities. Table 3 lists the variables and instruments related to each of the three research questions.

I used a think-aloud protocol to capture teachers' thinking during the tasks (Chi et al., 1981; Larkin & Rainard, 1984). I video-recorded all activities and used screen recording software to capture teachers' activity with PERT. Since I am interested in understanding how scaffolds in this study help teachers understand and use information about unit structures in their lesson selection process, the unit of analysis in this study is cases of participating teachers. I conducted a qualitative verbal analysis to transform qualitative data into numerical values, and used Wilcoxon paired signed-rank tests to examine the roles of the software scaffolds in helping teachers consider higher levels of unit structures in their modification practice.

Table 3. Relationship between research questions, variables, and instruments.

Research question	Variable	Data collection
How does the amount of teaching experience relate to teachers' understanding of curricular coherence?	• Understanding of unit structures • Amount of experience with curriculum units	• worksheet • survey
What are the roles of software scaffolds in helping teachers consider more complex elements of curricular coherence when they modify curriculum units?	• Modification practices (examine lessons and unit structures) • Use of software scaffolds	• screen recording • video/audio recording • worksheet
When teachers make changes in curriculum units with the assistance of the software scaffolds, how do they reflect on their understanding of curricular coherence and their curriculum modification strategies?	• Modification practices (examine understanding and modification strategy) • Use of software scaffolds	• screen recording • video/audio recording

3.1.2. The big picture: Design experiment methodology

I view this study as one component of a design experiment (A. L. Brown, 1992; Collins et al., 1989) in which I examine how software scaffolds can help teachers learn to use complex curriculum materials. The central idea of design experiments is to capture the design process of creating and testing an innovation in an educational environment with a complex set of interacting features. Each component of the design experiment suggests how the innovation may be modified to better fit its circumstances of use (diSessa & Cobb, 2004). The process of design experimentation includes iterations of developing, implementing, testing, and refining ideas. The initial design is based on current theoretical understandings of learning and specific goals. Then, teachers and researchers work together to make meaningful changes in the learning environment by paying attention to emergent features of the setting and foster other potential learning paths. At the end of each iteration of implementation, researchers refine their designs based on empirical results and variable design for next iteration (Design-Based Research Collective, 2003)

The current study addresses the third phase of my design experiment. In the first stage of this work (Lin & Fishman, 2004), I interviewed teachers in order to understand their lesson planning process, the factors they take into consideration, and the resources used. Teachers also used the first version of software scaffolds and gave me feedback on what can be improved. In the second phase of the design experiment (Lin & Fishman, 2006a, 2006b), I investigated teachers' understanding of unit structures and found that teachers did not understand higher-level unit structures very well. In my current study, I conducted a scaffolding analysis to explore the role of scaffolds in helping teachers better understand what makes a project-based science unit coherent. I compare two situations: the with-scaffolds situation and the without-scaffolds situation and see how the additional features of the with-scaffold situation lead to changes in modification practice. Through this comparison, I can focus on the things that differ between the two situations being compared, which indicates what the contributions of the scaffolds might be.

3.1.3. Setting

Project based science (PBS) curriculum units are used in the modification activities in this study (Krajcik, Czerniak, & Berger, 1999). PBS is one type of inquiry learning, which focuses on students' active construction of knowledge by engaging in tasks such as explaining, gathering evidence, generalizing, representing, and applying ideas (National Research Council, 2000). PBS units encourage investigations that allow students to ask and refine questions, debate ideas, make predictions, design experiments, collect and analyze data, draw conclusions, and communicate their ideas and findings to others.

Curriculum designers of PBS units use several strategies to connect activities to learning goals and are sequenced to create a coherent story line. First, driving questions and sub questions serve to organize concepts and principles, and drive students' investigations (Krajcik et al., 1999). Second, students experience multiple and varied phenomena repeatedly cycled back to the central content. Third, artifacts across different lessons of a project allow students to learn concepts, apply information, and represent knowledge in a variety of ways. This design makes PBS curricula particularly challenging for teachers to use (Crawford, 2000), and there are many ways in which a teacher's modification of a PBS unit might lead to an enactment that is not congruent with the designers' original intent (Blumenfeld et al., 2006).

Three PBS units were chosen as the focus units in this study: (1) How can I Make New Stuff from Old Stuff? (*Stuff*); (2) Seeing the Light: Can I Believe My Eyes? (*Light*); and (3) Struggle in Natural Environments: What Will Survive? (*Survive*). They were all designed based on the project-based science design principles and a learning-goals-driven design model (Krajcik et al., 2006) that aim to create coherent science curricula. I will use the *Stuff* unit as an example here to illustrate its suitability as the focus of this study.

The *Stuff* unit is an eight-week seventh grade science unit addressing the driving question, “How can I make new stuff from old stuff?” (Stuff; Krajcik et al., 1999; McNeill, Lizotte, Krajcik, & Marx, 2006) was developed as part of the NSF-funded Investigating and Questioning our World through Science and Technology (IQWST) project. The designers of the Stuff unit identified a set of interrelated ideas, the important connections among the ideas in the set, and approaches to help students make connections among the ideas and use them to explain phenomena (Krajcik et al., in press; McNeill et al., 2006). Three strands of national science content standards are addressed in the Stuff unit: (1) *substance and properties*: a substance has characteristic properties, such as density, a boiling point, and solubility, all of which are independent of the amount of the sample; (2) *chemical reaction*: substances react chemically in characteristic ways with other substances to form new substances with different characteristic properties; and (3) *conservation of mass*: no matter how substances within a closed system interact with one another, or how they combine or break apart, the total weight (mass) of the system remains the same (McNeill et al., 2006). The coverage of content standards in each lesson is shown in 0. The *Stuff* unit focuses on eight inquiry elements: (1) *define*; (2) *identify*; (3) *design investigation*; (4) *conduct Investigation*; (5)

analyze & interpret; (6) *explain*; (7) *construct model*; and (8) *use model* (McNeill et al., 2006). The coverage of inquiry standards in each lesson is shown in 0.

I interviewed key curriculum developers of this unit in order to identify the connections between lessons. The connections between lessons by content standards and inquiry standards are described in 0 and 0, respectively. Stuff also has links to topics about properties of substances addressed in units in other grade levels (cross-unit coherence). This key concept is first introduced in a sixth grade IQWST chemistry unit and a seventh grade IQWST physics unit in which students use this concept to investigate thermal and electrical energy. Then in the Stuff unit, students use this concept to investigate chemical reactions (Krajcik et al., in press; Shwartz et al., in press). This information was then represented within PERT, using the scaffolds described in Chapter Two, to provide teachers with feedback on the effects of various modifications to the unit. For instance, if a teacher elects to omit a particular lesson, the number of content and inquiry elements taught might be reduced. This indexing of each unit also allowed me to calculate the difference between teachers' decision making about enactment changes and developers' idealized goals for the unit, if it was taught in its entirety.

3.2. Participants

As indicated above, I recruited, interviewed, and observed a total of twenty teachers in this study. The goal of my selection of participants is to achieve informational redundancy or theoretical saturation (Lincoln & Guba, 1985; Strauss & Corbin, 1998; Yin, 2003). Theoretical saturation ensures that the conclusions adequately represent the entire range of variation, rather than only the typical members. This is done by defining the relevant types of variation in the larger population that are relevant to this study and then selecting individuals or settings that represent the most important variations (Strauss & Corbin, 1998). According to the conceptual framework mentioned earlier, teachers' experience and understanding of unit structures (defined in Chapter Two) seems to play an important role in their modification strategies and use supports in the unit modification activities. Thus, my goal was to identify teachers representing a wide range of experience and with a various levels of understanding of unit structures. Descriptive statistics of experience and understanding are presented in Chapter 4 that follows this one.

In order to collect enough cases for this study, I kept recruiting teachers until the sample represented different levels of experience teaching PBS units and understanding of unit structure. I emailed teachers who have used the three focus units in this study and described the nature of this study and see whether they would like to participate in this study. If I did not hear back from them after a week, I made phone calls to their schools. Each teacher participating in this study received a 30-dollar gift card. The twenty participants are science teachers from Detroit, Ann Arbor, and Chicago, who each had varying experience with one or more of the focus units. The number of teachers teaching *Stuff*, *Light*, and *Survive* are thirteen, three, and four, respectively. In this study, I refer to a teacher by a code that combines a letter representing the focus unit and a two-digit serial number. The letters for *Stuff*, *Light*, and *Survive* are S, T, U, respectively. The two-digit serial number starts from 00 and up to the number of teachers teaching the focus unit. For example, the tenth teacher recruited among the *Stuff* teachers is S10.

3.3. Procedure

I visited participating teachers one by one at their schools to conduct interviews that lasted for two-hours. I used a video camera to record the whole interview. I brought a laptop computer for teachers to use PERT and used screen recording software called Camtasia to capture the screen and mouse movement. I also generated log files with the software to keep track of features used and information input by teachers in the database. The interview included four major parts: (1) a survey of their teaching experience, (2) a curriculum modification task in the without-scaffolds situation, (3) a PERT Tutorial, and (4) a curriculum modification task in the with-scaffolds situation. The overview of the activities is shown in Table 4. The details of these activities will be described below.

3.3.1. Survey of teaching experience

Teachers filled out a survey asking for information about: (1) the numbers of years teaching science; (2) the number of times teaching project-based science units; and (3) the specific lessons in the focus unit they have read and taught each year. A sample survey for teachers teaching Stuff is shown in 0.

3.3.2. Lesson selection in the without-scaffolds situation

In this activity, teachers were asked to shorten the focus unit to about two-thirds of its original number of class periods. From observation of previous enactments, teachers often have about two-thirds of the amount of time designed to teach project-based science curriculum units. Therefore, this task represented a situation that was common in actual practice. However, teachers were not normally asked to think explicitly about their strategies to shorten units. Oftentimes, these modification decisions are made on-the-fly by teachers as they realize that they are running out of time, which means that it is not possible for them to make thoughtful decisions about curriculum modifications that take the *entire* unit into account.

Table 4. Overview of procedure, instrument, and variables.

Activity	Time	Data collection	Variable
Survey	5 minutes	• worksheet	• teaching experience
Lesson selection in the without-scaffolds situation	45 minutes	• video/audio recording • worksheet	• understanding of unit structure • modification practice
PERT tutorial	15 minutes	• Screen recording, video/audio recording	• use of scaffolds
Lesson selection in the with-scaffolds situation	45 minutes	• Screen recording • video/audio recording • worksheet	• understanding of unit structure • use of scaffolds • modification practice
Post-task interview	10 minutes	• video/audio recording	• use of scaffolds • modification practice

The lesson selection activity in the without-scaffolds situation includes three parts: (1) selecting lessons in the focus unit so that it can be shortened to the target number of class periods; (2) estimating the coverage rates of standards and connections of the modified unit; and (3) picking the five most important lessons in the focus unit. Before teachers started the lesson selection activity, I gave them instructions of this activity according to interview protocol (see 0). Then, I showed them definitions of terms used throughout the interview. The first term was "learning performance," a key concept behind the design of

IQWST curriculum. The second set of terms were related to the content standards addressed in the focus unit. The third set of terms are inquiry standards addressed in the focus unit. The fourth set of terms is the definition of “coverage rates of standards” and “coverage rates of connections.” Teachers could ask questions to clarify the definitions.

I prepared several worksheets for this activity. The first one is a list of lessons and descriptions of the focus unit that teachers could use to mark their lesson selections (see 0). After selecting lessons, teachers wrote down their estimations for coverage rates of standards and connections on the worksheets (see 0). They also wrote down the five most important lessons on this worksheet. Teachers had printed curriculum materials for the focus unit to refer to as they wished. Teachers were allowed to bring resources they would like to use for this activity. For example, they would bring their original plans, pacing chart, descriptions of science standards, and so on.

Teachers were asked to think aloud during the two lesson selection activities. Think aloud protocol has frequently been used in studies that aim to measure the differences between experts and novices when they solve problems (Chi et al., 1981; Larkin & Rainard, 1984). This approach makes explicit the knowledge participants have stored in memory related to the task, how they structure this knowledge, and the mental procedures they use to solve the problem. One of the advantages of using think-aloud protocol is that it gets people verbalize thoughts in response to specific cues. These types of cues are usually not available and recall of past thoughts is difficult in post-experimental interviews (Ericsson & Simon, 1993). My role in these think-aloud activities was to monitor the verbalizations and try not to get involved in shaping behavior. I explained to teachers that during the task I would only provide assistance when necessary. I reminded teachers to speak when they were silent for more than fifteen seconds.

3.3.3. PERT tutorial

Teachers followed a step-by-step tutorial on a printed handout to get familiar with the features of PERT. The first part was an overview of the major parts of PERT. The second part of the tutorial guided teachers through the content in each tab and asks teachers to do some activities at the end of each section. The exemplary content used for the tutorial is made up and not related to any focus unit.

In the tutorial, I described the main point of the graph to help teachers interpret the visual representations. The reason for providing this type of help is that people's ability to map between different visual features and the meaning of those features may differ as a function of experience (Leinhardt et al., 1990). Therefore, the instruction on the meaning of the representations is intended to reduce the influence of pre-existing interpretation skills in making sense of the curricular coherence information made apparent by the software scaffolds.

3.3.4. Lesson selection activity in the with-scaffolds situation

In the lesson selection activity in the with-scaffolds situation, teachers first examined their estimation of coverage rates of the modified curriculum unit. Teachers referred to their worksheet in the first lesson selection activity and entered their lesson selections into PERT. Then they checked the coverage rates of content standards, inquiry standards, content connections, and inquiry connections of their modified unit using PERT's various displays. They wrote down the values of each type of coverage provided by PERT on a worksheet. They calculated the difference between their estimation and the value provided by PERT. Teachers were asked about their reaction to the difference between the values. Then they marked the value of coverage they wanted to know more about and explored the details with PERT. A sample worksheet is shown in 0.

Next, teachers had the opportunity to reconsider their lesson selections and reselect the five most important lessons. If teachers did not change their selection, I asked questions such as, “What might be some changes in your criteria for picking these lessons?” and “What about the differences between your estimation and the value provided by PERT in coverage rates of content standards, inquiry standards, and connections among lessons?” Next, teachers were provided with a scenario in which they have two to three more class periods for doing this unit than they originally were given, and were prompted with the statement, “In order to cover the important elements in the unit, what changes in lesson selection would you make?”

3.3.5. Post-task interview

Interviews can provide additional information that was missed in think-aloud task and can be used to check the accuracy of my observations. I asked teachers the following questions: “When you made your decision in selecting lessons to be omitted, what part of the information from the software do you think is helpful? Why so? (hint: bar graph in standards, bar graph in connection, description, class periods, things to think about)”, “When you teach Stuff this year (or next time), what would you consider differently in selecting lessons to be omitted? Could you give me some examples?”, “What features would you like to add to PERT?”, and “Would you like to add anything about your experience using this tool?”

3.3.6. Data management

For each of the twenty teachers, I recorded two hours of video. I also took 70 minutes of screen recording for the tutorial, lesson selection activities in the with-scaffolds situation, and the post-interview. I also collected five worksheets from each teacher. I saved the original interviews tapes and worksheets in a secure place and made two backups. I transformed these video tapes into H.264 video files and use these files for data analysis. I scanned the worksheets into PDF files.

3.4. Analysis

Since I am interested in what teachers think and do when they conduct curriculum modification practices with the software scaffolds, I followed procedures of verbal analysis (Chi, 1997) to analyze my data. The goal of the verbal analysis is to determine what a person knows and how that knowledge influences the way the person reasons and solves problems. This involves a process of refining codes iteratively in order to ensure that the data are fully explored (Chi, 1997; Miles & Huberman, 1994). The method of coding and analyzing verbal data I employed consisted of the following steps: reducing or sampling the protocols, segmenting the protocols, coding the verbal data according to my coding scheme, and seeking and interpreting patterns. I will describe the details of these steps in the following sections.

3.4.1. Reducing or sampling the protocols

I analyzed interview data right after finishing the first interview and continued to analyze the data set as I gathered more interviews. The initial step in this data analysis is to listen to interview voice files and write notes on what teachers said in the interviews.

Then I transcribed the recording segments and typed them into text files. I also exported the usage tracking logs from computer to text files for later steps of analysis.

3.4.2. Segmenting the protocols

In this study, I chose to use syntactic boundaries to segment the protocols (Chi, 1997). Syntactic boundaries mark the transition from one conceptual section of a conversation or text to another concept. There are a couple of reasons why a segmentation of this protocol at the episode level is a more appropriate unit of analysis than a sentence. First, an idea might need several sentences to convey, so that coding at the sentence level might overestimate the number of substantive ideas discussed. Second, the same idea could be repeated several times by talkative people, so that counting sentences as the unit of analysis would credit talkative people with more output even though they are generating the same idea. When I was coding the transcript, I counted a segment when teachers shifted their attention between different perspectives of coverage rates of a standards or a connection (see Table 9), or different perspectives of a lesson (see Table 8). For example, if a teacher examined the number of connections of a lesson and then examined the coverage rate of a content standard, then there are two segments. The average number of turns per teacher is 28 in the without-scaffolds situation and 33 in the with-scaffolds situation. The total number of turns in all of my data set is 557 in the without-scaffolds situation and 653 in the with-scaffolds situation.

3.4.3. Code the verbal data according to the coding scheme

Coding schemes used in this analysis were developed through an iterative process of creating codes, coding, modifying and refining codes, and recoding (Miles & Huberman, 1994). The five parts of my coding scheme are: (1) used features related to characteristics of lessons (Table 5); (2) used features related to coverage rates of standards and connections (Table 6); (3) used features related to changed coverage rates of standards and connections (Table 7); (4) examination of curriculum unit (Table 8); and (5) examination of understanding and modification strategies (Table 9). I also coded the methods teachers used to estimate the coverage of standards and connections. I used a computer software program called NVivo to assign and manage codes to transcripts.

In order to determine the reliability of my coding, another educational researcher coded transcripts for three teachers from each of the three focus units using my final coding scheme. The process used was that I explained the meaning of each code to the other coder and tried a shorter transcript before the whole coding process together. One of the issues of inter-rater reliability is on whether discrepancies between two coders should always be resolved. There are two kinds of discrepancies. In the one kind, both coders have solid ideas about which code a particular segment of protocols should be assigned. This kind of discrepancy is the kind that is computed in an inter-rater reliability index. However, a second kind of discrepancy can occur not because the coders disagree with each other, but because each coder is unsure which code should be assigned to an ambiguous segment. In these cases, instead of resolving the discrepancies between the two coders, I completed the coding and then counted the number of these ambiguous cases as the un-codable portion of the data. The inter-rater reliability according to Cohen’s Kappa (J. Cohen, 1960) was calculated at 83%, which was deemed satisfactory.

3.4.4. Calculating scores

I calculated scores for each teacher's experience, understanding of unit structures, and methods used for estimation. I developed a scale to describe teacher experience with the focus unit and other project-based science units. The score for a teacher's experience is calculated by adding up the number of times each lessons in the focus unit was taught and a weighting factor. The use of weighting factor is to account for how recently a unit was taught (which would affect recall). The formula for the weighting factor is:

$$\text{Weight factor} = 1 - (2008 - \text{year of teaching a lesson}) \times 0.5$$

The year of teaching a particular lesson is determined by the starting year of that school year. For example, if a teacher taught a lesson in 2004-2005 school year, the score for it is calculated as 1 - (2007-2004) x 0.05 = 0.85.

The total score for a teacher's experience with her/his focus unit ranges from 0 to 100. Getting 100 points in the scale means that a teacher has taught every lesson in the focus unit every year since the unit was first used in schools. A teacher's total amount of experience with content or inquiry standards addressed in the focus unit was calculated by adding up an individual teacher's experience with the focus unit and other units.

A teacher's score for her/his understanding of one element of unit structures was calculated based on the amount of difference between the estimated and the actual coverage rates of the modified curriculum units. For example, if a teacher estimated that the coverage rate for the *conservation of mass* content standard is 80% in her modified plan and the actual coverage rate is 60%, then the difference is 20%. The score for her understanding of the coverage rate of "conservation of mass" is 80 (100-20=80).

Table 5. Use of features related to scaffolds for revealing characteristics of lessons

	Feature	Definition	Example
1.1.1	Content standards covered by a lesson	Refer to or mention content standards addressed by a lesson	“In lesson 4, we talked about chemical reaction”
1.1.2	Inquiry standards covered by a lesson	Refer to or mention inquiry standards addressed by a lesson	“In lesson 16, students design their own experiment”
1.1.3	Content connections related to a lesson	Refer to or mention other lessons connected to a lesson through content standard	“Lesson 6 and 8 are connected to lesson 10 through Properties “
1.1.4	Inquiry connections related to a lesson	Refer to or mention the relationship between lessons through a inquiry standard	“Lesson 4 and 10 and lesson 3 and 4 are connected by collecting data”
1.1.5	Number of content standards covered by a lesson	Refer to or mention the number of content standards covered by a lesson	“Lesson 6 covers 2content standards”
1.1.6	Number of inquiry standards covered by a lesson	Refer to or mention the number of inquiry standards covered by a lesson	“Lesson 8 covers 3 inquiry standards”
1.1.7	Number of content connections related to a lesson	Refer to or mention the number of connections for a lesson	“Lesson 5 has 6 connections with other lessons”
1.1.8	Number of inquiry connections related to a lesson	Refer to or mention the number of connections for a lesson	“Lesson 11 has3 connections with other lessons through construct models”

Table 6. Use of features related to scaffolds for revealing coverage rates of standards and connections

	Feature	Definition	Example
1.2.1	Relative coverage rates of content standards	Refer to percentage or bar graph of coverage for content standards by the modified unit	"The coverage rate of Properties is 60% now"
1.2.2	Relative coverage rates of inquiry standards	Refer to percentage or bar graph of coverage for inquiry standards by the modified unit	"The coverage rate of Properties is 60% now"
1.2.3	Relative coverage rates of content connections	Refer to percentage or bar graph of coverage for content connections by the modified unit	"The coverage rate of chemical reaction is 30% now"
1.2.4	Relative coverage rates of inquiry connections	Refer to percentage or bar graph of coverage for content connections by the modified unit	"The coverage rate of use model is 30% now"
1.2.5	Lessons related to a content standard	Refer to or mention lessons addressing a content standard	"Students learn about conservation of mass in lesson 15 and 16"
1.2.6	Lessons related to an inquiry standard	Refer to or mention lessons addressing a inquiry standard	"Students explain in lesson 15 and 16"
1.2.7	Content connections related to a content standard	Refer to or mention the relationship between lessons through a content standard	"Lesson 2 and 3 and lesson 7 and 9 are connected by conservation of mass"
1.2.8	Inquiry connections related to an inquiry standard	Refer to or mention other lessons connected to a lesson through inquiry standard	"Lesson 2 and 6 are connected to lesson 12 through explain"

Table 7. Use of features related to scaffolds for revealing changed coverage rates of standards and connections

	Feature	Definition	Example
1.3.1	Changed coverage rates of content standards	Refer to the heights of bar graphs or buttons with orange background of content standards	“The coverage rate of conservation of mass dropped to 50 percent.”
1.3.2	Changed coverage rates of inquiry standards	Refer to the heights of bar graphs or buttons with orange background of inquiry standards	“The coverage rate of predict becomes 100 percent now.”
1.3.3	Changed coverage rates of content connections	Refer to the heights of bar graphs or buttons with orange background of content connections	“The coverage rate of substance and properties dropped to 75 percent.”
1.3.4	Changed coverage rates of inquiry connections	Refer to the heights of bar graphs or buttons with orange background of inquiry connections	“The coverage rate of design investigation increase.”

Table 8. Curriculum modification practice

			Definition	Examples
Compare lessons	2.1.1	Point out advantages of including a lesson	Mention how a lesson is better than another one	“Lesson 8 covers more inquiry standards than lesson 10 does”
	2.1.2	Point out disadvantages of including a lesson	Mention how a lesson is not as important as another one	“Lesson 6 covers only one content standard”
Examine coverage	2.2.1	Point out the strong coverage rates	Mention higher coverage rates of standards or connections	“Explain is 70%, which is well covered”
	2.2.2	Point out the weak coverage rates	Mention lower coverage rate of standards or connections	“Construct model is only 20%, which is not good”
Identify change in coverage	2.2.3	Point out the improved coverage rates	Mention raised coverage rate of standards or connections	“Identify jumps to 80%!”
	2.2.4	Point out the worsened coverage rates	Mention decreased coverage rate of standards or connections	“conduct experiment drops to 30%!”

Table 9. Examination of understanding and modification strategy

Examine understanding	2.3.2	Improve understanding	Mention better understanding of one aspect of unit structures	“I had a broader definition of explain”
	2.3.3	Confirm original understanding	Mention that information provided is what the teacher knows	“I knew that lesson 6 is related to previous lessons”
	2.3.4	Keep original understanding	Don’t agree with information provided	“I don’t think lesson 9 covers construct model”
Select lesson	2.4.1	Keep a part	Keep a lesson in the modified unit	“I will keep lesson 9”
	2.4.2	Remove a part	Remove a lesson in the modified unit	“I will skip lesson 4”
Evaluate modification strategy	2.4.3	Not satisfied with modification	Mention that current coverage is not good enough	“The coverage rate of conservation of mass is too low”
	2.4.4	Satisfied with modification	Mention that current coverage is good	“I got each content standards covers about the same amount”

Next, the score for estimation methods for coverage rates of the modified unit was generated according to how precise the method is. More precise methods received higher scores. Accordingly, the score for a teacher's estimation methods was assigned by the following scale: (1) guess the coverage = 1 point; (2) think that coverage is all over unit = 2 points; (3) refer to other estimated value = 3 points; (4) count and guess = 4 points; (5) count = 5 points; (6) count by referring to the learning performance table in curriculum materials = 6 points.

For levels of unit structures, I assigned a score to each occurrence of a teacher's mentioning of a type of unit structures. The scores for basic, intermediate, and advanced levels are 1, 2, and 3, respectively (see Table 1 for an overview of levels of unit structures in Chapter Two).

3.4.5. Seeking and interpreting patterns.

The coding results were examined to see if patterns could be detected in the data. I rearranged the coded data into categories that facilitate comparison between things in the same category. After I coded all the single cases, I began cross-case analysis to look for patterns. I created tables and graphs from the data and to identify relationship between categories (Miles & Huberman, 1994). I created tables to examine the relationship between the variables in this study. In this table, the columns represented coding categories and the rows represented curriculum modification practice. This type of table helped me see the relationships between categories in different perspectives. I created bar graphs to compare the scores teachers have on types of unit structures. I generated scatter plots to examine the relationship between scores of pairs of variables.

I counted instances where the three types of scaffolds helped teachers carry out the curriculum modification practice. The three feature-modification practice pairs are: (1) show characteristics of lesson – compare lessons; (2) Show coverage – compare coverage; and (3) show change of coverage – evaluate modification. Each type of scaffolds has several sub-elements (see Table 5, Table 6, and Table 7) and so does curriculum modification practice (see Table 8). For example, the "show characteristics of a lesson" feature has eight sub-elements (1.1.1 to 1.1.8 in Table 5) and the "compare lessons" modification practice has two sub elements (2.1.1 and 2.1.2 in Table 8). Therefore, I counted the number of instances of each of the sixteen pairs of sub-elements of the first pair of scaffold and modification practice.

In order to examine the difference between teachers' use of unit structures in the without-scaffolds and with-scaffolds situations, I conducted Wilcoxon paired signed-rank tests to examine the significance of mean difference of the number of types of unit structures and number of times of unit structures between the without-scaffolds and the with-scaffolds situations. Wilcoxon paired signed-rank tests are the most appropriate statistical tool to use for this data because of the small sample size of this study. For comparison, I also computed more commonly used t-tests for the dataset and found the same results. I therefore opted to use the more appropriate Wilcoxon paired sign-rank test.

In order to examine the difference between the levels of unit structures used by teachers in the without-scaffolds and the with-scaffolds situations, I conducted Wilcoxon paired signed-rank test to examine the significance of mean difference of levels of unit structures. I calculated the Pearson's correlation coefficient to examine the relationship between teachers' individual characteristics (amount of experience with curriculum units, existing understanding of unit structures, and methods used for estimating the coverage rate) and the number of types of unit structures mentioned, number of times of unit structures mentioned, and levels of unit structures mentioned by teachers in each of the curriculum modification practices.

3.4.6. Validity

Validity was maintained by establishing correct operational measures for the concepts being studied. I selected the specific variables and related them to the research questions and the conceptual framework of the study. In this study, I examined the following variables: (1) Amount of experience teaching project-based science curriculum units; (2) Level of understanding of unit structures; (3) Methods used to estimate coverage rates of standards and connections; (4) Use of scaffolds; (5) Curriculum modification practice; and (6) Examinations of understanding of unit structures and modification strategy. The coding scheme for these variables was developed according to literatures and my pilot studies, as described in earlier sections in this chapter.

Internal validity was addressed by carefully establishing assertions from dataset. First, in order to reduce the risk that my conclusions reflect only the systematic biases or limitations of a specific source or method, I studied multiple teachers' use of the software scaffolds with three different curriculum units. This strategy allowed me to gain a broader and more secure understanding of the roles of the scaffolds in helping teachers consider deeper levels of design intent in when they make changes to curriculum units. Second, some teachers may reflect on their experience in the without-scaffolds situation before they participate in the with-scaffolds situation. If some teachers improve their understanding of unit structures before doing the activities in the with-scaffolds situation, their ability to consider unit structures when they modify units might be better than other teachers'. In order to lower the impact of this type of potential bias, I kept the without-scaffolds and with-scaffolds situations as close to each other in time as possible. The only activity between them is the tutorial activity for PERT.

Reliability is achieved by demonstrating that the operations (such as data collection procedure) can be repeated with the same results. First, I documented the procedures used in the study in detail. Second, I used task and interview protocols to guide the data collection from each teacher. Third, I used empty "table shells" (Miles & Huberman, 1994) that define the rows and columns of a data array to be collected. The table cells forced me to identify exactly what data should be collected and ensure that parallel information is collected with different participants. The fourth strategy was to use a second coder for my qualitative data to assure that my coding was reasonable and repeatable.

I utilized three strategies to enhance the external validity of the findings of study. First, I kept recruiting teachers until the group of participants' amount of experience with project-based science units and level of understanding of structures range from low to high in my scoring system. The purpose of this strategy is to enable me to see how the software scaffolds work with teachers with a wide range of backgrounds. If the scaffolds work for different types of teachers, then the findings of this study hold a better chance to be true for other teachers. Second, I recruited teachers teaching three different curriculum units designed based on the same learning-goal-driven curriculum design strategy. The purpose is to strengthen my findings in that the software scaffolds can be useful for teachers not only with a specific curriculum unit, but also units designed based on the same design strategy. Third, I designed the lesson selection activities that resemble conditions teachers have when they plan and enact curricula. In the activities, teachers modified curriculum units with time constraints, curriculum materials, and their notes from previous enactment, just like their usually unit planning. The purpose of this strategy is to enhance the opportunity to apply my findings to the "real-world", not just the setting for this study.

3.5. Summary

In this chapter, I described the settings for conducting this study, as well as approaches I used to recruit teachers. I explained how I coded the interview data with the coding schemes developed according to theoretical framework. I used Wilcoxon paired signed-rank tests to examine the statistically difference between the mean score the constructs in the without-scaffolds and with-scaffolds situations. Then I presented strategies used to address validity issues. In the next chapter, I will present the findings on the roles of the software scaffolds in helping teachers consider higher levels of unit structures when they modify curriculum units.

CHAPTER 4

RESULTS

The research questions addressed in this study are: (1) How does the amount of teaching experience relate to teachers' understanding of curricular coherence? (2) What are the roles of software scaffolds in helping teachers consider more complex elements of curricular coherence when they modify curriculum units? (3) When teachers make changes in curriculum units with the assistance of the software scaffolds, how do they reflect on their understanding of curricular coherence and their curriculum modification strategies? In this chapter, I present results that will be used to answer these research questions. First, I present results regarding the relationship between teachers' experience with project-based science curriculum units, understanding of unit structures, and methods used for estimation (section 4.1). Second, I demonstrate two cases of how the software scaffolds help teachers consider higher levels of unit structures when modifying curriculum units (section 0). Third, I describe how the software scaffolds help teachers make decisions when modifying curriculum units. The focus scaffolds are: (1) Scaffolds designed to help teachers identify the strong and weak coverage rates of standards and lesson connections (section 4.3); (2) Scaffolds designed to help teachers identify advantage and disadvantage of including a lesson (section 4.4); and (3) Scaffolds designed to help teachers identify the improved and the worsened coverage rates of unit structures (section 4.5). Fourth, I present findings about the opportunities for teachers to examine their understanding and modification strategies, including (1) Clarifying understanding of unit structures as a result of noticing the weak coverage rates (section 4.6); (2) Selecting lessons based on identified advantage and disadvantage of including a lesson (section 4.7); and (3) Evaluating modifications based on the identified strong and weak coverage rates of standards and connections (section 4.8) in the unit.

4.1. Teachers' experience, understanding, and estimation methods

In this section, I present the relationship between the amount of experience teachers have with project-based science curriculum units, their existing understanding of unit structures, and the methods they used to estimate coverage rates in their modified unit. In this study, I refer to a teacher by a code that combines a letter representing the focus unit and a two-digit serial number. The letters for *Stuff*, *Light*, and *Survive* are S, T, U, respectively. The maximum two-digit serial number for *Stuff*, *Light*, and *Survive* are: 13, 03, and 04, respectively. For example, a teacher whose focus unit is *Stuff* might be labeled "S10."

4.1.1. Teachers' amount of experience with project-based science curriculum units

As described in Chapter Three, I used a scale to describe teacher experience with the focus unit and other project-based science units. The possible points for a teacher's experience with the focus unit ranges from 0 to 100. Getting 100 points in the scale means that a teacher taught the focus unit every year since the unit was first used in schools. A teacher's total amount of experience with content or inquiry standards addressed in the focus unit was calculated by adding up this teacher's points for experience with the focus unit and with other project-based science units.

Table 10 demonstrates that teachers participating in this study have a wide range of experience teaching project-based science curriculum units (scores range from less than 10 to more than 70). Teachers S01, S02, S06, S05 have the most experience in all three aspects (see Table 11, Table 12, and Table 13). Teachers S11, S12, S03, and T03 have the least amount of experience in all three aspects.

Table 10. Teachers' amount of experience with the focus unit, content standards, and inquiry standards.

		Min	Max	Average	SD
Experience	Focus unit	0.0	93.1	41.6	25.9
	Other units	2.5	66.3	24.1	19.0
	Content standards	2.3	88.0	39.9	24.2
	Inquiry standards	9.2	72.8	34.6	20.0

Table 11. Scores for each teacher's amount of experience with the focus unit.

Teacher	S01	S02	S06	S05	U01	U02	U03	S13	S09	T01	S07	S08	S04	U04	S10	T02	T03	S12	S03	S11
Score	94	93	82	69	60	60	60	57	44	43	42	41	35	33	21	19	19	11	3	0

Table 12. Scores for each teacher's amount of experience with content standards.

Teacher	S01	S02	S06	S05	U02	U03	S13	U01	S09	S08	T01	S07	S04	U04	S10	T02	T03	S12	S03	S11
Score	89	88	78	67	58	55	55	55	46	41	39	38	33	31	19	18	17	11	5	2

Table 13. Scores for each teacher's amount of experience with inquiry standards.

Teacher	S01	S02	S06	S05	U02	S09	S13	U03	S08	U01	T01	S07	S04	U04	T02	S10	T03	S03	S12	S11
Score	76	73	64	61	54	53	50	41	41	40	27	26	26	24	16	14	13	13	12	9

4.1.2. Teachers' existing understanding of unit structures

Teachers in the study knew more about standards than about connections. The average score for understanding of content standards (64.3) is much higher than that for content connections (20.2) (see Table 14). A Wilcoxon paired signed-rank test showed a statistically reliable difference between the mean score for understanding of content standards and the mean score for understanding of content connections, $z(19) = 2.389$, $p = .017$. In addition, the average score for understanding of inquiry standards (61.3) is much higher than that of inquiry connections (39.2). A Wilcoxon paired signed-rank test showed a statistically reliable difference between the mean score for understanding of inquiry standards and the mean score for understanding of inquiry connections, $z(19) = 3.547, p < .001$. Table 15 shows each teacher's score for their pre-existing understanding of content standards, inquiry standards, content connections, and inquiry connections. Teachers S09, S11 have better understanding in all four aspects (see Table 16, Table 17, and Table 18). Teacher U04 has the least understanding of all four aspects.

Table 14. Teachers know more about standards than about connections

		Min	Max	Average	STD
Existing understanding	Content standards	64.3	97.0	79.7	9.2
	Inquiry standards	61.3	90.1	79.6	8.5
	Content connections	20.2	90.3	67.4	17.4
	Inquiry connections	39.2	83.0	64.1	11.8

Table 15. Scores for each teacher's understanding of content standards.

Teacher	S13	S11	S09	U03	S08	S01	T03	U01	T01	U02	S06	S03	T02	S07	S04	S05	S10	S12	U04	S02
Score	97	96	90	89	87	85	84	82	79	79	79	78	78	78	76	72	69	68	65	64

Table 16. Scores for each teacher's understanding of inquiry standards.

Teacher	S01	U01	S06	S09	U03	S11	S08	T02	T03	S10	S12	U04	U02	S04	S02	S03	S13	S05	S07	T01
Score	90	90	89	89	88	87	86	84	83	81	81	80	79	75	72	71	71	69	69	61

Table 17. Scores for each teacher's understanding of content connections.

Teacher	S12	S03	S06	S09	S01	S02	S11	T03	T01	T02	U02	S05	S07	S13	U03	S10	U01	S04	S08	U04
Score	90	89	87	81	80	80	79	77	73	71	69	67	65	65	58	54	53	46	46	20

Table 18. Scores for each teacher's understanding of inquiry connections.

Teacher	S11	S02	U02	S03	S06	S01	U01	T02	S07	S09	S13	U03	S12	T03	S04	S10	T01	S08	S05	U04
Score	83	82	79	77	71	70	70	70	69	67	64	63	61	60	55	53	51	51	49	39

4.1.3. Methods used for estimating the coverage rates of unit structures

As described in Chapter Three, the score for teachers' methods used for estimating coverage rates of standards and connections was calculated according to the following scale: guess (1 point), think that coverage is all over unit (2 points), refer to other value (3 points), count and guess (4 points), count (5 points), count by referring to the learning performance table in curriculum materials (6 points). The higher the score, the more precise the methods used by teachers in estimating the coverage rates of a modified unit.

Teachers were able to use more precise methods for estimating the coverage rates for standards than for connections (see Table 19). A Wilcoxon paired signed-rank test showed a statistically reliable difference between the mean score for methods of estimating content standards and the mean score for methods of estimating content connections, $z(19) = 3.929$, $p < .001$. In addition, a Wilcoxon paired signed-rank test showed a statistically reliable difference between the mean score of methods for estimating inquiry standards and the mean score for methods of estimating inquiry connections, $z(19) = 3.671$, $p < .001$. Teachers U01, U03, and S01 used more precise methods for estimation (see Table 22, Table 23, Table 24, and Table 25).

Table 19. Teachers used more precise methods to estimate the coverage rates of standards than that for connections in the modified curriculum unit.

		Min	Max	Average	STD
Methods for estimating coverage	Content standards	66.7	100.0	84.2	8.5
	Inquiry standards	33.3	100.0	72.2	17.9
	Content connections	7.4	73.3	30.1	22.8
	Inquiry connections	16.7	68.8	39.4	20.6

4.1.4. Relationship between teachers' amount of experience and existing understanding of unit structures

A teacher's amount of experience was not related to their level of understanding of unit structures. None of the values for Pearson product-moment correlation coefficients were significant (see Table 20).

Table 20. A teacher's amount of experience is not related to the level of understanding of unit structures.

		Existing understanding			
		Content standards	Inquiry standards	Content connections	Inquiry connections
Experience	Focus unit	-0.054	0.058	0.028	0.119
	Content standards	-0.034	0.068	0.049	0.134
	Inquiry standards	0.045	0.103	0.128	0.188

4.1.5. Relationship between teachers' experience and estimation methods

Teachers' amount of experience was not related to the types of methods used for estimation. One exception is that teachers who have more experience with inquiry standards used more precise methods for estimating the coverage rates of inquiry standards in the modified unit (see Table 21).

Table 21. More experienced teachers do not use more precise estimation methods.

		Estimation method			
		Content standards	Inquiry standards	Content connections	Inquiry connections
Experience	Focus unit	0.195	0.434	-0.070	0.190
	Content standards	0.177	0.441	-0.091	0.191
	Inquiry standards	0.099	**0.450***	-0.168	0.188

*p<0.05, **p<0.01

Table 22. Scores for each teacher's methods of estimating the coverage rates for content standards.

Teacher	S13	U01	U03	S01	S02	S03	S04	S06	S07	S08	S09	S10	S11	T01	T02	T03	U02	U04	S05	S12
Score	100	100	100	83	83	83	83	83	83	83	83	83	83	83	83	83	83	83	67	67

Table 23. Scores for each teacher's methods of estimating the coverage rates for inquiry standards.

Teacher	U01	U03	S01	S05	S06	S07	S09	S11	S13	U02	T02	S02	S03	S08	S10	T01	T03	U04	S12	S04
Score	100	100	83	83	83	83	83	83	83	83	71	67	67	67	67	60	58	47	42	33

Table 24. Scores for each teacher's methods of estimating the coverage rates for content connections.

Teacher	T02	T01	T03	U01	U02	U03	U04	S09	S01	S06	S08	S11	S13	S12	S02	S03	S04	S05	S07	S10
Score	73	67	67	50	50	50	50	30	24	24	24	19	19	13	7	7	7	7	7	7

Table 25. Scores for each teacher's methods of estimating the coverage rates for inquiry connections.

Teacher	S09	S01	T01	U04	S07	S08	S13	T02	U01	U02	U03	S11	S02	S03	S04	S05	S06	S10	S12	T03
Score	69	67	67	67	52	50	50	50	50	50	50	33	17	17	17	17	17	17	17	17

4.1.6. Relationship between estimation methods and understanding

Teachers' methods used for estimation seem to be related to their understanding of content standards and inquiry standards, but not related to their understanding of connections. Table 26 shows the Pearson product-moment correlation coefficients for estimation methods and understanding. For content and inquiry standards, teachers can use estimation methods closer to that used by curriculum designers and can make closer estimation of the coverage rates of unit structures. On the other hand, for content and inquiry standards, teachers' estimation methods are not related to their understanding.

Table 26. The level of understanding of unit structures is not related to the types of methods used for estimation.

		Estimation method			
		Content standards	Inquiry standards	Content connections	Inquiry connections
Existing understanding	Content standards	**0.531***	**0.526***	0.171	0.370
	Inquiry standards	0.229	0.326	0.209	0.141
	Content connections	-0.283	0.188	-0.153	-0.307
	Inquiry connections	0.196	**0.452***	-0.130	-0.127

*p<0.05, **p<0.01

4.2. Cases of how scaffolds help teachers consider more and higher levels of unit structures in their modification practices

In this section, I present two qualitative case descriptions of teachers' use of scaffolds when they make changes to the units. In the first case, a novice teacher chose among three lessons by considering multiple aspects and high levels of unit structures using the software scaffolds. In the second case, a experienced teacher tried to decide which lesson she should include in her plan by checking multiple perspectives and high levels of unit structures using the software scaffolds. The purpose of providing these two cases is to show, in a narrative format, how the software scaffolds helped both novice and experienced teachers consider high levels of unit structures when they modified curriculum units. In the following description of how teachers use features in PERT, I will refer to the corresponding numbers on the screen shots following the case.

4.2.1. Case #1

Teacher S03 taught *Stuff* for the first time and has taught middle school science for fifteen years, including five years of teaching project-based science units. She had high understanding of content and inquiry connections (see Table 15, Table 16, Table 17, Table 18). I chose to present this case because this teacher represents an extreme case in that she never taught Stuff before and has average understanding of unit structures. In this case, Teacher S03 was trying to decide whether she should select Lessons 9, 15, and 16. She checked the coverage rates of inquiry connections (#1 in Figure 5). She checked the buttons along the row of Lesson 16 and said, "I have Lesson 12 and Lesson 13, so I am considering whether I should add Lesson 15" (#2 in Figure 5). Then, she checked the buttons along the row of Lesson 15 to find out what are the lessons that are connected to

Lesson 15. She stated, “I have lessons 2, 3, 4, and 13” (#3 in Figure 5). Next, she said, “so putting Lesson 15 and 16 back in would recover many connections.” She then put Lesson 15 back in (#4 in Figure 5). She checked the bar graph of content standards and found that the coverage rate is low in the *chemical reaction* content standard (#5 in Figure 6). She reacted, “I want students to understand that manipulating molecules makes a new substance. I would definitely want them to get Lesson 9 (#6 in Figure 6). I also want them to be able to come up with their own investigation and carry Lesson 16 out. So I have to decide which one is more important.” She referred to the bar graph for the coverage rates of inquiry standards and said, “They have done many investigations in my selected lessons. But *chemical reaction* is the essence of Stuff.” Therefore, she removed Lesson 16 and added Lesson 9 (#7 in Figure 6). She then referred to the red buttons along the row and column of Lesson 9 to find lessons that have broken inquiry connections with Lesson 9 (#8 in Figure 6). She found Lesson 11. She added Lesson 11 (#9 in Figure 6).

In this case, Teacher S03 considered the coverage rates of inquiry connections and the coverage rates of content standards before she reached her decision for picking a lesson to include in her plan. She did not consider these higher-level unit structures when she conducted the modification activity in the without-scaffolds situation. In addition, she did not compare the pros and cons among several lessons by checking standards and connections covered. This case demonstrates how software scaffolds can help teachers consider more and higher-levels of unit structures when they make modifications to curriculum materials.

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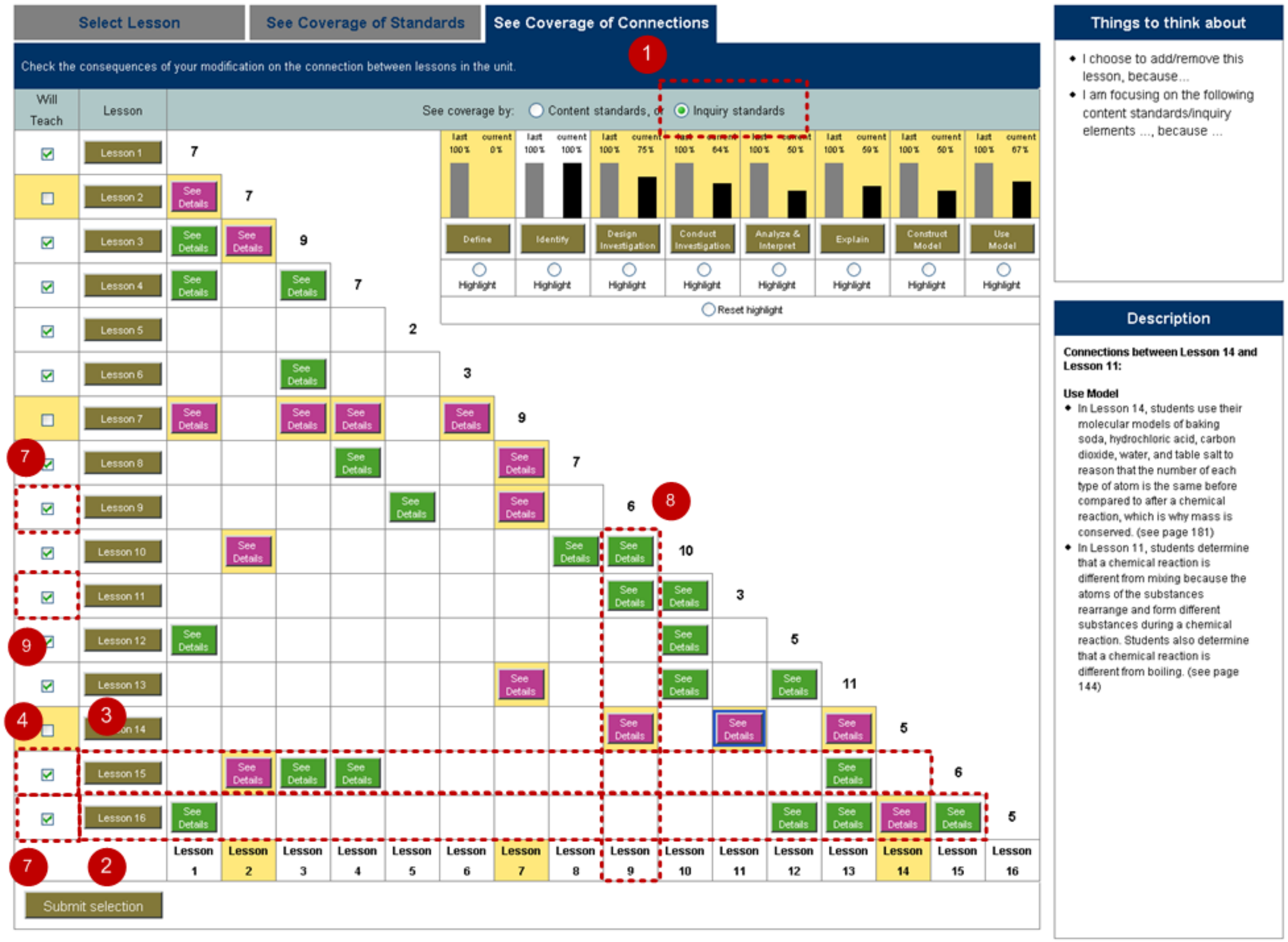

Figure 5. Teacher S03 examined the coverage rates for connections by inquiry standards.

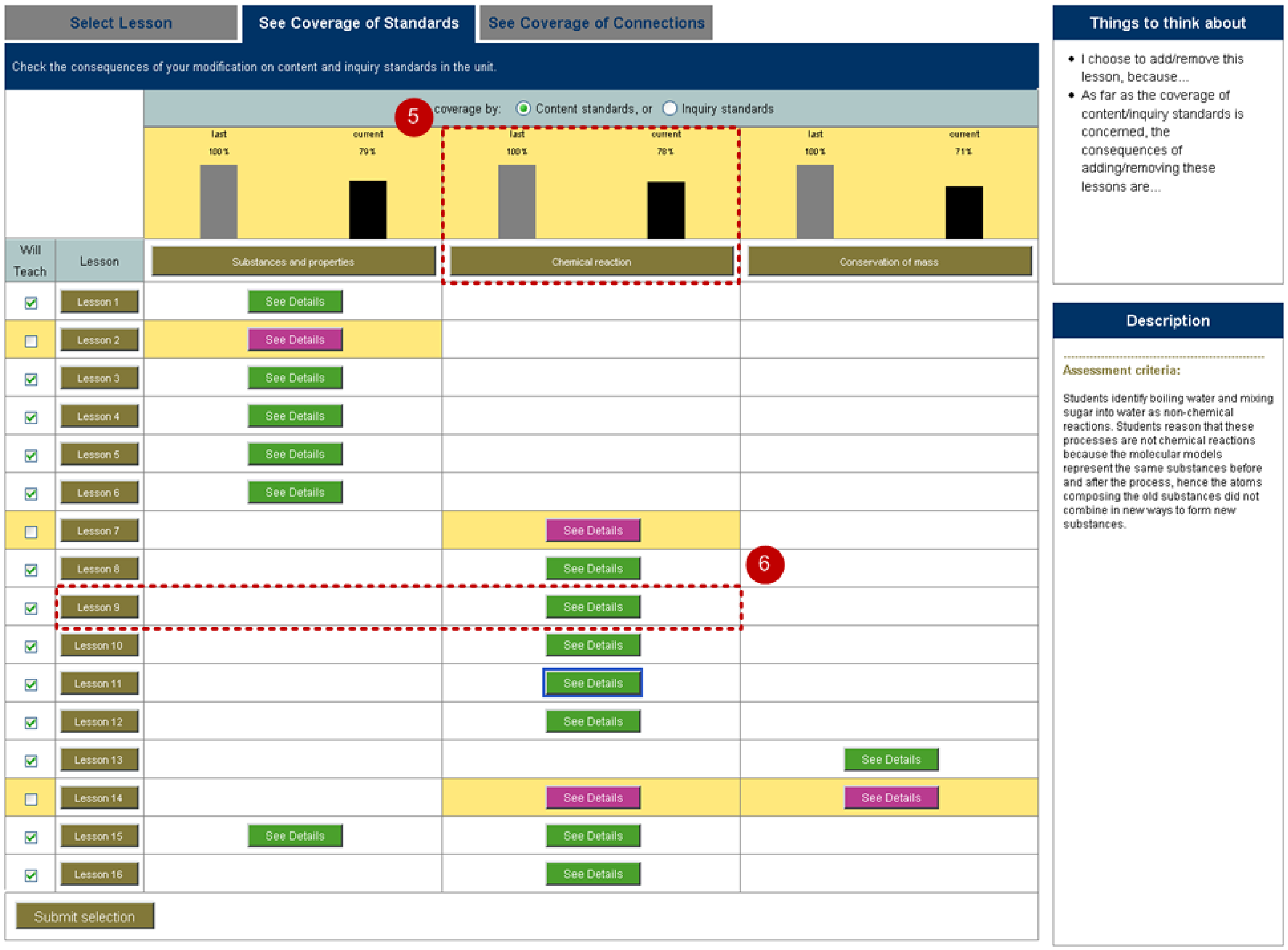

Figure 6. Teacher S03 examined the coverage rates for content standards.

4.2.2. Case #2

Teacher S05 had the 4th highest scores in terms of the amount of experience with the focus unit and other project-based science units (see Table 11, Table 12, and Table 13). She had lower than average understanding of standards and connections. In this case, Teacher S05 was trying to decide whether she should select Lessons 4 or Lesson 15.

First, she removed Lesson 4 (#1 in Figure 7). She went to check the bar graphs in the *See Coverage of Connections* tab and found that the coverage rates for connections by *analyze & interpret* dropped (#2 in Figure 7). She was not happy with this result and put Lesson 4 back (#3 in Figure 7). She examined the coverage rates of content standards and said, "I am concerned about the low coverage rate of chemical reaction" (#4 in Figure 8)

She checked the red buttons in the column for *chemical reaction* and stated, "I want to figure out if I can add Lesson 15 for kids to see making soap is a chemical reaction" (#5 in Figure 8). She then checked the coverage rates for inquiry connections and noticed that *conduct investigation* was made slightly higher by referring to its bar graphs (#6 in Figure 7). She highlighted *conduct investigation* (#7 in Figure 7). She checked the buttons and notice that Lesson 15 has several connections in *conducting investigation*. She said, "I would be comfortable with chemical reaction if I add Lesson 15" (#8 in Figure 7). She checked the coverage rates of content connections and found that *substance and properties* gets better (#9 in Figure 9) and that *chemical reaction* is the lowest (#10 in Figure 9). She highlighted *chemical reaction* (#11 in Figure 9) and noticed that Lesson 15 has several connections by checking the red buttons. She said, "Overall I would improve chemical reaction with Lesson 15" (#12 in Figure 9). As a result, she added Lesson 15 and removed Lesson 4 (#13 in Figure 9). She checked the coverage rates of content standards and found that *chemical reaction* increased (#14 in Figure 8) and *substance and properties* dropped (#15 in Figure 8). She was fine with the results.

In this case, Teacher S05 considered the coverage rates for inquiry connections and the coverage rates for content standards before she reached her decision of picking Lesson 15 in her plan. She did not consider these higher-level unit structures when she conducted the modification activity in the without-scaffolds situation. In addition, she did not compare the pros and cons among several lessons by checking standard and connections covered. This case demonstrates how the software scaffolds can help teachers consider more and higher-levels of unit structures when they make modifications to curriculum materials.

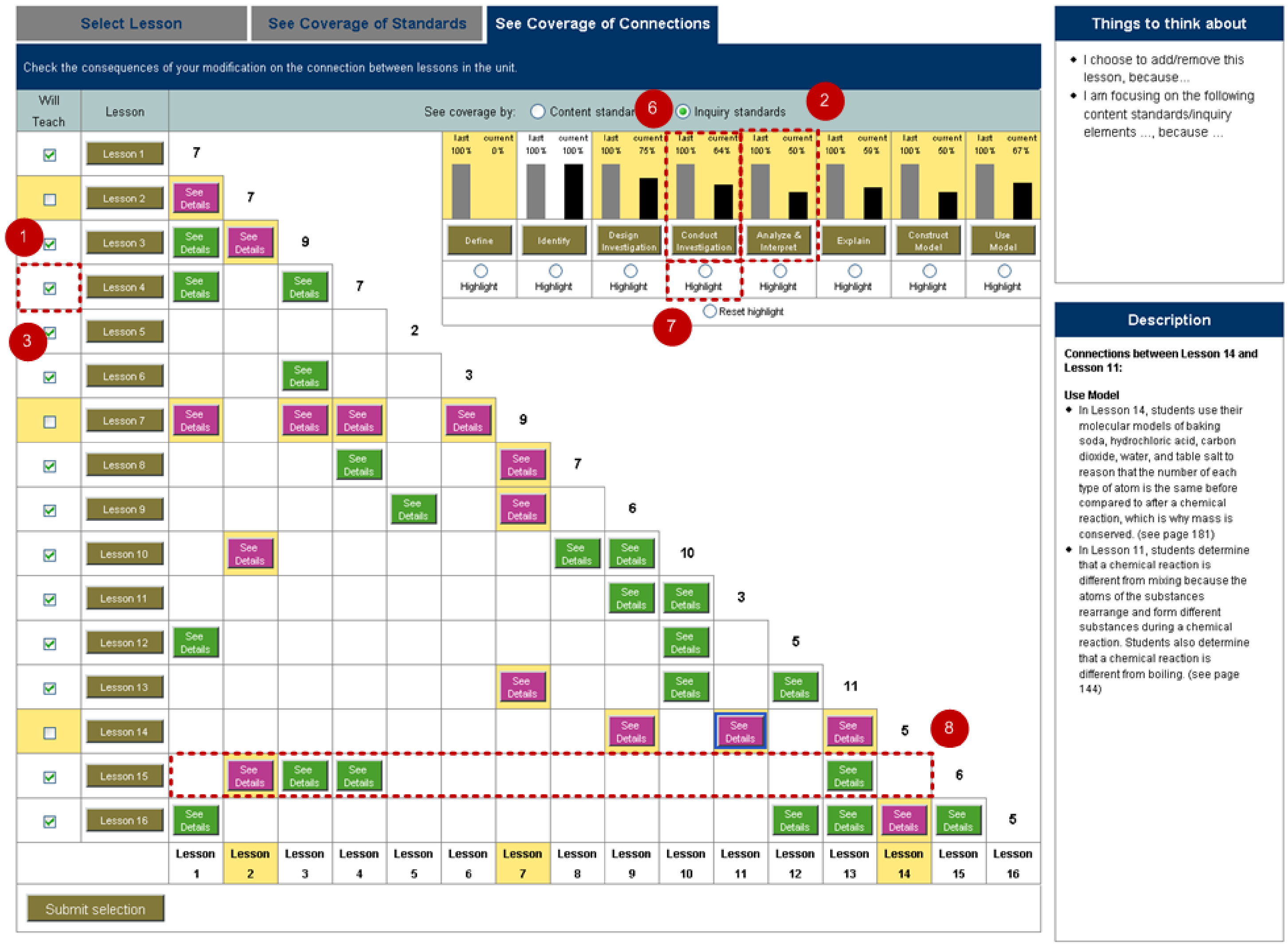

Figure 7. Teacher S05 examined the coverage rates for connections by inquiry standards.

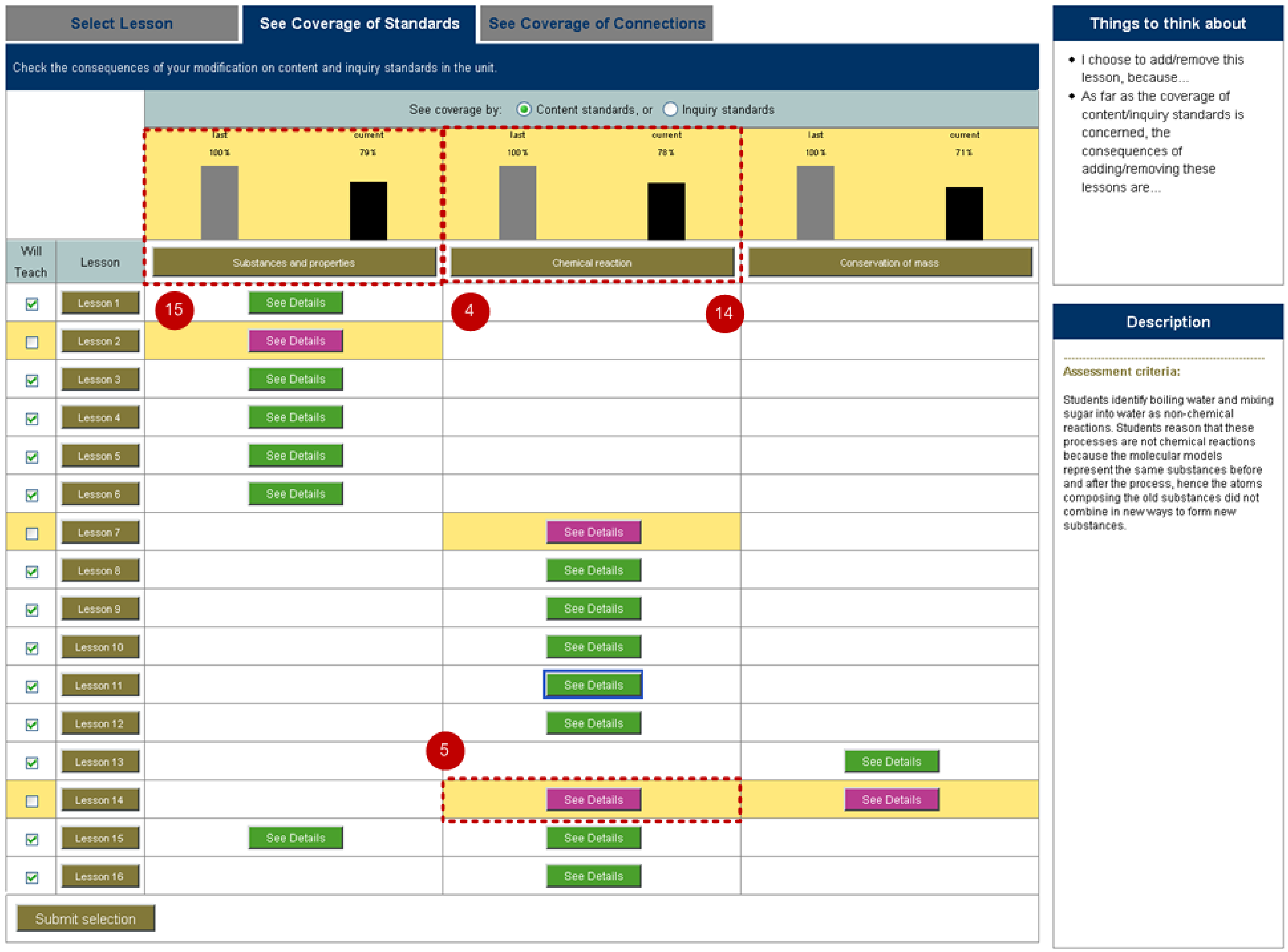

Figure 8. Teacher S05 examined the coverage rates for inquiry standards.

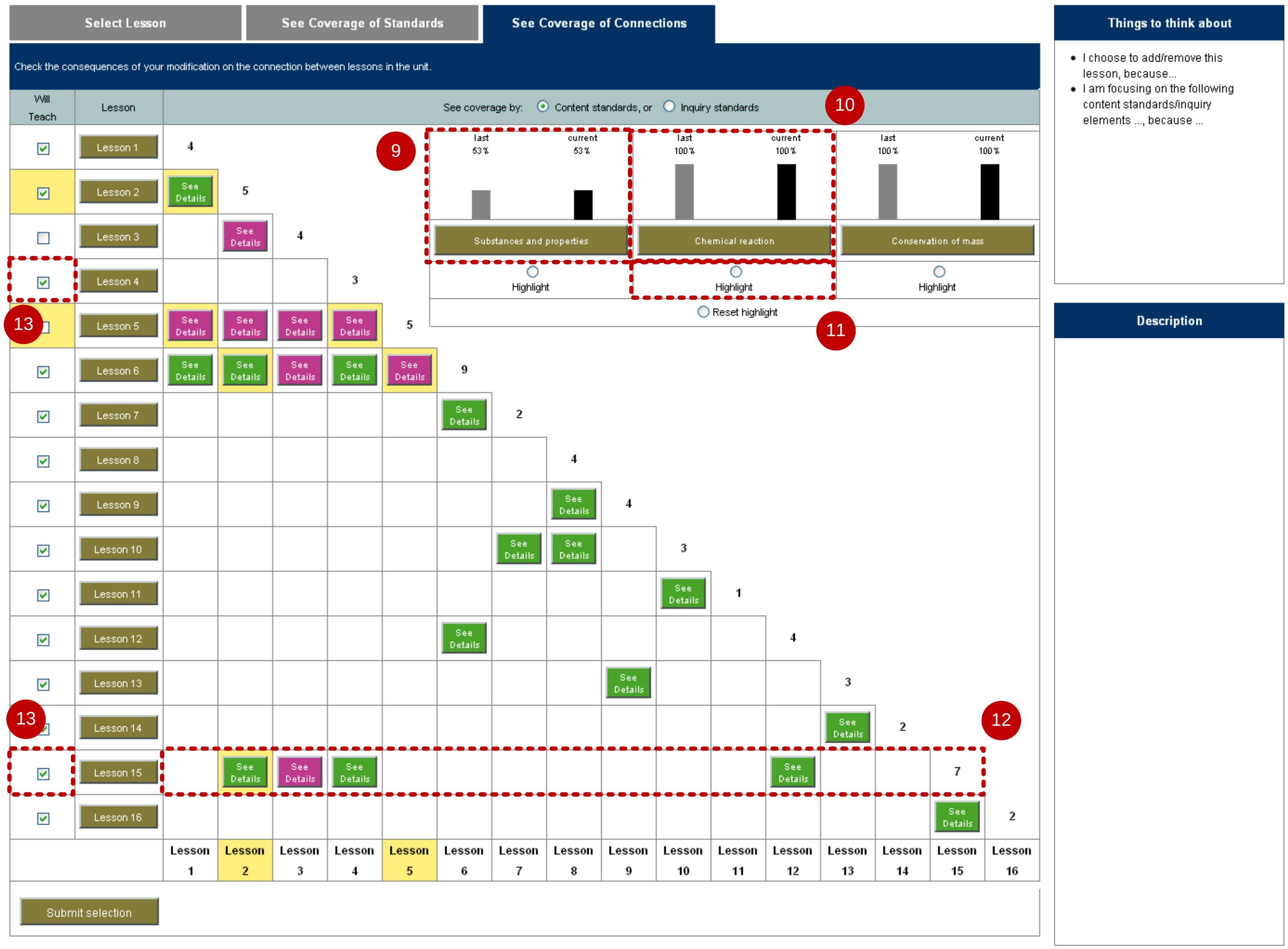

Figure 9. Teacher S05 examined the coverage rates for connections by content standards.

4.3. Scaffolds for helping teachers identify strong and weak coverage rates for standards and lesson connections

In this section, I present findings related to how the scaffolds helped teachers identify strong and weak coverage rates in the modified curriculum unit. As described in Chapter Two, one major difference between experts and novices is that experts can identify strong and weak aspects of their lesson plans by noticing deeper and less apparent patterns in terms of instructional strategies and learning objectives. Conversely, novices are more likely to focus on superficial elements of their plans and to examine them in fragments (Chi et al., 1981; Clermont, Borko, & Krajcik, 1994). In this study, teachers with a good understanding of curricular coherence should be able to examine the following eight types of unit structures when they identify strong and weak coverage rates of standards and connections: (1) Relative coverage rates of content standards; (2) Relative coverage rates of inquiry standards; (3) Relative coverage rates of content connections; (4) Relative coverage rates of inquiry connections; (5) Lessons related to a content standard; (6) Lessons related to an inquiry standard; (7) Content connections related to a content standard; (8) Inquiry connections related to an inquiry standard (see Table 6).

In order to help teachers identify strong and weak aspects of their modified curriculum, I developed scaffolds according to scaffolding strategy #1: Providing visualization to help teachers inspect multiple aspects of unit structures. The first type of scaffold shows the overall coverage rates of standards and connections in the modified curriculum unit. Its embodiment in the software tool is a set of bar graphs whose heights show the coverage rates of standards and connections addressed in a unit. The relative heights of bar graphs and accompanying percentage of coverage are used to help teachers identify which standards are covered more than others. Figure 10 shows an example of bar graphs that demonstrate the relative coverage rates of three content standards addressed in the *Stuff* unit.

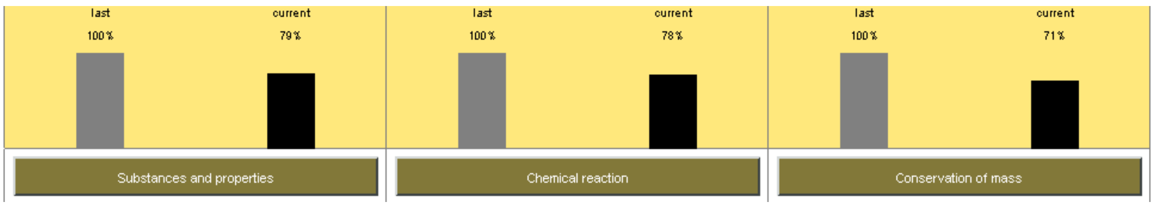

Figure 10. Bar graphs that represent relative coverage rates of standards

The second type of scaffold is designed to help teachers identify details of coverage rates of standards and connections. In the *See Coverage of Standards* tab (see Figure 11), the buttons in each column representing a standard indicate lessons addressing this standard. Figure 11 shows an example that demonstrates the details of strong (green button) and weak (red button) coverage of three content standards in the Stuff unit. In the *See Coverage of Connections* tab (see Figure 12), the buttons in the triangular matrix helped teachers identify where a lesson connects to other lessons in this unit. By clicking on the buttons, teachers can see details of these connections between lessons. The *highlight* feature helped teachers identify connections related to a specific standard. Figure 12 shows an example of buttons in a matrix that demonstrate the details of strong (green button) and weak (red button) coverage of lesson connections.

Lesson	Substances and properties	Chemical reaction	Conservation of mass
Lesson 1	See Details		
Lesson 2	See Details		
Lesson 3	See Details		
Lesson 4	See Details		
Lesson 5	See Details		
Lesson 6	See Details		
Lesson 7		See Details	
Lesson 8		See Details	
Lesson 9		See Details	
Lesson 10		See Details	
Lesson 11		See Details	
Lesson 12		See Details	
Lesson 13			See Details
Lesson 14		See Details	See Details
Lesson 15	See Details	See Details	
Lesson 16		See Details	

Figure 11. Table with buttons that mark strong (green) and weak (red) coverage of lessons related to standards

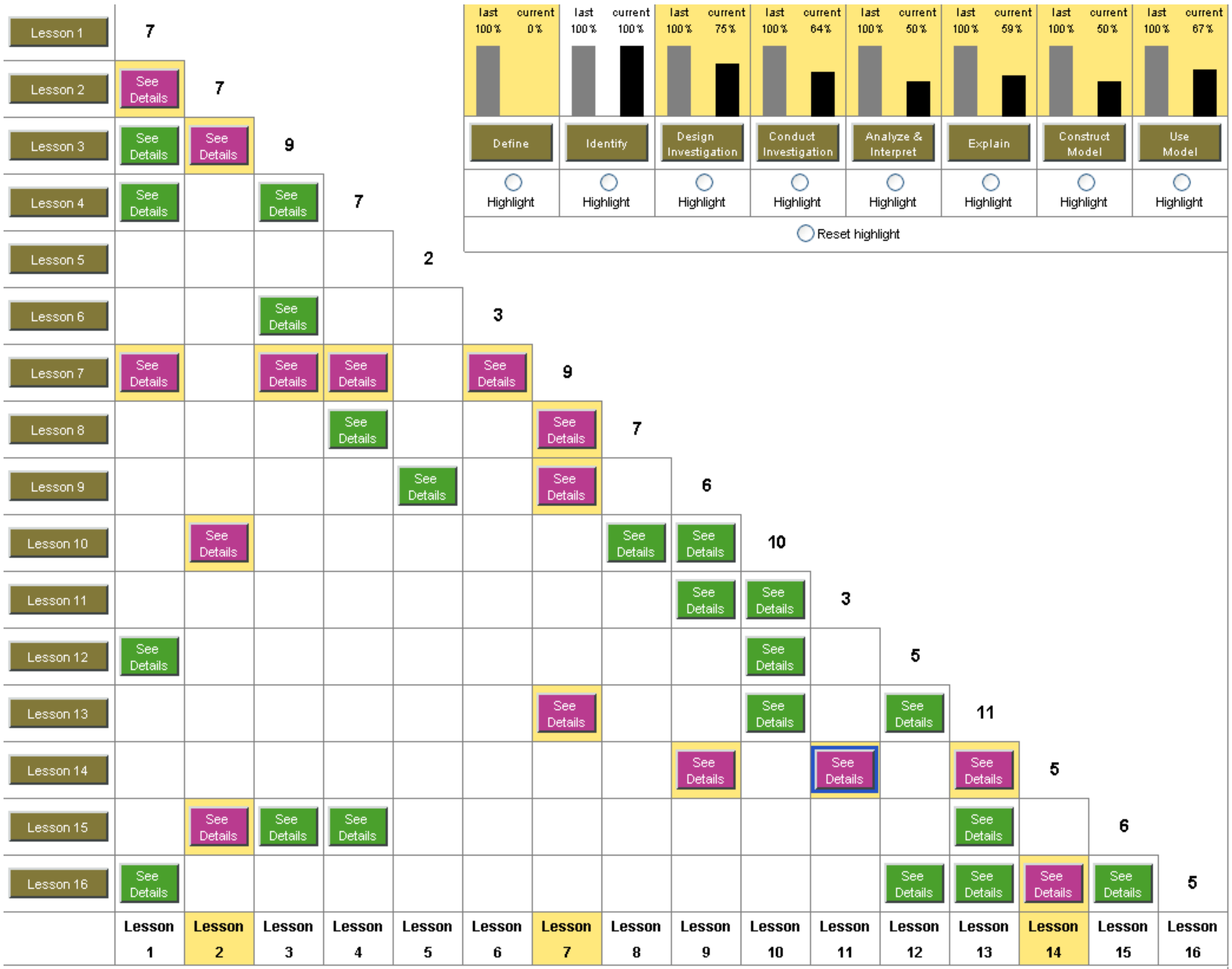

Figure 12. Table with buttons that mark the details of strong (green) and weak (red) coverage of connections

4.3.1. Teachers' use of scaffolds for identifying the strong coverage rates

Here are two examples for how this type of scaffolding helped teachers identify strong coverage rates. First, Teacher S01 checked the bar graphs in the *See Coverage of Connections* tab and found that the coverage rates matched her priority for addressing inquiry standards in this unit. To this end, she said, "My *analyze and interpret* and *define* are very high. The rest is kind of in the middle." Second, Teacher U04 checked the coverage rates of inquiry connections with bar graphs and found that the coverage rates of connections related to the *describe* inquiry standard was too high. She said, "I need to chop down some of the lessons in describe. It's 100%!"

Here are two examples for how this type of scaffolding helped teachers identify the details of the strong coverage rates. First, Teacher S07 noticed that the coverage rate of the *use model* inquiry standard was high and then went through each button in the column representing that standard. She said, "I see. It's in lesson 5, 9, and 14." Second, Teacher S09 noticed that the coverage rate of the *design investigation* inquiry standard was high. He used the *highlight* feature to show connections related to this standard and said, "I used lessons 2, 3, 4 to create opportunities for design investigation."

These examples show that the scaffolds helped teachers notice the strong coverage rates among standards and connections in the modified unit. Among the twenty teachers, fourteen teachers identified strong coverage rates in the with-scaffolds situation (50 times, 7.7% of total segments), while only one teacher did this in the without-scaffolds situation (2 times, 0.4% of total segments). Eleven teachers identified the details of strong coverage rates in the with-scaffolds situation (20 times, 3.1% of total segments), while nine teachers did this in the without-scaffolds situation (28 times, 5.0% of total segments).

4.3.2. Comparison for the use of types of unit structures when identifying strong coverage rates for standards and connections in the with-scaffolds and the without-scaffolds situations

In this study, the without-scaffolds situation refers to the unit modification activity that teachers completed before using PERT, without the scaffolds. In the with-scaffolds situation, teachers conducted the unit modification activity with support from the target software scaffolds in PERT.

In the with-scaffolds situation, teachers were able to pay attention to more types of unit structures when they identified strong coverage rates of unit structures than they did in the without-scaffolds situation (see Table 27). Four of the eight related types of unit structures were mentioned by teachers in the without-scaffolds situation, while all eight types of unit structures were mentioned in the with-scaffolds situation when teachers identified the strong coverage rates of unit structures. A Wilcoxon paired signed-rank test showed a statistically reliable difference between the mean number of types of unit structures mentioned in the without-scaffolds situation (M = 0.65, s = 0.81) and in the with-scaffolds situation (M = 2.45, s = 2.06) when teachers identified the strong coverage rates, z(19) = 3.017, p = .003. In addition, a Wilcoxon paired signed-rank test shows a statistically reliable difference between the mean number of unit structures mentioned in the without-scaffolds situation (M = 1.50, s = 2.64) and with-scaffolds situation (M = 3.56, s = 3.50) when teachers identified strong coverage rates, z(19) = 2.637, p = .008.

The scaffolds helped teachers pay more attention to the relative coverage rates of standards and connections in the with-scaffolds situation than in the without-scaffolds situation. I conducted Wilcoxon paired signed-rank tests for each of the eight related types of unit structures. The test results indicate that the mean differences are significant only for types of unit structures related to showing relative coverage rates of standards and connections, but not for those related to showing details of coverage (see Table 27).

Teachers paid more attention to higher levels of unit structures when they identified the strong coverage rates of standards and connections in the with-scaffolds situation than they did in the without-scaffolds situation. As defined in Chapter Two, there are three levels of unit structures: basic, intermediate, and advanced (see Table 1). In the coding process, the scores assigned to the basic, intermediate, and advanced levels are 1, 2, and 3, respectively. The mean of level of unit structures mentioned by teachers changed from 0.6 in the without-scaffolds situation to 1.6 in the with-scaffolds situation when they were identifying the strong coverage rates of standards and connections. These scores indicate that, overall, teachers only considered basic-level unit structures when they identified the strong coverage rates in the without-scaffolds situation. In contrast, they considered basic to intermediate levels of unit structures when they identified strong coverage in the with-scaffolds situation. A Wilcoxon paired signed-rank test also shows a statistically reliable difference between the mean number of level of unit structures in the without-scaffolds situation ($M = 0.57$, $s = 0.63$) and with-scaffolds situation ($M = 1.57$, $s = 1.01$) when teachers identified strong coverage rate, $z(19) = 3.894$, $p < .001$.

Table 27. Scaffolds helped teachers focused more on overall coverage rates when they identified the strong coverage rates of modified units in the with-scaffolds situation than in the without-scaffolds situation.

Level of unit structures	Basic		Intermediate				Advanced	
Types of unit structures	Lessons related to a standard		Relative coverage rate				Connections related to a standard	
	Content standard	Inquiry standard	content standards	inquiry standards	content connections	inquiry connections	content standard	inquiry standard
Mentioned in the without-scaffolds situation	X	X	X				X	
Mentioned in the with-scaffolds situation	X	X	X	X	X	X	X	X
Wilcoxon paired signed-rank test	1.601	1.277	**2.448***	**2.938****	1.826	**2.524***	0.447	1.604

*p<0.05, **p<0.01

4.3.3. Relationship between teachers' individual characteristics and their use of unit structures when identifying the strong coverage rates of standards and connections

I tested the relationships between teachers' individual characteristics and their use of types of unit structures when identifying strong and weak coverage rates in the without-scaffolds and the with-scaffolds situations. Teachers' individual characteristics refer to their: amount of experience teaching project-based science units, pre-existing understanding of unit structures, and methods used for estimating coverage rates of standards and connections. Descriptive results related to these characteristics are presented in earlier sections of this chapter (see Table 10, Table 14, and Table 19). My measure of teachers' use of types of unit structures refers to: types of unit structures used, number of times mentioning unit structures, and level of types of unit structures mentioned. I calculated the Pearson correlation coefficients to examine the relationship between teachers' individual characteristics and their use of unit structures (see Table 28).

First, the results indicate that amount of experience with project-based science units is not related to teachers' use of unit structures when they identified strong coverage rates in both of the without-scaffolds and the with-scaffolds situations. In earlier sections of this chapter, results indicated that teachers' amount of experience with the unit is not related to their understanding of unit structures, either. Second, teachers' pre-existing understanding of content and inquiry standards is related to teachers' use of unit structures when they identified strong coverage rates in the without-scaffolds situation. Specifically, teachers who have a better understanding of content standards mentioned more types of unit structures when they identified the strong coverage rates in the without-scaffolds situation ($r=0.450$, $p<0.05$). Similarly, teachers with better understanding of inquiry standards examined more types of unit structures ($r=0.477$, $p<0.05$), mentioned more times of unit structures ($r=0.481$, $p<0.05$), and referred to higher levels of types of unit structures ($r=0.509$, $p<0.05$). In earlier sections of this chapter, results also indicated that that teachers' understanding of inquiry standards is related to their methods used for estimating the remaining coverage rates of inquiry standards in the modified unit. Third, teachers who used more precise methods to estimate coverage rates of standards and connections focused on fewer number of types of unit structures ($r=-0.494$, $p<0.05$), mentioned fewer number of unit structures ($r=-0.495$, $p<0.05$), and examined lower levels of unit structures ($r=-0.559$, $p<0.05$) in the with-scaffolds situation.

4.3.4. Teachers' use of scaffolds for identifying weak coverage rates

The following are two examples for how the scaffolds helped teachers identify weak coverage rates. First, Teacher S02 checked the coverage rates of content standards for her modified unit by checking the bar graph in the *See Coverage of Connections* tab. She found that the coverage rates of the *Substance and Properties* content standard was much lower than her expectation. She stated, "I want to cover the standards evenly. The coverage rate of substance and properties is too low." Another example is that Teacher S06 examined the coverage rates of inquiry connections in her modified unit by checking the bar graphs in the *See Coverage of Connections* tab. She found that the bar graphs for the *Define* inquiry standard was zero and said, "Oh, wait. Currently, there is no defining at all?"

Table 28. Correlation between teachers' individual characteristics and their use of unit structures when identifying strong coverage rates of standards and connections.

	Number of types of unit structures (without-scaffolds)	Number of types of unit structures (with-scaffolds)	Number of unit structures (without-scaffolds)	Number of unit structures (with-scaffolds)	Level of unit structures (without-scaffolds)	Level of unit structures (with-scaffolds)
Experience with focus unit	-0.166	0.125	0.207	0.171	0.101	-0.086
Experience with content standards	-0.156	0.140	0.197	0.177	0.116	-0.064
Experience with inquiry standards	-0.109	0.192	0.153	0.192	0.169	0.021
Existing understanding of content standards	**0.450***	-0.065	0.111	-0.055	0.381	-0.073
Existing understanding of inquiry standards	**0.477***	-0.112	**0.481***	-0.063	**0.509***	-0.345
Existing understanding of content connection	0.136	0.343	0.192	0.243	0.217	0.310
Existing understanding of inquiry connection	0.375	0.174	0.277	0.210	0.271	-0.015
Estimation method for content standard	0.298	-0.222	0.227	-0.046	0.235	-0.302
Estimation method for inquiry standard	0.359	-0.056	0.346	0.055	0.305	-0.263
Estimation method for content connection	-0.056	**-0.494***	0.008	**-0.495***	-0.099	**-0.559***
Estimation method for inquiry connection	0.126	-0.036	-0.115	-0.175	0.271	-0.361

*p<0.05, **p<0.01

Here are two examples of how the scaffold helps teachers identify details of weak coverage rates. Teacher T03 noticed the relative lower coverage rate of *Eye Detection* by checking bar graphs and then checked the button along the column of *Eye Detection* for missing coverage represented by the red buttons in the rows of lesson 4, 6, and 10. Another example is that Teacher T01 found that the coverage rate of connections by *Use Model* is quite low. So she highlighted *Use Model* to check the red buttons and found the broken connection between lessons 4 and 5.

These examples demonstrate how the scaffolds can help teachers notice weak coverage rates among standards and connections in the modified unit. All of the twenty teachers checked the weak coverage rates in the with-scaffolds situation (248 times, 44.6% of all segments), while only two teachers checked in the without-scaffolds situation (6 times, 1.1% of all segments). Twenty teachers checked the details of weak coverage rates in the with-scaffolds situation (182 times, 32.7% of all segments), while no teacher checked in the without-scaffolds situation.

4.3.5. Comparison for the use of types of unit structures when identifying weak coverage rates of standards and connections in the with- and without-scaffolds situations

In the with-scaffolds situation, teachers were able to pay attention to more types of unit structures when they identified weak coverage rates of unit structures than they did in the without-scaffolds situations (see Table 29). Only two of the eight related types of unit structures were mentioned in the without-scaffolds situation, while all eight types of unit structures were mentioned by teachers in the with-scaffolds situation. A Wilcoxon paired signed-rank test also showed a statistically reliable difference between the mean number of types of unit structures mentioned in the without-scaffolds situation ($M = 0.15$, s = 0.50) and with-scaffolds situation (M = 6.95, s = 1.32) when teachers identified the weak coverage rates, z(19) = 3.955, *p*<.001. In addition, a Wilcoxon paired signed-rank test showed a statistically reliable difference between the mean number of times unit structures were mentioned in the without-scaffolds situation (M = 0.31, s = 1.12) and the with-scaffolds situation (M = 21.69, s = 8.01) when teachers identified the weak coverage rates, z(19) = 3.921, p < .001. I also conducted Wilcoxon paired signed-rank tests for each of the related types of unit structures and the test results indicate that the mean differences are significant for all eight types of unit structures (see Table 29). Therefore, scaffolds helped teachers consider overall coverage more often and the details of coverage when they identified weak coverage rates of unit structures.

Teachers paid more attention to higher levels of unit structures when they identified weak coverage rates of standards and connections in the with-scaffolds situation than they did in the without-scaffolds situation. The mean of level of unit structures mentioned by teachers changed from 0.2 in the without-scaffolds situation to 2.3 in the with-scaffolds situation when identifying the weak coverage rates of standards and connections. These scores indicate that, overall, teachers almost did not consider unit structures when they identified weak coverage in the without-scaffolds situation. In contrast, they considered intermediate to advanced levels of unit structures when they identified weak coverage in the with-scaffolds situation. A Wilcoxon paired signed-rank test also showed a statistically reliable difference between the mean number of level of unit structures in the without-scaffolds situation (M = 0.20, s = 0.62) and the with-scaffolds situation (M = 2.30, s = 0.24) when teachers identified weak coverage rate, z(19) = 3.009, p < .001.

Table 29. Scaffolds helped teachers pay attention to all eight related types of unit structures when they identified weak coverage rates in the with-scaffolds situation.

Level of unit structures	Basic		Intermediate				Advanced	
Types of unit structures	Lessons related to a standard		Relative coverage rate				Connections related to a standard	
	Content standard	Inquiry standard	content standards	inquiry standards	content connections	inquiry connections	content standard	inquiry standard
Mentioned in the without-scaffolds situation			X	X				
Mentioned in the with-scaffolds situation	X	X	X	X	X	X	X	X
Wilcoxon paired signed-rank test	**3.824****	**3.519****	**3.783****	**3.724****	**3.726****	**3.823****	**3.298****	**3.516****

*p<0.05, **p<0.01

4.3.6. Relationship between teachers' individual characteristics and their use of unit structures when identifying weak coverage rates of standards and connections

First, the results indicate that the amount of experience with project-based science units is not related to teachers' use of unit structures when they identified weak coverage rates in both the without-scaffolds and the with-scaffolds situations. In earlier sections of this chapter, results also indicated that teachers' amount of experience with the unit is not related to their understanding of unit structures. Second, teachers who have better understanding of content connections mentioned lower levels of unit structures when they identified weak coverage rates in the with-scaffolds situation ($r=-0.444$, $p<0.05$). Third, teachers' estimation methods were not related to their use of unit structures when they identified weak coverage rate.

4.3.7. Teachers paid more attention to weak than strong coverage in the with-scaffolds situation

In the with-scaffolds situation, teachers identified more weak coverage rates than strong coverage rates. A Wilcoxon paired signed-rank test shows a statistically reliable difference between the mean number of times identifying weak coverage rates ($M = 21.69$, $s = 8.01$) and times identifying strong coverage rates ($M = 3.56$, $s = 3.51$) in the with-scaffolds situation, $t(19) = -8.50$, $p < .001$. Results from Wilcoxon paired signed-rank tests for each of the eight related types of unit structures also showed that the mean differences are significant for all eight types of unit structures (see Table 31).

Table 30. Correlation between teachers’ individual characteristics and their use of unit structures when identifying weak coverage rates of standards and connections.

	Number of types of unit structures (without-scaffolds)	Number of types of unit structures (with-scaffolds)	Number of unit structures (without-scaffolds)	Number of unit structures (with-scaffolds)	Level of unit structures (without-scaffolds)	Level of unit structures (with-scaffolds)
Experience with focus unit	-0.151	-0.360	0.314	-0.271	0.033	-0.144
Experience with content standards	-0.137	-0.367	0.322	-0.281	0.046	-0.146
Experience with inquiry standards	-0.078	-0.383	0.341	-0.308	0.093	-0.148
Existing understanding of content standards	0.430	-0.006	0.230	-0.070	0.388	0.075
Existing understanding of inquiry standards	0.315	-0.429	0.337	-0.038	0.356	-0.288
Existing understanding of content connection	0.216	-0.312	0.203	-0.432	0.232	**-0.444***
Existing understanding of inquiry connection	0.402	-0.263	0.219	-0.227	0.364	-0.304
Estimation method for content standard	-0.032	0.004	-0.029	0.130	-0.034	0.086
Estimation method for inquiry standard	0.200	-0.223	0.181	-0.139	0.212	-0.199
Estimation method for content connection	-0.138	-0.043	-0.093	0.240	-0.133	-0.130
Estimation method for inquiry connection	0.079	0.036	0.287	0.183	0.176	0.071

*p<0.05, **p<0.01

Table 31. Scaffolds helped teachers focus more on weak coverage than on strong coverage for all eight related types of unit structures.

Level of unit structures	Basic		Intermediate				Advanced	
Types of unit structures	Lessons related to a standard		Relative coverage rate				Connections related to a standard	
	Content standard	Inquiry standard	content standards	inquiry standards	content connections	inquiry connections	content standard	inquiry standard
Wilcoxon paired signed-rank test	**4.442****	**3.239****	**5.339****	**3.939****	**5.366****	**5.292****	**4.518****	**5.300****

*p<0.05, **p<0.01

4.3.8. Summary

This section presents findings for teachers' use of scaffolds when identifying strong and weak coverage rates of the modified units. I identified three major differences in teachers' modification practices between the without-scaffolds and with-scaffolds situations. First, the results indicate that in the with-scaffolds situation, teachers were able to consider more types of unit structures when they identified strong and weak coverage rates of the modified units. Teachers paid more attention to comparing relative coverage rates than checking details of coverage when identifying *strong coverage rates* of unit structures. In contrast, scaffolds provide supports for both comparing relative coverage rates and checking details of coverage when teachers identified *weak* coverage rates of unit structures. Second, teachers paid more attention to higher levels of unit structures when they identified both strong and weak coverage rates in the with-scaffolds situation than in the without-scaffolds situation. Third, in the with-scaffolds situation, teachers focused more on weak coverage rates than on the strong coverage rates of unit structures.

I identified three types of relationships between teachers' individual characteristics and their use of unit structures when identifying strong and weak coverage rates of unit structures. First, the amount of experience with project-based science units was not related to teachers' use of unit structures when they identified strong and weak coverage in both the without-scaffolds and the with-scaffolds situations. Second, teachers' pre-existing understanding of content and inquiry standards was related to their use of unit structures when they identified strong coverage in the without-scaffolds situation. Third, teachers who used more precise methods for estimating coverage rates of inquiry connections mentioned more types of unit structures and more times of unit structures when identifying strong coverage in the without-scaffolds situation.

4.4. Scaffolds for helping teachers identify advantages and disadvantages of including a lesson

In this section, I present findings related to how the scaffolds helped teachers identify advantages and disadvantages of including any particular lesson in their modified curriculum units. As described in Chapter Two, one major difference between expert and novice teachers is that expert teachers can identify the advantages and disadvantages of including a lesson by considering deeper and less apparent patterns in terms of instructional strategies and learning objectives. Conversely, novices are more likely to focus on superficial characteristics of lessons in their plans. Teachers who have a good understanding of curriculum coherence should be able to examine the following eight perspectives when they identify advantages and disadvantages of including a lesson: (1) Content standards covered by a lesson; (2) Inquiry standards covered by a lesson; (3) Content connections related to a lesson; (4) Inquiry connections related to a lesson; (5) Number of content standards covered by a lesson; (6) Number of inquiry standards covered by a lesson; (7) Number of content connections related to a lesson; (8) Number of inquiry connections related to a lesson (see Table 5).

In order to help teachers identify advantages and disadvantages of including a lesson in a modified curriculum unit, I developed scaffolds according to scaffolding strategy #1: Providing visualization to help teachers inspect multiple aspects of unit structures. Two types of representations were designed to help teachers visualize the advantage and disadvantage of including a lesson. The first type of representation demonstrates the standards and connections related to each lesson by showing a table where the rows represent lessons and columns represent standards. The buttons in the table indicate the standards covered in each lesson. Figure 13 shows an example of a table with buttons that demonstrates the coverage of content standards in each lesson of the *Stuff* unit.

The second type of representation demonstrates the number of standards and connections related to each lesson. In the *See Coverage of Standards* tab, the number of buttons in each row of lessons helps teachers compare the numbers of standards addressed by lessons in this unit. In the *See Coverage of Connections* tab, the number at the end of each row of lessons help teachers identify the amount of connections related to each lesson. When a standard is highlighted, the numbers shows the numbers of connections related to each lesson by this specific standard. In the example shown in Figure 14, Lesson 13 has the greatest number of connections (11 connections) and Lesson 5 has the least number of connections (2 connections).

Lesson	Substances and properties	Chemical reaction	Conservation of mass
Lesson 1	See Details		
Lesson 2	See Details		
Lesson 3	See Details		
Lesson 4	See Details		
Lesson 5	See Details		
Lesson 6	See Details		
Lesson 7		See Details	
Lesson 8		See Details	
Lesson 9		See Details	
Lesson 10		See Details	
Lesson 11		See Details	
Lesson 12		See Details	
Lesson 13			See Details
Lesson 14		See Details	See Details
Lesson 15	See Details	See Details	
Lesson 16		See Details	

Figure 13. Buttons in a table that represent differences between lessons in terms of covered standards

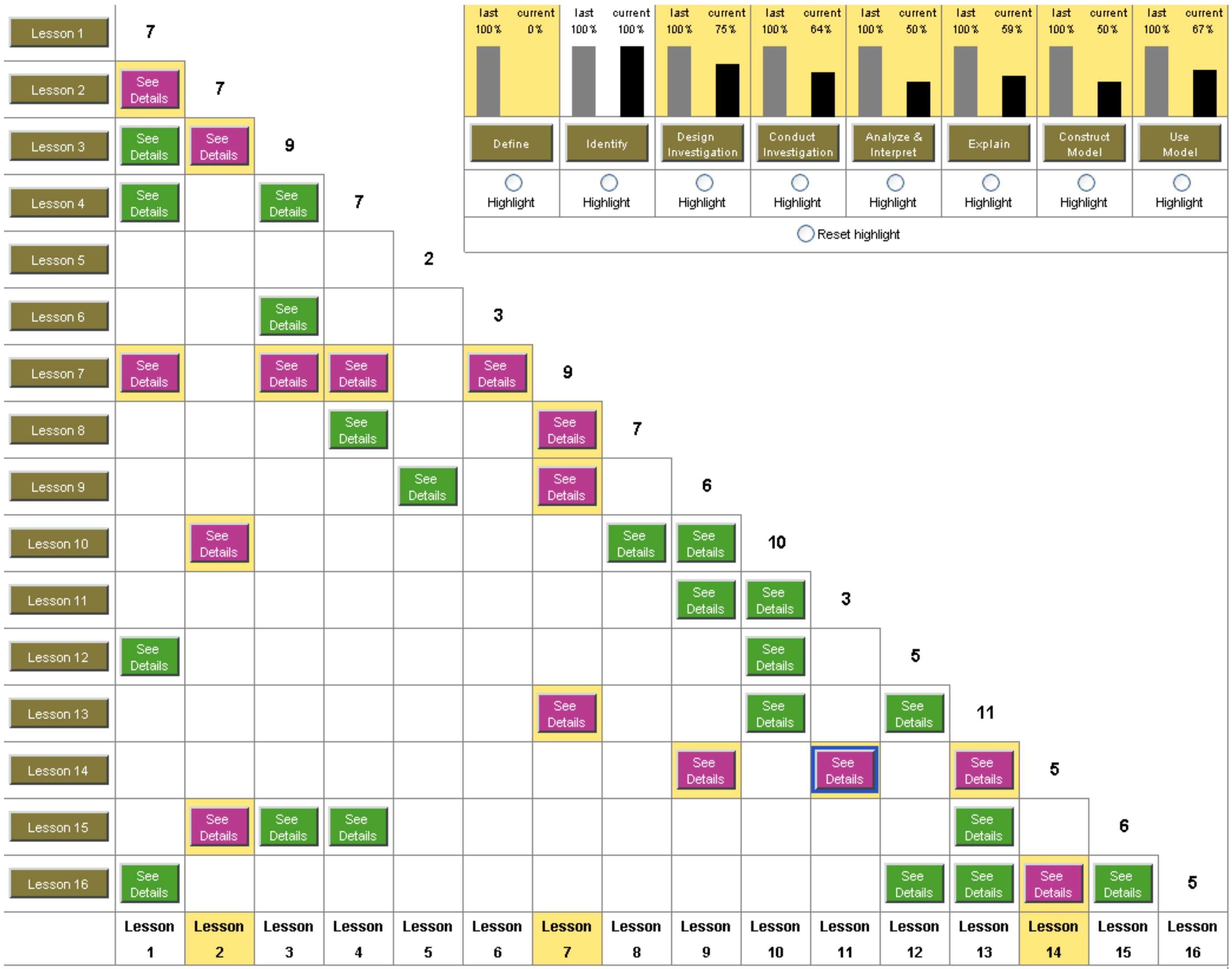

Figure 14. Numbers at the end of each row of lessons help teachers compare numbers of connections related to a lesson.

4.4.1. Teachers' use of scaffolds for identifying advantages of a lesson in terms of covered standards and related connections

Here are two examples for how this type of scaffold helped teachers identify advantages of including a lesson. First, Teacher S07 checked the buttons in the *See Coverage of Standards* tab and found that Lesson 7 is the only remaining lesson that addresses the *substance and property* content standard. To this end, she said, "I can't take out lesson seven, because I need property." Second, Teacher S10 checked the coverage rates of inquiry standards and found that Lesson 1 had been removed and it addressed several inquiry standards. She said, "I would put back lesson 1, since it adds percentage across the broad, especially identify and conduct investigation."

Here are two examples of how this type of scaffold helped teachers identify advantages of a lesson in terms of numbers of covered standards and related connections. Teacher U03 checked the coverage rates of inquiry standards and found the row of Lesson 7 full of red buttons. She said, "Lesson seven was the only lesson addressing all the inquiry standard and I took it out." Another example is that Teacher S04 found that Lesson 6 has four connections for *Substance and Properties* by checking the number at the end of the row of Lesson 6. She stated, "Lesson six is important, because it has a lot of connections for substance and properties."

These examples demonstrate how the scaffolds may help teachers notice advantages of including a lesson in terms of standards and connections related to this lesson. Twelve teachers checked the standards and connections covered by a lesson in the with-scaffolds situation (29 times, 5.2% of all segments), while six teachers did this in the without-scaffolds situation (9 times, 1.6% of all segments). Thirteen teachers checked the number of standards and connections covered by a lesson in the with-scaffolds situation (38 times, 6.8% of all segments), while no teacher did this in the without-scaffolds situation.

4.4.2. Comparison for the use of types of unit structures when identifying advantages of including a lesson in the with-scaffolds and the without-scaffolds situations

In the with-scaffolds situation, teachers were able to pay attention to more types of unit structures when they identified advantages of including a lesson. Only four of the eight related types of unit structures were mentioned in the without-scaffolds situation when teachers identified advantages of including a lesson, while all the eight types of unit structures were mentioned in the with-scaffolds situation (see Table 32). A Wilcoxon paired signed-rank test showed a statistically reliable difference between the mean number of types of unit structures mentioned in the without-scaffolds situation (M = 0.35, s = 0.59) and with-scaffolds situation (M = 2.35, s = 1.35) when teachers identified advantages of including a lesson, $z(19) = 3.503$, $p < .001$. In addition, a Wilcoxon paired signed-rank test showed a statistically reliable difference between the mean number of times unit structures were mentioned in the without-scaffolds situation (M = 0.48, s = 0.84) and with-scaffolds situation (M = 3.39, s = 2.45) when teachers identified advantages of including a lesson, $z(19) = 3.441$, $p < .001$.

I also conducted Wilcoxon paired signed-rank tests for each of the eight types of unit structures (see Table 32) and the test results indicate that the mean differences are significant for advanced-level unit structures.

Table 32. Scaffolds helped teachers focus more on higher levels of unit structures when they identified advantages of lessons in the with-scaffolds situation than in the without-scaffolds situation.

Level of unit structures	Basic		Intermediate				Advanced	
Types of unit structures	Standards covered by a lesson		Connections related to a lesson		Number of standards covered by a lesson		Number of standards covered by a lesson	
	Content standard	Inquiry standard	Content standard	Inquiry standard	Content standard	Inquiry standard	Content standard	Inquiry standard
Mentioned in the without-scaffolds situation	X	X	X	X				
Mentioned in the with-scaffolds situation	X	X	X	X	X	X	X	X
Wilcoxon paired signed-rank test	1.014	1.402	1.156	1.187	1.826	1.841	**2.805****	**2.207***

*p<0.05, **p<0.01

Teachers paid more attention to higher levels of unit structures when they identified advantages of including a lesson in the with-scaffolds situation than in the without-scaffolds situation. The mean of level of unit structures mentioned by teachers changed from 0.4 in the without-scaffolds situation to 1.8 in the with-scaffolds situation when they identified advantages of including a lesson. A Wilcoxon paired signed-rank test also shows a statistically reliable difference between the mean number of level of unit structures in the without-scaffolds situation (M = 0.4, s = 0.68) and with-scaffolds situation (M = 1.82, s = 1.00) when teachers identified advantages of including a lesson, z(19) = 3.206, $p < .001$. These scores indicate that, overall, teachers did not consider unit structures when they identified advantages of including a lesson in the without-scaffolds situation. In contrast, they considered the intermediate level of unit structures when they identified advantages in the with-scaffolds situation.

4.4.3. Relationship between teachers' individual characteristics and their use of unit structures when identifying advantages of including a lesson

I tested the relationships between teachers' individual characteristics and their use of unit structures when identifying advantages and disadvantages of including a lesson in the without-scaffolds and the with-scaffolds situations (see Table 33). First, the results indicate that the amount of experience with project-based science units was not related to their use of unit structures when they identified advantages of including a lesson in both the without-scaffolds and the with-scaffolds situations. Second, teachers with better understanding of inquiry standards paid more attention to lower-level unit structures when they identified advantages of including a lesson in the without-scaffolds situation ($r = -0.470$, $p < 0.05$). Third, the type of estimation methods used by teachers was not related to the use of unit structures when teachers identified the advantages of including a lesson in both the without-scaffolds and the with-scaffolds situations.

4.4.4. Teachers' use of scaffolds for identifying disadvantages of a lesson in terms of covered standards and related connections

The following are two examples for how this type of scaffold helped teachers identify disadvantages of a lesson. First, Teacher S05 checked the coverage rates of content connections and noticed that the *conservation of mass* content standard had a high coverage rate. He highlighted connections related to this standard and noticed that Lesson 13 only connected to Lesson 9. He stated, "Lesson thirteen is less important, because it has only one connections related to this standard." Another example is that Teacher S11 examined the coverage rate of *construct model* inquiry standard by checking the buttons in the *See Coverage of Standards* tab. She found that Lesson 5 and Lesson 9 both cover this inquiry standard and said, "In lesson five, kids build simple molecular model. It's not that important if they build more advanced model in later lessons."

The following are two examples of how this type of scaffold helped teachers identify disadvantages of a lesson in terms of numbers of covered standards and related connections. Teacher S09 checked the coverage rates of inquiry standards and found that Lesson 5 and 11 has the fewest number of buttons in their rows. He responded, "Lessons five and eleven are less critical, because they only hit one inquiry standard." Another example is that Teacher S06 checked the coverage rates of content connections and found that Lesson 12 has only one connection. She stated, "Lesson twelve is pretty ripped and I kept it. It only has one connection."

Table 33. Correlation between teachers' individual characteristics and their use of unit structures when identifying advantages of including a lesson.

	Number of types of unit structures (without-scaffolds)	Number of types of unit structures (with-scaffolds)	Number of unit structures (without-scaffolds)	Number of unit structures (with-scaffolds)	Level of unit structures (without-scaffolds)	Level of unit structures (with-scaffolds)
Experience with focus unit	0.291	-0.266	0.371	0.167	0.245	-0.400
Experience with content standards	0.270	-0.250	0.353	0.167	0.221	-0.408
Experience with inquiry standards	0.180	-0.179	0.268	0.157	0.118	-0.425
Existing understanding of content standards	-0.028	0.395	0.011	0.253	-0.041	-0.084
Existing understanding of inquiry standards	-0.430	0.258	-0.210	0.376	**-0.470***	0.332
Existing understanding of content connection	0.102	0.192	0.145	0.020	0.077	-0.290
Existing understanding of inquiry connection	-0.125	-0.058	-0.116	0.005	-0.078	-0.312
Estimation method for content standard	-0.061	-0.027	0.002	0.165	-0.061	0.040
Estimation method for inquiry standard	0.243	0.249	0.292	0.466	0.258	-0.133
Estimation method for content connection	0.240	-0.163	0.236	-0.071	0.130	-0.053
Estimation method for inquiry connection	0.187	-0.226	0.061	-0.164	0.209	-0.274

*p<0.05, **p<0.01

These examples demonstrate how scaffolds can help teachers notice disadvantages of including a lesson in terms of standards and connections covered by this lesson. Five teachers identified disadvantages of a lesson by checking its covered standards and connections in the with-scaffolds situation (10 times, 1.8% of all segments), while seventeen teachers did this in the without-scaffolds situation (71 times, 12.8% of all segments). Eleven teachers identified disadvantages of a lesson by checking its number of covered standards and connections in the with-scaffolds situation (32 times, 5.7% of all segments), while only one teacher did this in the without-scaffolds situation (2 times, 0.4% of all segments).

4.4.5. Comparison for the use of types of unit structures when identifying disadvantages of including a lesson in the with-scaffolds and the without-scaffolds situations

Next, I present results related to identifying disadvantages of including a lesson. Four of the eight related types of unit structures were mentioned in the without-scaffolds situation, while all of the eight types of unit structures were mentioned in the with-scaffolds situation, except for inquiry connections related to a lesson. A Wilcoxon paired signed-rank test did *not* show a statistically reliable difference between the mean number of types of unit structures mentioned in the without-scaffolds situation ($M = 1.60$, $s = 0.88$) and the with-scaffolds situation ($M = 1.25$, $s = 1.12$) when teachers identified disadvantage of lessons, $z(19) = 1.355$. However, a Wilcoxon paired signed-rank test *did* show a statistically reliable difference between the mean number of times of unit structures mentioned in the without-scaffolds situation ($M = 3.53$, $s = 3.30$) and the with-scaffolds situation ($M = 2.16$, $s = 2.70$) when teachers identified disadvantages of lessons, $z(19) = 2.178$, $p < .05$. I also conducted Wilcoxon paired signed-rank tests for each of the eight related types of unit structures and the results indicated that the scaffolds helped teachers pay less attention to lower level of unit structures and pay more attention to the advanced level of unit structures when they identified disadvantages of including a lesson in the with-scaffolds situation (see Table 34).

The mean number of level of unit structures mentioned by teachers changed from 1.28 in the without-scaffolds situation to 1.61 in the with-scaffolds situation when they identified disadvantages of including a lesson. However, a Wilcoxon paired signed-rank test did *not* show a statistically reliable difference between the mean number of level of unit structures in the without-scaffolds situation ($M = 1.28$, $s = 0.56$) and the with-scaffolds situation ($M = 1.61$, $s = 1.21$) when teachers identified disadvantages of including a lesson, $z(19) = 1.109$.

4.4.6. Relationship between teachers' individual characteristics and their use of unit structures when identifying disadvantages of including a lesson

I tested the relationships between teachers' individual characteristics and their use of unit structures when they identified disadvantages of including a lesson in the without-scaffolds and the with-scaffolds situations (see Table 35). First, the results indicated that the amount of experience with project-based science units is not related to teachers' use of unit structures when they identified disadvantages of including a lesson in both the without-scaffolds and the with-scaffolds situations. Second, teachers with better understanding of inquiry standards paid more attention to lower-level types of unit structures when they identified disadvantages of including a lesson in the without-scaffolds situation ($r = -0.456$, $p < 0.05$). Third, teachers who used more precise estimation methods for content standards mentioned fewer types of unit structures when they identified disadvantages of lessons in the without-scaffolds situation ($r = -0.458$, $p < 0.05$).

4.4.7. *Teachers paid more attention to the disadvantages than advantages of including a lesson in the with-scaffolds situation*

In the with-scaffolds situation, teachers paid more attention to the disadvantages than to the advantages of including a lesson. A Wilcoxon paired signed-rank test showed a statistically reliable difference between the mean number of times identifying the disadvantages of including a lesson ($M = 2.16$, $s = 2.69$) and the advantages of including a lesson ($M = 3.39$, $s = 2.45$) in the with-scaffolds situation, $z(19) = 2.34$, $p = 0.031$. I also conducted Wilcoxon paired signed-rank tests for each of the eight related types of unit structures. The test results indicated that the mean differences were significant for several types of unit structures that are at the basic and intermediate level (see Table 36).

4.4.8. *Summary*

This section described teachers' use of scaffolds for identifying the advantages and the disadvantages of including individual lessons in their modified curriculum units. I identified three major findings. First, the results indicated that teachers were able to pay attention to more types of unit structures when they identified the advantages and the disadvantages of including a lesson in the with-scaffolds situation than in the without-scaffolds situation. Second, teachers paid more attention to higher levels of unit structures when they identified the advantages and the disadvantages of including a lesson in the with-scaffolds situation than in the without-scaffolds situation. Third, in the with-scaffolds situation, teachers focused more on the advantages than on the disadvantages of including a lesson.

I identified two major findings for the relationships between teachers’ individual characteristics and their use of unit structures when they identified the advantages and the disadvantages of including a lesson. First, the amount of experience with project-based science units was not related to their use of unit structures when they identified the advantages and the disadvantages of including a lesson in both the without-scaffolds and the with-scaffolds situations. Second, teachers with better understanding of inquiry standards paid more attention to lower-level types of unit structures when they identified disadvantages of including a lesson in the without-scaffolds situation. Third, teachers who used more precise estimation methods for content standards mentioned fewer types of unit structures when they identified disadvantages of lessons in the without-scaffolds situation.

Table 34. Scaffolds helped teachers focused more on higher levels of unit structures when they identified disadvantages of lessons in the with-scaffolds situation than in the without-scaffolds situation.

Level of unit structures	Basic		Intermediate				Advanced	
Types of unit structures	Standards covered by a lesson		Connections related to a lesson		Number of standards covered by a lesson		Number of standards covered by a lesson	
	Content standard	Inquiry standard	Content standard	Inquiry standard	Content standard	Inquiry standard	Content standard	Inquiry standard
Mentioned in the without-scaffolds situation	X	X	X		X			
Mentioned in the with-scaffolds situation	X	X	X	X	X	X	X	X
Wilcoxon paired signed-rank test	**-2.197***	**-2.827****	**-3.061****	1.865	1.826	1.826	**2.371***	**2.023***

*p<0.05, **p<0.01

Table 35. Correlation between teachers' individual characteristics and their use of unit structures when identifying disadvantages of including a lesson.

	Number of types of unit structures (without-scaffolds)	Number of types of unit structures (with-scaffolds)	Number of unit structures (without-scaffolds)	Number of unit structures (with-scaffolds)	Level of unit structures (without-scaffolds)	Level of unit structures (with-scaffolds)
Experience with focus unit	-0.235	0.315	-0.169	0.335	-0.038	-0.029
Experience with content standards	-0.247	0.311	-0.179	0.320	-0.047	-0.037
Experience with inquiry standards	-0.284	0.282	-0.211	0.250	-0.081	-0.063
Existing understanding of content standards	-0.104	-0.416	-0.074	-0.219	-0.334	-0.433
Existing understanding of inquiry standards	-0.261	0.272	-0.125	0.335	**-0.456***	0.302
Existing understanding of content connection	0.030	0.035	0.045	0.016	0.278	0.112
Existing understanding of inquiry connection	0.092	-0.061	0.138	0.026	-0.243	-0.068
Estimation method for content standard	0.164	-0.115	0.143	0.097	**-0.458***	-0.095
Estimation method for inquiry standard	-0.164	-0.019	-0.072	0.073	-0.282	0.002
Estimation method for content connection	0.088	0.012	0.236	0.002	-0.098	-0.035
Estimation method for inquiry connection	-0.252	-0.226	-0.161	-0.280	-0.301	-0.411

*p<0.05, **p<0.01

Table 36. Scaffolds helped teachers focus more on advantages than disadvantages of lessons for basic and intermediate levels of unit structures.

Level of unit structures	Basic		Intermediate				Advanced	
Types of unit structures	Standards covered by a lesson		Connections related to a lesson		Number of standards covered by a lesson		Number of standards covered by a lesson	
	Content standard	Inquiry standard	Content standard	Inquiry standard	Content standard	Inquiry standard	Content standard	Inquiry standard
Wilcoxon paired signed-rank test	0.537	**2.416***	**2.256***	**2.127***	-0.572	-0.719	0.928	1.178

*$p<0.05$, **$p<0.01$

4.5. Scaffolds for helping teachers identify improved and worsened coverage rates of unit structures

In this section, I present results related to how the scaffolds helped teachers identify improved and worsened coverage rates of unit structures in their curriculum units. As described in Chapter Two, one major difference between experts and novices is that experts can evaluate their modifications by identifying improved and worsened aspects of coverage rates for higher-level unit structures. Conversely, novices would be more likely to focus on lower-level unit structures. Teachers with a good understanding of curriculum coherence should be able to identify changes in coverage rates in terms of the following four related unit structures: (1) the coverage rates of content standards; (2) the coverage rates of inquiry standards; (3) the coverage rates of content connections; and (4) the coverage rates of inquiry connections.

In order to help teachers identify improved and the worsened coverage rates of unit structures, I developed scaffolds according to scaffolding strategy #2: Demonstrating changes in coverage rates of unit structures as consequence of modification. I used the height difference between two bars to represent a change in coverage rates of standards or connections as a result of adding or removing lessons. In addition, a yellow background was used to mark places where the coverage rates of standards or connections changed. Figure 15 shows an example of bar graphs that demonstrate the drop in coverage rates of each content standard as a result of cutting lessons in the Stuff unit.

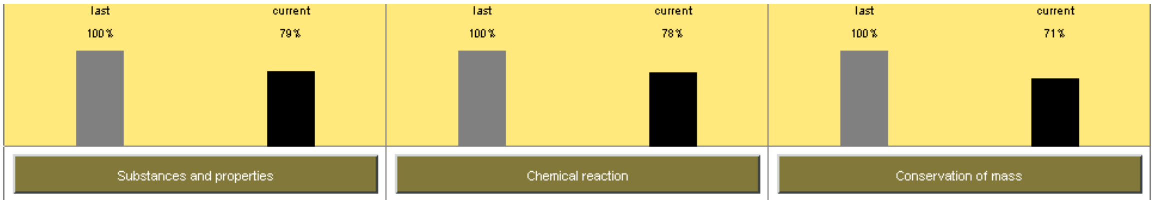

Figure 15. Bar graphs show worsened coverage rates of content standards.

4.5.1. Teachers' use of scaffolds for identifying improved coverage rates of unit structures

Here are two examples of how this type of scaffold helped teachers identify improved coverage rates for unit structures. First, Teacher S05 checked the bar graphs of content standards in the *See Coverage of Standards* tab and found that the heights of bars changed. To this end, she said, "chemical reaction increased, but substance and properties dropped." Second, Teacher S07 checked the coverage rates of inquiry connections and found that the black bar is much higher than the gray bar for the *design investigation* inquiry standard. She said, "Design investigation jumped up a lot. The grey and black bars show me that it's a substantial growth."These examples demonstrate how scaffolds can help teachers notice improved coverage rates of standards and connections. Eighteen of the twenty teachers checked the improved coverage rates in the with-scaffolds situation (82 times, 14.7% of all segments), while none of the twenty teachers did this in the without-scaffolds situation.

4.5.2. Comparison for the use of types of unit structures when identifying improved coverage rates of unit structures in the with-scaffolds and the without-scaffolds situations

In the with-scaffolds situation, teachers were able to pay attention to more types of unit structures when they identified improved coverage rates of unit structures. No teacher mentioned change of coverage in the without-scaffolds situation. In contrast, all four related types of unit structures were mentioned in the with-scaffolds situation (see Table 37). A Wilcoxon paired signed-rank test showed a statistically reliable difference between the mean number of types of unit structures mentioned in the without-scaffolds situation (M = 0.00, s = 0.00) and with-scaffolds situation (M = 2.50, s = 1.43) when they identified the improved coverage rates, z(19) = 3.759, $p < .001$. A Wilcoxon paired signed-rank test also showed a statistically reliable difference between the mean number of times of unit structures mentioned in the without-scaffolds situation (M = 0.00, s = 0.00) and with-scaffolds situation (M = 4.12, s = 3.49) when teachers identified advantages of including a lesson, z(19) = 3.724, $p < .001$.

The scaffolds helped teachers identify improved coverage rates in all four related types of unit structures. I conducted Wilcoxon paired signed-rank tests for each of the four related types of unit structures and the test results indicated that the mean differences are significant for all four related types of unit structures (see Table 37).

Table 37. Scaffolds helped teachers pay attention to improved coverage rates of all four types of related unit structures in the with-scaffolds situation, compared to none in the without-scaffolds situation.

Level of unit structures	Intermediate		Advanced	
Types of unit structures	Changed coverage rate		Changed coverage rate	
	content standards	inquiry standards	content connections	inquiry connections
Mentioned in the without-scaffolds situation				
Mentioned in the with-scaffolds situation	X	X	X	X
Wilcoxon paired signed-rank test	**3.062****	**3.302****	**3.061****	**3.063****

*p<0.05, **p<0.01

Teachers paid more attention to higher levels of unit structures when they identified improved coverage rates of unit structures in the with-scaffolds situation than in the without-scaffolds situation. The mean of level of unit structures mentioned by teachers changed from 0 in the without-scaffolds situation to 2.2 in the with-scaffolds situation when teachers identified improved coverage rates. These scores indicate that, overall, teachers did not consider unit structures when they were identifying improved coverage rates of standards and connections in the without-scaffolds situation. In contrast, teachers considered intermediate to advanced levels of unit structures when they identified improved coverage rates in the with-scaffolds situation. A Wilcoxon paired signed-rank test showed a statistically reliable difference between the mean of level of unit structures in the without-scaffolds situation (M = 0, s = 0) and with-scaffolds situation (M = 2.25, s = 0.82) when teachers identified improved coverage rates, $z(19) = 3.743$, $p < .001$.

4.5.3. Relationship between teachers' individual characteristics and their use of unit structures when identifying improved coverage rates of unit structures

I tested the relationships between teachers' individual characteristics and their use of types of unit structures when identifying improved coverage rates of unit structures in the without-scaffolds and the with-scaffolds situations (see Table 38). First, the results indicate that the amount of experience with project-based science units was not related to teachers' use of unit structures when they identified improved coverage rates of unit structures in both the without-scaffolds and the with-scaffolds situations. Second, teachers who had better understanding of inquiry connections referred to lower levels of unit structures' in the with-scaffolds situation ($r = -.489$, $p < .05$). Third, the type of estimation method used is not related to teachers' use of unit structures when they identified improved coverage rates of unit structures in either the without-scaffolds and the with-scaffolds situations.

4.5.4. Teachers' use of scaffolds for identifying worsened coverage rates of unit structures

The following are two examples for how the scaffolds helped teachers identify worsened coverage rates of unit structures. First, Teacher U01 checked the coverage rates for content coverage after removing a lesson. He noticed that most of the bar graphs had an orange background and the black bars were lower than the gray bars. He stated, "All but environmental conditions went down." Another example is that Teacher T03 examined the coverage rates of inquiry connections in the *See Coverage of Connections* tab and found that the black bar of the *construct model* inquiry standard is gone. She said, "Oh oh. Construct model drop to 0%."

These examples show that the scaffolds helped teachers notice the worsened coverage rates of standards and connections. Fourteen teachers checked the worsened coverage in the with-scaffolds situation (51 times, 9.2% of all segments), while none of the teachers did this in the without-scaffolds situation.

Table 38. Correlation between teachers' individual characteristics and their use of unit structures when identifying improved coverage rates.

	Number of types of unit structures (without-scaffolds)	Number of types of unit structures (with-scaffolds)	Number of unit structures (without-scaffolds)	Number of unit structures (with-scaffolds)	Level of unit structures (without-scaffolds)	Level of unit structures (with-scaffolds)
Experience with focus unit	N/A	-0.073	N/A	0.048	N/A	0.113
Experience with content standards	N/A	-0.087	N/A	0.041	N/A	0.096
Experience with inquiry standards	N/A	-0.138	N/A	0.013	N/A	0.028
Existing understanding of content standards	N/A	0.207	N/A	0.151	N/A	0.078
Existing understanding of inquiry standards	N/A	0.142	N/A	0.225	N/A	0.143
Existing understanding of content connection	N/A	0.083	N/A	-0.049	N/A	-0.333
Existing understanding of inquiry connection	N/A	-0.037	N/A	-0.047	N/A	**-0.489***
Estimation method for content standard	N/A	-0.108	N/A	0.068	N/A	0.069
Estimation method for inquiry standard	N/A	0.059	N/A	0.124	N/A	-0.029
Estimation method for content connection	N/A	-0.038	N/A	0.233	N/A	0.166
Estimation method for inquiry connection	N/A	-0.252	N/A	-0.088	N/A	0.278

*$p<0.05$, **$p<0.01$

4.5.5. Comparison for the use of types of unit structures when identifying worsened coverage rates of unit structures in the with-scaffolds and the without-scaffolds situations

In the with-scaffolds situation, teachers were able to pay attention to more types of unit structures when they identified worsened coverage rates of standards and connections. No teacher identified worsened coverage rates of standards and connections in the without-scaffolds situation. In contrast, all four related types of unit structures were mentioned in the with-scaffolds situation. A Wilcoxon paired signed-rank test showed a statistically reliable difference between the mean number of types of unit structures mentioned in the without-scaffolds situation (M = 0.00, s = 0.00) and with-scaffolds situation (M = 1.75, s = 1.52) when teachers identified worsened coverage rates, z(19) = 3.325, p<.001. A Wilcoxon paired signed-rank test also showed a statistically reliable difference between the mean number of times of unit structures mentioned in the without-scaffolds situation (M = 0.00, s = 0.00) and with-scaffolds situation (M = 2.57, s = 2.66) when teachers identified the worsened coverage rates, z(19) = 3.297, $p < .001$. I also conducted Wilcoxon paired signed-rank tests for each of the four related types of unit structures and the test results indicated that the mean differences were significant for all four related types of unit structures (see Table 39). Therefore, the scaffolds helped teachers identify worsened coverage rates in all four related types of unit structures.

Teachers also paid more attention to higher levels of unit structures when they identified worsened coverage rates of unit structures in the with-scaffolds situation as compared to the without-scaffolds situation. The mean of level of unit structures mentioned by teachers changed from 0 in the without-scaffolds situation to 2.95 in the with-scaffolds situation when they were identifying the improved coverage rates. A Wilcoxon paired signed-rank test showed a statistically reliable difference between the mean number of level of unit structures in the without-scaffolds situation (M = 0, s = 0) and with-scaffolds situation (M = 2.95, s = 3.04) when teachers identified worsened coverage rates, z(19) = 3.307, $p < .001$. These scores indicate that, overall, teachers did not consider any types of unit structures if they identified worsened coverage rates in the without-scaffolds situation. In contrast, they considered advanced level of unit structures when they identified worsened coverage rates in the with-scaffolds situation.

Table 39. Scaffolds helped teachers paid attention to worsened coverage rates when in the with-scaffolds situation, but not in the without-scaffolds situation.

Level of unit structures	Basic		Intermediate	
Types of unit structures	Changed coverage rate		Changed coverage rate	
	content standards	inquiry standards	content connections	inquiry connections
Mentioned in the without-scaffolds situation				
Mentioned in the with-scaffolds situation	X	X	X	X
Wilcoxon paired signed-rank test	**2.668****	**2.812****	**2.524***	**2.523***

4.5.6. Relationship between teachers' individual characteristics and their use of unit structures when identifying the worsened coverage rates of unit structures

I tested the relationships between teachers' individual characteristics and their use of types of unit structures when they identified worsened coverage rates of unit structures in the without-scaffolds and the with-scaffolds situations (see Table 40). The results indicate that teachers' amount of experience, existing understanding of unit structures, and estimation methods are not related to their use of types of unit structures when they identified the worsened coverage rates of unit structures in both the without-scaffolds and the with-scaffolds situations.

4.5.7. Difference between identifying improved and worsened coverage rates in the with-scaffolds situation

In the with-scaffolds situation, the scaffolds enabled teachers to pay attention to both the improved and worsened coverage rates. A Wilcoxon paired signed-rank test did not show a statistically reliable difference between the mean number of times identifying improved coverage rates ($M = 2.57$, $s = 2.66$) and worsened coverage rates ($M = 4.12$, $s = 3.49$) in the with-scaffolds situation, $z(19) = 1.902$. I also conducted Wilcoxon paired signed-rank tests for each of the four related types of unit structures and the test results indicated that the mean differences were not significant for any of the four types of related unit structures (see Table 41).

Table 40. Correlation between teachers' individual characteristics and their use of unit structures when identifying worsened coverage rates.

	Number of types of unit structures (without-scaffolds)	Number of types of unit structures (with-scaffolds)	Number of unit structures (without-scaffolds)	Number of unit structures (with-scaffolds)	Level of unit structures (without-scaffolds)	Level of unit structures (with-scaffolds)
Experience with focus unit	N/A	0.279	N/A	0.402	N/A	0.130
Experience with content standards	N/A	0.288	N/A	0.409	N/A	0.136
Experience with inquiry standards	N/A	0.312	N/A	0.421	N/A	0.153
Existing understanding of content standards	N/A	0.011	N/A	-0.131	N/A	0.077
Existing understanding of inquiry standards	N/A	0.024	N/A	0.063	N/A	0.059
Existing understanding of content connection	N/A	0.110	N/A	0.306	N/A	0.088
Existing understanding of inquiry connection	N/A	-0.027	N/A	0.061	N/A	-0.014
Estimation method for content standard	N/A	0.017	N/A	-0.174	N/A	-0.062
Estimation method for inquiry standard	N/A	0.023	N/A	0.079	N/A	-0.154
Estimation method for content connection	N/A	0.149	N/A	-0.015	N/A	0.074
Estimation method for inquiry connection	N/A	-0.033	N/A	-0.356	N/A	-0.052

*p<0.05, **p<0.01

Table 41. Teachers did not pay more attention to either improved or worsened coverage rates for any of the four types of unit structures.

Level of unit structures	Basic		Intermediate	
Types of unit structures	Changed coverage rate		Changed coverage rate	
	content standards	inquiry standards	content connections	inquiry connections
Wilcoxon paired signed-rank test	1.534	1.736	1.173	0.819

*p<0.05, **p<0.01

4.5.8. Summary

This section described how scaffolds helped teachers identify improved and worsened coverage rates of standards as a consequence of their modifications. I identified two major findings for the change in modification practices between the without-scaffolds and with-scaffolds situations. First, in the with-scaffolds situation, teachers were able to pay attention to more types of unit structures when they identified both the improved and the worsened coverage rates of unit structures. Second, teachers paid more attention to higher levels of unit structures when they identified the improved and the worsened coverage rates of unit structures in the with-scaffolds situation than in the without-scaffolds situation. Third, teachers' amount of experience, prior understanding of unit structures, and types of estimation methods were not related to their use of unit structures when they identified improved and worsened coverage rates of unit structures in both the without-scaffolds and the with-scaffolds situations.

4.6. Clarifying understanding of unit structures as a result of noticing weak coverage

The scaffolds that show relative coverage rates of unit structures not only helped teachers identify weak coverage rates of unit structures in their modified unit as described earlier, but also encouraged teachers to clarify their understanding of unit structures. All of the twenty teachers clarified their understanding of unit structures in their focus unit.

4.6.1. Teachers' use of scaffolds for clarifying understanding of unit structures

Here are two examples for how these types of scaffolds helped teachers clarify their understanding. First, Teacher T01 believed that the *Light* unit really focused on the *use models* inquiry standard. Therefore, she highlighted *use models* to check how she did on covering this standard. She referred to the red buttons to look for broken connections and found that the connection between Lessons 4 and 5 was gone because she omitted Lesson 4. Second, Teacher S12 noticed that the coverage rates of connections for the *chemical reaction* content standard is low and highlighted it to see the details of broken connections. She realized that she used the same kind of reasoning to estimate the coverage rates of connection as the coverage rates of standards. She stated, "I see the connections now. The information from PERT is like reminder that some of the lessons actually address standards I did not think of."

These examples demonstrate how the scaffolds can help teachers clarify their understanding of unit structures as a result of identifying weak coverage in their modified units. Twenty teachers clarified their understanding of unit structures as a result of identifying weak coverage in the with-scaffolds situation (102 times, 18.3% of all segments), while none of the teachers did this in the without-scaffolds situation. Nineteen teachers clarified their understanding of unit structures as a result of identifying the details of weak coverage in the with-scaffolds situation (93 times, 16.7% of all segments), while none of the teachers did this in the without-scaffolds situation. Next, I will present the difference between teachers' use of different types of unit structures in clarifying their understanding of unit structures when they identified weak coverage in the with-scaffolds and the without-scaffolds situations.

4.6.2. Comparison for the use of types of unit structures in clarifying understanding in the with-scaffolds and the without-scaffolds situations

The scaffolds helped teachers clarify their understanding all eight related types of unit structures. In the without-scaffolds situation, teachers did not explicitly clarify their understanding of unit structures when they were modifying units. In contrast, in the with-scaffolds situation, teachers were able to pay attention to all of the eight related types of unit structures for clarifying their understanding when they identified weak coverage (see Table 42). A Wilcoxon paired signed-rank test showed a statistically reliable difference between the mean number of types of unit structures mentioned in the without-scaffolds situation (M = 0.00, s = 0.00) and with-scaffolds situation (M = 5.25, s = 1.91) in terms of clarifying understanding of unit structures, $z(19) = 3.939$, $p < .001$. A Wilcoxon paired signed-rank test showed a statistically reliable difference between the mean number of times of unit structures mentioned in the without-scaffolds situation (M = 0.00, s = 0.00) and with-scaffolds situation (M = 9.75, s = 6.04) when teachers clarified understanding of unit structures, $z(19) = 3.920$, $p < .001$. I also conducted Wilcoxon paired signed-rank tests for each of the types of unit structures and the results indicated that the mean differences were significant for all the types of unit structures (see Table 42).

Teachers also paid more attention to higher levels of unit structures when they clarified understanding in the with-scaffolds situation than in the without-scaffolds situation. The mean of level of unit structures mentioned by teachers changed from 0 in the without-scaffolds situation to 2.2 in the with-scaffolds situation when they clarified understanding of unit structures. These scores indicate that, overall, teachers did not examine their understanding in the without-scaffolds situation. In contrast, they clarified their understanding of intermediate to advanced levels of unit structures in the with-scaffolds situation. A Wilcoxon paired signed-rank test showed a statistically reliable difference between the mean number of level of unit structures used in the without-scaffolds situation (M = 0, s = 0) and in the with-scaffolds situation (M = 2.31, s = 0.39) when teachers clarified understanding, z(19) = 3.920, $p < .001$.

4.6.3. Relationship between teachers' individual characteristics and their use of unit structures in clarifying understanding of unit structures

I tested the relationships between teachers' individual characteristics and their use of types of unit structures in clarifying their understanding of unit structures in the without-scaffolds and the with-scaffolds situations (see Table 43). First, the results indicated that the amount of experience with project-based science units was not related to teachers' use of unit structures when they clarified their understanding of unit structures in both the without-scaffolds and the with-scaffolds situations. Second, teachers' pre-existing understanding of unit structures was not related to their use of unit structures, except that teachers who had a better understanding of inquiry standards mentioned more lower levels of unit structures when they clarified understanding ($r = -.605$, $p < 0.05$). Third, the type of estimation method used was not related to teachers' use of unit structures when they clarified understanding of unit structures. These results imply that, overall, scaffolds helped teachers clarify understanding of unit structures regardless of their individual characteristics.

4.6.4. Summary

This section described how scaffolds helped teachers clarify their understanding of unit structures when they identified weak coverage rates in their modified units. First, in the with-scaffolds situation, teachers were able to pay attention to more types of unit structures when they clarified their understanding of unit structures. Second, teachers paid more attention to higher levels of unit structures when they clarified their understanding of unit structures in the with-scaffolds situation than in the without-scaffolds situation. The results indicate that teachers' amount of experience, prior understanding of unit structures, and types of estimation methods were not related to their use of unit structures when they clarified understanding of unit structures in both the without-scaffolds and the with-scaffolds situations.

Table 42. The scaffolds help teachers clarify understanding of all eight related types of unit structures when they identified weak coverage

Level of unit structures	Basic		Intermediate				Advanced	
Types of unit structures	Lessons related to a standard		Relative coverage rate				Connections related to a standard	
	Content standard	Inquiry standard	content standards	inquiry standards	content connections	inquiry connections	content standard	inquiry standard
Mentioned in the without-scaffolds situation								
Mentioned in the with-scaffolds situation	X	X	X	X	X	X	X	X
Wilcoxon paired signed-rank test	**3.301****	**3.185****	**3.411****	**3.306****	**2.809****	**3.411****	**2.805****	**3.297****

*p < 0.05, **p < 0.01

Table 43. Correlation between teachers' individual characteristics and their use of unit structures when clarifying understanding

	Number of types of unit structures (without-scaffolds)	Number of types of unit structures (with-scaffolds)	Number of unit structures (without-scaffolds)	Number of unit structures (with-scaffolds)	Level of unit structures (without-scaffolds)	Level of unit structures (with-scaffolds)
Experience with focus unit	N/A	-0.360	N/A	-0.243	N/A	-0.128
Experience with content standards	N/A	-0.355	N/A	-0.245	N/A	-0.122
Experience with inquiry standards	N/A	-0.324	N/A	-0.246	N/A	-0.093
Existing understanding of content standards	N/A	0.014	N/A	-0.009	N/A	-0.189
Existing understanding of inquiry standards	N/A	-0.111	N/A	-0.047	N/A	**-0.605****
Existing understanding of content connection	N/A	-0.434	N/A	-0.212	N/A	0.093
Existing understanding of inquiry connection	N/A	-0.221	N/A	-0.065	N/A	-0.043
Estimation method for content standard	N/A	0.040	N/A	-0.001	N/A	-0.247
Estimation method for inquiry standard	N/A	-0.069	N/A	-0.014	N/A	-0.415
Estimation method for content connection	N/A	-0.049	N/A	0.263	N/A	-0.218
Estimation method for inquiry connection	N/A	-0.012	N/A	0.144	N/A	-0.190

$*p < 0.05$, $**p < 0.01$

4.7. Lesson selection based on identified advantages and disadvantages of including a lesson

The scaffolds that show characteristics of lessons not only helped teachers identify advantages and disadvantages of including a lesson, but also encouraged teachers to make decisions about their modifications. Twenty teachers selected lessons based on identified advantages in the without-scaffolds situation, while seventeen teachers selected lessons based on identified advantages in the with- scaffolds situation. Nineteen teachers removed lessons based on identified disadvantages in the without-scaffolds situation, while sixteen teachers removed lessons based on identified disadvantages in the with-scaffolds situation.

4.7.1. Teachers' use of scaffolds for selecting lessons based on identified advantages

Here are two examples for how this type of scaffold helped teachers identify advantages of a lesson and decided to keep this lesson in the modified unit. First, Teacher S12 found that Lessons 10 and 16 were not selected and both were related to the *design investigation* inquiry standards in the *See Coverage of Standards* tab and wondered, "Which one would I pick?" She checked the buttons along each row of the lessons and realized that they covered different inquiry standards in addition to *design investigation*. She stated, "Lesson ten would increase more inquiry standards than lesson sixteen does. I would select lesson ten." Second, Teacher U01 went to the *See Coverage of Connections* tab and checked the number of total connections of each lesson by referring to the number at the end of each row of lessons. He said, "I am putting lesson seven back, because it covers more connections. Content connection is the most important factor in my consideration.”

These examples demonstrate how the scaffolds can help teachers select lessons based on identified advantages. Twelve teachers selected lessons based on identified coverage rates for standards or connections in the with-scaffolds situation (25 times, 4.5% of all segments), while nineteen teachers did this in the without-scaffolds situation (262 times, 47.1% of all segments). Eleven teachers selected lessons based on number of identified coverage rates for standards or connections in the with-scaffolds situation (26 times, 4.7% of all segments), while none of the teachers did this in the without-scaffolds situation.

4.7.2. Comparison for the use of types of unit structures in keeping lessons with identified advantages in the with-scaffolds and the without-scaffolds situations

In the with-scaffolds situation, teachers were able to pay attention to more types of unit structures when they kept lessons based on identified advantages of including a lesson. Results show that only four of the eight related types of unit structures were mentioned in the without-scaffolds situation when teachers kept a lesson based on identified advantages, while all eight types of unit structures were mentioned in the with-scaffolds situation (see Table 44). A Wilcoxon paired signed-rank test showed a statistically reliable difference between the mean number of types of unit structures mentioned in the without-scaffolds situation ($M = 3.10$, $s = 1.17$) and with-scaffolds situation ($M = 1.85$, $s = 1.14$) when teachers kept lessons by identifying advantages of including a lesson, $z(19) = 2.660$, $p = .008$. A Wilcoxon paired signed-rank test also showed a statistically reliable difference between the mean number of times of unit structures mentioned in the without-scaffolds situation (M = 13.07, s = 5.92) and with-scaffolds situation (M = 2.64, s = 1.90) when teachers kept lessons by identifying advantages of including a lesson, z(19) = 3.809, $p < .001$.

I also conducted Wilcoxon paired signed-rank tests for each of the eight related types of unit structures and the test results indicated that teachers paid less attention to lower levels of types of unit structures (standards and connections related to a lesson) in the with-scaffolds situation than in the without-scaffolds situation (see Table 44). Teachers paid more attention to higher levels of types of unit structures (number of connections related to a lesson) in the with-scaffolds situation than in the without-scaffolds situation.

Next, I present results related to the difference between levels of types of unit structures considered by teachers when they kept lessons based on advantages of lessons in the with-scaffolds situation and in the without-scaffolds situation. The mean level of unit structures mentioned by teachers changed from 1.31 in the without-scaffolds situation to 1.71 in the with-scaffolds situation when they kept lessons based on identified advantages of including a lesson. A Wilcoxon paired signed-rank test shows a statistically reliable difference between the mean number of level of unit structures in the without-scaffolds situation (M = 1.31, s = 0.36) and the with-scaffolds situation (M = 1.71, s = 0.98), z(19) = 3.613, p<.005

4.7.3. Relationship between teachers' individual characteristics and their use of unit structures in keeping lessons based on identified advantages of including a lesson

I tested the relationships between teachers' individual characteristics and their use of types of unit structures when they kept lessons based on identified advantages of including a lesson in both the without-scaffolds and the with-scaffolds situations (see

Table 45). First, the amount of experience with the focus unit was not related to teachers' use of types of unit structures when they kept lessons based on advantages of including a lesson. Second, teachers with better understanding of content standards mentioned more types of unit structures ($r = 0.560$, $p < 0.05$) in the with-scaffolds situation. In addition, teachers with better understanding of inquiry standards mentioned more types of unit structures ($r = 0.579$, $p < 0.01$) in the with-scaffolds situation. Third, teachers who used more precise methods mentioned more types of unit structures ($r = 0.448$, $p < 0.05$) in the with-scaffolds situation.

4.7.4. Teachers' use of scaffolds for removing lessons based on identified disadvantages

The following are two examples for how this type of scaffold helped teachers identify disadvantages of a lesson and then remove the lesson. First, Teacher U04 realized that the total number of class periods used were over the limit and she need to omit some lessons. She checked along the rows of each lesson in the *See Coverage of Standards* tab. She said, "I would like to take out lessons that have a few skills. For example, lesson nine has only two inquiry skills." Another example is that Teacher S09 was trying to decide which lesson to remove in order to meet the time constraint. He went to the *See Coverage of Standards* tab and found that maybe Lesson 5 and 11 can go, because they only hit one inquiry standards. She then checked the coverage rates of content standards and found that Lesson 11 has only two connections with other lessons. Therefore, she decided to remove Lesson 5.

Table 44. The scaffolds helps teachers paid more attention to higher levels of unit structures when they kept lessons because of identified advantages of including a lesson in the with-scaffolds situation than in the without-scaffolds situation.

Level of unit structures	Basic		Intermediate				Advanced	
Type of unit structures	Standards covered by a lesson		Connections related to a lesson		Number of standards covered by a lesson		Number of standards covered by a lesson	
	Content standard	Inquiry standard	Content standard	Inquiry standard	Content standard	Inquiry standard	Content standard	Inquiry standard
Mentioned in the without-scaffolds situation	X	X	X	X				
Mentioned in the with-scaffolds situation	X	X	X	X	X	X	X	X
Wilcoxon paired signed-rank test	**-3.823****	**-2.768****	**-3.622****	**-2.902****	1.342	1.841	**2.201***	**1.841***

*p<0.05, **p<0.01

Table 45. Correlation between teachers' individual characteristics and their use of unit structures when keeping lessons based on advantages of lessons.

	Number of types of unit structures (without-scaffolds)	Number of types of unit structures (with-scaffolds)	Number of unit structures (without-scaffolds)	Number of unit structures (with-scaffolds)	Level of unit structures (without-scaffolds)	Level of unit structures (with-scaffolds)
Experience with focus unit	0.110	-0.411	0.189	0.020	-0.083	-0.421
Experience with content standards	0.111	-0.396	0.188	0.015	-0.070	-0.433
Experience with inquiry standards	0.112	-0.325	0.176	-0.004	-0.018	-0.259
Existing understanding of content standards	0.418	**0.560***	0.298	0.404	0.301	-0.043
Existing understanding of inquiry standards	-0.140	0.394	0.185	**0.579****	-0.060	0.341
Existing understanding of content connection	0.048	0.149	0.217	-0.012	0.338	-0.377
Existing understanding of inquiry connection	0.273	0.118	0.359	0.175	0.365	-0.315
Estimation method for content standard	0.345	0.286	0.140	0.438	-0.030	0.146
Estimation method for inquiry standard	0.419	0.267	0.162	**0.448***	0.102	-0.138
Estimation method for content connection	0.398	-0.028	0.225	0.085	0.226	0.016
Estimation method for inquiry connection	0.379	-0.029	-0.042	0.043	0.282	-0.224

*p<0.05, **p<0.01

These examples demonstrate how the scaffolds can help teachers remove a lesson based on identified disadvantages of this lesson. Four teachers removed a lesson based on identified disadvantages in terms of covered standards or connections in the with-scaffolds situation (9 times, 1.6% of all segments), while sixteen teachers did this in the without-scaffolds situation (70 times, 12.6% of all segments). Ten teachers removed a lesson based on identified disadvantages in terms of the details of covered standards or connections in the with-scaffolds situation (21 times, 3.8% of all segments), while one teacher did this in the without-scaffolds situation (2 times, 0.4% of all segments).

4.7.5. Comparison for the use of types of unit structures in removing lessons with identified disadvantages in the with-scaffolds and the without-scaffolds situations

Teachers were able to pay attention to more types of unit structures when they removed lessons based on identified disadvantages of including a lesson in the with-scaffolds situation than in the without-scaffolds situation. Results showed that only four of the eight related types of unit structures were mentioned in the without-scaffolds situation, while all eight types of unit structures were mentioned in the with-scaffolds situation, except for inquiry standards covered by a lesson and inquiry connections related to a lesson (see Table 46). A Wilcoxon paired signed-rank test showed a statistically reliable difference between the mean number of types of unit structures mentioned in the without-scaffolds situation ($M = 1.55$, $s = 0.94$) and with-scaffolds situation ($M = 0.95$, $s = 0.83$) when teachers removed lessons because of identified disadvantages of lessons, $z(19) = 2.174$, $p = .030$. A Wilcoxon paired signed-rank test also showed a statistically reliable difference between the mean number of times of unit structures mentioned in the without-scaffolds situation ($M = 3.46$, $s = 3.34$) and with-scaffolds situation (M = 1.56, s = 1.58) when teachers removed lessons because of identified disadvantages of lessons, z(19) = 2.793, *p* = .005.

I also conducted Wilcoxon paired signed-rank tests for each of the types of unit structures and the test results indicated that teachers paid less attention to lower levels of types of unit structures (standards and connections related to a lesson) when they removed lessons based on identified disadvantages of them in the with-scaffolds situation than in the without-scaffolds situation (see Table 46). Teachers paid more attention to higher levels of types of unit structures (number of connections related to a lesson) when they removed lessons based on identified disadvantages of them in the with-scaffolds situation than in the without-scaffolds situation.

Next, I present results related to the difference between levels of types of unit structures considered by teachers when they removed lessons based on identified disadvantages of lessons in the with-scaffolds situation and in the without-scaffolds situation. When teachers removed lessons based on identified disadvantages of these lessons, the mean of level of unit structures mentioned changed from 1.28 in the without-scaffolds situation to 1.46 in the with-scaffolds situation. A Wilcoxon paired signed-rank test show a statistically reliable difference between the mean number of level of unit structures in the without-scaffolds situation (M = 1.23, s = 0.63) and the with-scaffolds situation (M = 1.46, s = 1.21), z(19) = 2.593, $p<.005$.

4.7.6. Relationship between teachers' individual characteristics and their use of unit structures in removing lessons based on identified disadvantages of a lesson

I tested the relationships between teachers' individual characteristics and their use of types of unit structures in removing lessons based on identified disadvantages of including a lesson (see Table 47). First, the results showed that the amount of experience with project-based science units was not related to their use of unit structures. Second, teachers with better understanding of content standards mentioned more lower levels of types of unit structures in the without-scaffolds situation ($r = -0.445$, $p < 0.05$). In addition, teachers with better understanding of inquiry standards also mentioned more lower levels of types of unit structures in the without-scaffolds situation ($r = -0.488$, $p < 0.05$). Third, the estimation methods used was not related to teachers' use of types of unit structures.

4.7.7. Summary

This section described findings related to teachers' use of scaffolds for selecting lessons based on identified advantages and disadvantages of individual lessons. First, teachers shifted their focus from lower to higher levels of types of unit structures when they kept or removed lessons based identified advantages or disadvantages of these lessons in the with-scaffolds situation. Second, teachers considered more types of unit structures when they selected lessons based on identified advantages and disadvantages of including these lessons. Third, teachers with a better understanding of content or inquiry standards focused more on lower level of unit structures when they removed lessons based on disadvantages of these lessons in the with-scaffolds situation than in the without-scaffolds situation.

Table 46. The scaffolds helped teachers pay more attention to higher levels of unit structures when omitting lessons because of identified disadvantages of including a lesson in the with-scaffolds situation than in the without-scaffolds situation.

Level of unit structures	Basic				Intermediate		Advanced	
Type of unit structures	Standards covered by a lesson		Connections related to a lesson		Number of standards covered by a lesson		Number of standards covered by a lesson	
	Content standard	Inquiry standard	Content standard	Inquiry standard	Content standard	Inquiry standard	Content standard	Inquiry standard
Mentioned in the without-scaffolds situation	X	X	X		X			
Mentioned in the with-scaffolds situation	X	X	X	X	X	X	X	X
Wilcoxon paired signed-rank test	**-2.197***	**-2.805****	**-3.061****	N/A	1.604	1.614	**2.032***	1.604

*p<0.05, **p<0.01

Table 47. Correlation between teachers' individual characteristics and their use of unit structures when omitting lessons based on disadvantages of lessons.

	Number of types of unit structures (without-scaffolds)	Number of types of unit structures (with-scaffolds)	Number of unit structures (without-scaffolds)	Number of unit structures (with-scaffolds)	Level of unit structures (without-scaffolds)	Level of unit structures (with-scaffolds)
Experience with focus unit	-0.131	0.382	-0.149	0.262	0.099	0.136
Experience with content standards	-0.145	0.372	-0.158	0.237	0.086	0.120
Experience with inquiry standards	-0.194	0.319	-0.189	0.131	0.030	0.051
Existing understanding of content standards	-0.194	-0.423	-0.090	-0.288	**-0.445***	-0.432
Existing understanding of inquiry standards	-0.291	0.296	-0.121	0.315	**-0.488***	0.420
Existing understanding of content connection	-0.008	-0.154	0.038	-0.333	0.192	-0.103
Existing understanding of inquiry connection	-0.003	-0.190	0.115	-0.138	-0.348	-0.246
Estimation method for content standard	0.158	-0.119	0.143	0.205	-0.400	-0.081
Estimation method for inquiry standard	-0.188	-0.014	-0.084	-0.008	-0.298	0.013
Estimation method for content connection	0.111	0.139	0.248	0.128	-0.052	0.111
Estimation method for inquiry connection	-0.219	-0.039	-0.161	-0.103	-0.238	-0.231

*p<0.05, **p<0.01

4.8. Evaluation of modification based on identified strong and weak coverage rates of standards and connections

The scaffolds that helped teachers examine coverage rates for standards and connections not only helped teachers identify strong and weak coverage rates in their modified unit, but also encouraged teachers to evaluate their modifications. None of the twenty teachers mentioned that they were satisfied with their modifications based on identification of the strong coverage rates for standards and connections in the without-scaffolds situation, while thirteen teachers did this in the with-scaffolds situation. Only one teacher mentioned that she was not satisfied with her modifications based on identified weak coverage rates for standards and connections in the without-scaffolds situation, while nineteen teachers did this in the with-scaffolds situation.

4.8.1. Teachers' use of scaffolds for evaluating modifications based on identified strong coverage

Here are two examples for how this type of scaffold helped teachers evaluate modifications based on identified strong coverage rates. First, Teacher U04 put Lesson 12 back to the unit and then went to check the coverage rates of inquiry standards by referring to the bar graphs. She said, "I am satisfied with the coverage. There are certain ones that are higher, but all of them are close to fifty percent or so." Second, Teacher T01 examined her modified unit by checking the coverage rates of inquiry connections. She highlighted the *use model* inquiry standard because it was one of the key things she tried to bring into the unit. After checking the highlighted green and red buttons, she stated, "Of four of them, I am only cutting one. It's good, isn't it?"

These examples showed that the scaffolds helped teachers evaluate modifications based on identified strong coverage rates. Fourteen teachers were satisfied with their modifications based on the identified strong coverage rates of standards or connections in the with-scaffolds situation (50 times, 9.0% of all segments), while one teacher did this in the without-scaffolds situation (2 times, 0.4% of all segments). Eleven teachers were satisfied with their modifications based on the details of identified strong coverage rates of standards or connections in the with-scaffolds situation (20 times, 3.6% of all segments), while nine teachers did this in the without-scaffolds situation (28 times, 5.0% of all segments).

4.8.2. Comparison for the use of types of unit structures in evaluating modifications based on identified strong coverage in the with-scaffolds and the without-scaffolds situations

In the with-scaffolds situation, teachers were able to pay attention to more types of unit structures when they were satisfied with their modified unit based on the identified strong coverage rates of standards and connections. Results showed that four of the eight related types of unit structures were mentioned in the without-scaffolds situation, while all of the eight types of unit structures were considered in the with-scaffolds situation (see Table 48). A Wilcoxon paired signed-rank test showed a statistically reliable difference between the mean number of types of unit structures mentioned in the without-scaffolds situation ($M = 0.65$, $s = 0.81$) and the with-scaffolds situation ($M = 2.45$, $s = 2.06$) when they felt satisfied with modified units based on identified strong coverage, $z(19) = 3.017$, $p < .001$. A Wilcoxon paired signed-rank test also showed a statistically reliable difference between the mean number of times unit structures were mentioned in the without-scaffolds situation (M = 1.50, s = 2.64) and the with-scaffolds situation (M = 3.56, s = 3.50) when teachers felt satisfied with their modified units based on identified strong coverage, z(19) = 2.202, $p = .028$. I also conducted Wilcoxon paired signed-rank tests for each of the eight related types of unit structures and the test results indicated that teachers paid more attention to the relative coverage rates of standards and connections to evaluate their modified units in the with-scaffolds situation than they did in the without-scaffolds situation (see Table 48).

Next, I present results related to the difference between levels of types of unit structures considered by teachers when they evaluated modified units based on strong coverage rates of standards and connections in the with-scaffolds situation and in the without-scaffolds situation. The mean level of unit structures mentioned by teachers changed from 0.96 in the without-scaffolds situation to 1.18 in the with-scaffolds situation when they were satisfied with their modified unit based on identified strong coverage. However, a Wilcoxon paired signed-rank test did *not* show a statistically reliable difference between the mean number of level of unit structures in the without-scaffolds situation (M = 0.96, s = 1.01) and the with-scaffolds situation (M = 1.18, s = 0.75), z(19) = 0.828.

4.8.3. Relationship between teachers' individual characteristics and their use of unit structures in evaluating modifications based on identified strong coverage

I tested the relationships between teachers' individual characteristics and their use of types of unit structures when they were evaluating their modified units based on identified strong coverage (see Table 49). First, the results showed that teachers' amount of experience with project-based science units was not related to their use of types of unit structures. Second, teachers with a better understanding of content standards mentioned more types of unit structures ($r = 0.450$, $p < 0.05$). In addition, teachers with a better understanding of inquiry standards mentioned more types of elements ($r = 0.477$, $p < 0.05$) and a greater number of elements ($r = 0.481$, $p < 0.05$) of unit structures when they were satisfied with their modified unit in the without-scaffolds situation. Teachers with better understanding of inquiry standards also focused more on lower level of types of unit structures when they were satisfied with their modified unit in the with-scaffolds situation ($r = -0.450$, $p < 0.05$). Third, the type of estimation method used was not related to teachers' use of unit structures when they were satisfied with their modified units based on identified strong coverage.

4.8.4. Teachers' use of scaffolds for evaluating modifications based on identified weak coverage

Here are two examples of how this type of scaffold helped teachers evaluate modifications based on identified weak coverage. First, Teacher S06 examined her modified unit and checked the bar graph of inquiry connections. She noticed the empty bar graph for the *define* inquiry standard and said, "Oh! Wait. Currently, there is no defining at all?" She also referred to the green and red buttons for inquiry connections and stated, "Look at these reds. Reds are out, right? I only got seven connections left!" Second, Teacher S12 browsed through the bar graphs for inquiry coverage rates to look for lower ones. She noticed that the *conduct investigation* inquiry standard is the lowest. She then checked the buttons related to that inquiry standards and found that Lesson 4 was not selected.

Table 48. Scaffolds helped teachers pay more attention to relative coverage rates when they were satisfied with their modified unit in the with-scaffolds situation.

Level of unit structures	Basic		Intermediate				Advanced	
Type of unit structures	Lessons related to a standard		Relative coverage rate				Connections related to a standard	
	Content standard	Inquiry standard	content standards	inquiry standards	content connections	inquiry connections	content standard	inquiry standard
Mentioned in the without-scaffolds situation	X	X	X				X	
Mentioned in the with-scaffolds situation	X	X	X	X	X	X	X	X
Wilcoxon paired signed-rank test	-1.601	1.277	**2.448***	**2.938****	1.826	**2.524***	0.447	1.604

*p < 0.05, **p < 0.01

Table 49. Correlation between teachers' individual characteristics and their use of unit structures when satisfied with their modified units based on identified strong coverage.

	Number of types of unit structures (without-scaffolds)	Number of types of unit structures (with-scaffolds)	Number of unit structures (without-scaffolds)	Number of unit structures (with-scaffolds)	Level of unit structures (without-scaffolds)	Level of unit structures (with-scaffolds)
Experience with focus unit	-0.166	0.125	0.207	0.171	-0.104	-0.001
Experience with content standards	-0.156	0.140	0.197	0.177	-0.090	0.013
Experience with inquiry standards	-0.109	0.192	0.153	0.192	-0.034	0.066
Existing understanding of content standards	**0.450***	-0.065	0.111	-0.055	0.334	-0.118
Existing understanding of inquiry standards	**0.477***	-0.112	**0.481***	-0.063	0.412	**-0.450***
Existing understanding of content connection	0.136	0.343	0.192	0.243	0.138	0.370
Existing understanding of inquiry connection	0.375	0.174	0.277	0.210	0.204	-0.001
Estimation method for content standard	0.298	-0.222	0.227	-0.046	0.310	-0.313
Estimation method for inquiry standard	0.359	-0.056	0.346	0.055	0.261	-0.206
Estimation method for content connection	-0.056	**-0.494***	0.008	**-0.495***	-0.066	**-0.536***
Estimation method for inquiry connection	0.126	-0.036	-0.115	-0.175	0.138	-0.124

*p<0.05, **p<0.01

These examples demonstrate how the scaffolds can help teachers evaluate modifications based on identified weak coverage. Nineteen teachers were dissatisfied with their modifications when they identified weak coverage rates of standards or connections in the with-scaffolds situation (81 times, 14.6% of all segments), while two teachers did this in the without-scaffolds situation (6 times, 1.1% of all segments). Seventeen teachers were dissatisfied with their modifications based on the details of identified weak coverage rates of standards or connections in the with-scaffolds situation (48 times, 8.6% of all segments), while no teacher did this in the without-scaffolds situation.

4.8.5. *Comparison for the use of types of unit structures in evaluating modifications based on identified weak coverage in the with-scaffolds and the without-scaffolds situations*

In the with-scaffolds situation, teachers were able to pay attention to more types of unit structures when they were dissatisfied with their modified unit based on identified weak coverage rates of standards and connections. Results indicated that only two of the eight related types of unit structures were mentioned in the without-scaffolds situation, while all of the eight types were considered in the with-scaffolds situation (see Table 50). A Wilcoxon paired signed-rank test showed a statistically reliable difference between the mean number of types of unit structures mentioned in the without-scaffolds situation ($M = 0.15$, $s = 0.49$) and the with-scaffolds situation ($M = 3.65$, $s = 1.79$) when teachers felt dissatisfied with their modified units based on identified weak coverage, $z(19) = 3.849$, $p < .001$. A Wilcoxon paired signed-rank test showed a statistically reliable difference between the mean number of times of unit structures were mentioned in the without-scaffolds situation (M = 0.31, s = 1.12) and the with-scaffolds situation (M = 6.40, s = 4.63) when teachers felt dissatisfied with their modified units based on identified weak coverage, z(19) = 3.784, $p < .001$. I also conducted Wilcoxon paired signed-rank tests for each of the types of unit structures and the results indicated that teachers paid more attention to all eight related types of unit structures when they were dissatisfied with their modified units in the with-scaffolds situation than they did in the without-scaffolds situation (see Table 50).

Teachers paid more attention to intermediate level of types of unit structures in the with-scaffolds situation. When teachers were dissatisfied with their modified units based on identified weak coverage, the mean of level of unit structures mentioned changed from 0.1 in the without-scaffolds situation to 1.86 in the with-scaffolds situation A Wilcoxon paired signed-rank test showed a statistically reliable difference between the mean number of level of unit structures in the without-scaffolds situation (M = 0.10, s = 0.31) and the with-scaffolds situation (M = 1.86, s = 0.57), z(19) = 3.830, p < .001.

4.8.6. Relationship between teachers' individual characteristics and their use of unit structures in evaluating modifications based on identified weak coverage

I tested the relationships between teachers' individual characteristics and their use of types of unit structures when evaluating their modified units based on identified weak coverage (see Table 51). The results indicated that the amount of experience, existing understanding of unit structures, and estimation methods were not related to teachers' use of types of unit structures when they were dissatisfied with modified units based on identified weak coverage.

Table 50. Scaffolds helped teachers pay more attention to all eight related types of unit structures when dissatisfied with their modified unit in the with-scaffolds situation.

Level of unit structures	Basic			Intermediate		Advanced		
Type of unit structures	Lessons related to a standard			Relative coverage rate		Connections related to a standard		
	Content standard	Inquiry standard	content standards	inquiry standards	content connections	inquiry connections	content standard	inquiry standard
Mentioned in the without-scaffolds situation			X	X				
Mentioned in the with-scaffolds situation	X	X	X	X	X	X	X	X
Wilcoxon paired signed-rank test	**2.533***	**2.060***	**2.122***	**2.670****	**2.807****	**3.180****	**2.533***	**2.666****

*p < 0.05, **p < 0.01

4.8.7. Summary

This section described teachers' use of scaffolds for evaluating modified units based on identified strong and weak coverage rates of standards and connections. Teachers were able to pay attention to more types of unit structures when they were satisfied with their modified units based on identified strong and weak coverage rates of standards and connections. They also focused more on the relative coverage rates of standards and connections to evaluate their modified units in the with-scaffolds situation than in the without-scaffolds situation. In addition, teachers considered higher levels of unit structures in the with-scaffolds situation than in the without-scaffolds situation.

Table 51. Correlation between teachers' individual characteristics and their use of unit structures when dissatisfied with their modified units.

	Number of types of unit structures (without-scaffolds)	Number of types of unit structures (with-scaffolds)	Number of unit structures (without-scaffolds)	Number of unit structures (with-scaffolds)	Level of unit structures (without-scaffolds)	Level of unit structures (with-scaffolds)
Experience with focus unit	-0.151	-0.047	0.314	0.286	0.033	0.214
Experience with content standards	-0.137	-0.048	0.322	0.295	0.046	0.206
Experience with inquiry standards	-0.078	-0.052	0.341	0.318	0.093	0.164
Existing understanding of content standards	0.430	-0.158	0.230	-0.055	0.388	0.074
Existing understanding of inquiry standards	0.315	-0.393	0.337	-0.139	0.356	-0.187
Existing understanding of content connection	0.216	0.077	0.203	-0.044	0.232	-0.326
Existing understanding of inquiry connection	0.402	0.087	0.219	0.088	0.364	-0.137
Estimation method for content standard	-0.032	-0.269	-0.029	-0.102	-0.034	0.208
Estimation method for inquiry standard	0.200	-0.238	0.181	-0.108	0.212	0.069
Estimation method for content connection	-0.138	-0.386	-0.093	-0.300	-0.133	-0.371
Estimation method for inquiry connection	0.079	-0.100	0.287	-0.127	0.176	-0.134

*p<0.05, **p<0.01

4.9. Summary of findings

Teachers had a better understanding of and focused more on lower levels of unit structures in the lesson selection activities in the without-scaffolds situation. Teachers demonstrated a better understanding of basic and intermediate levels of unit structures and had much less understanding of advanced levels of unit structures. In addition, teachers showed better understanding of the coverage rates for standards than of the coverage rates for connections. As for estimation methods, teachers were able to use more precise methods for standards than for connections. In addition, teachers' estimation methods for connections varied more than that for standards. Although teachers with more experience and understanding were able to use more precise methods for estimation, the relationship mainly exists for simpler elements of curricular coherence, such as content and inquiry standards addressed in individual lessons.

Teachers' level of understanding of unit structures and their methods used for estimating the coverage rate of standards and connections is correlated with the number of elements of unit structures considered in the lesson selection activities. First, teachers who knew more about inquiry standards tended to pay attention to more types and higher levels of unit structures when they identified strong coverage in the without-scaffolds situation. Second, teachers who knew more about inquiry standards tended to consider more types of unit structures when they decided whether they were satisfied with their modified curriculum units in the without-scaffolds situation. Third, teachers who used more precise methods for estimating coverage rates of unit structures tended to focus on fewer types of unit structures when they identified strong coverage in the without-scaffolds situation. Fourth, teachers who used more precise methods for estimating coverage rates of unit structures tended to focus on fewer types of unit structures when they decided whether they were satisfied with their modified curriculum units in the with-scaffolds situation.

Three scaffolding strategies were examined in this study: (1) Providing visualization to help teachers inspect multiple aspects of unit structures; (2) Demonstrating changes in coverage rates of unit structures as a consequence of modification; and (3) Encouraging reflection. Findings indicated that these scaffolding strategies helped teachers consider more types of unit structures, consider unit structures more frequently, and consider higher levels of unit structures when they modify a curriculum unit and examine their understanding of unit structures and strategies for modifying curricula (see Table 52). The "X" sign in Table 52 indicates that, with statistical significance, teachers considered more of unit structures in a particular column when they performed the modification practices in the corresponding row. For example, the first "X" signs in the row of "compare relative coverage - weak coverage" and the column, "Consider more types of unit structures" indicates that teachers considered more types of elements of unit structures when they identified weak coverage in the with-scaffolds situation than they did in the without-scaffolds situation.

Table 53, Table 54, and Table 55 show the overall results for the roles of different types of scaffolding strategies in helping teachers consider more types of unit structures. In these tables, the "+" sign indicates that, with statistical significance, teachers considered more types of unit structures in a particular column when they performed the modification practices in the corresponding row. The "-" sign indicates that, with statistical significance, teachers considered fewer types of unit structures in a particular column when they performed the modification practices in the corresponding row.

Scaffolds for identifying strong and weak coverage rates helped teachers compare relative coverage by considering more types of unit structures (see Table 53). Scaffolds for identifying strong and weak coverage also helped teachers clarify their understanding by considering more types of unit structures (see Table 53). Teachers improved their understanding of all levels of unit structures with the support of the scaffolds.

Scaffolds for identifying advantages and disadvantages of including particular lessons helped teachers compare lessons and select lessons by considering higher levels of unit structures (see Table 54). Scaffolds for identifying advantages and disadvantages of including lessons helped teachers select lessons by considering higher levels of unit structures (see Table 54). Scaffolds that show improved and the worsened coverage rates helped teachers identify changed coverage rates in their modified curriculum unit and consider all four related types of unit structures (see Table 55). Finally, scaffolds for identifying the improved and worsened coverage rates of standards and connections helped teachers evaluate their modifications by considering higher levels of unit structures (see Table 55).

Table 52. The scaffolding strategies helped teachers consider more types, and higher levels of unit structures, more frequently, when they modify and examined understanding and strategies.

			Consider more types of unit structures	Consider more frequency of unit structures	Consider higher levels of unit structures
Modification practice	Compare relative coverage	Strong coverage	X	X	X
		Weak coverage	X	X	X
	Compare lessons	Advantage of lesson	X	X	X
		Disadvantage of lesson		X	
	Identify change	Improved coverage	X	X	X
		Worsened coverage	X	X	X
Examining understanding and strategies	Clarify understanding	Weak coverage	X	X	X
	Select lesson	Keep a lesson	X	X	X
		Remove a lesson	X	X	X
	Evaluate modification	Satisfied	X	X	
		Dissatisfied	X	X	X

Table 53. Scaffolds for identifying strong and weak coverage helped teachers compare relative coverage and clarify understanding by considering more types of unit structures.

		Coverage				Details of coverage			
		content standards	inquiry standards	content connections	inquiry connections	content standard	inquiry standard	content connections	inquiry connections
Compare relative coverage	Strong coverage	+	+		+				
	Weak coverage	+	+	+	+	+	+	+	+
Clarify understanding	Weak coverage	+	+	+	+	+	+	+	+

+ = significant increase from the without-scaffolds situation to the with-scaffolds situation;
- = significant decrease from the without-scaffolds situation to the with-scaffolds situation

Table 54. Scaffolds for identifying advantages and disadvantages of including lessons helped teachers compare lessons and select lessons by considering higher levels of unit structures.

		Standards and connections addressed by lesson				Number of coverage by a lesson			
		content standards	inquiry standards	content connections	inquiry connections	content standards	inquiry standard s	content connections	inquiry connections
Compare lessons	Advantage of lesson							+	+
	Disadvantage of lesson	-	-	-				+	+
Select lesson	Keep a lesson	-	-	-	-			+	+
	Remove a lesson	-	-	-				+	

+ = significant increase from the without-scaffolds situation to the with-scaffolds situation;
- = significant decrease from the without-scaffolds situation to the with-scaffolds situation

Table 55. Scaffolds for identifying the improved and the worsened coverage rates helped teachers identify changed coverage rates and evaluate their modifications by considering more unit structures.

		Changed coverage			
		content standards	inquiry standards	content connections	inquiry connections
Identify change	Improved coverage	+	+	+	+
	Worsened coverage	+	+	+	+
Evaluate modification	Satisfied	+	+		+
	Dissatisfied	+	+	+	+

+ = significant increase from the without-scaffolds situation to the with-scaffolds situation;
- = significant decrease from the without-scaffolds situation to the with-scaffolds situation

CHAPTER 5

DISCUSSION AND IMPLICATIONS

The goal of this study is to examine strategies for building supportive environments that help teachers make decisions about curriculum implementation in their local contexts that are coherent with respect to designers' intentions. More specifically, I examined the role of revealing the underlying structures of curricular coherence in helping teachers improve their understanding of the interconnection between elements in a curriculum unit, and how changes made in a unit can affect its overall coherence. I developed a software tool to help curricular coherence more apparent to teachers as their worked to make modifications to a focus unit. This research is potentially valuable to any curriculum developer who seeks to "scale up" their materials in order to make them available to large numbers of teachers. Coherent curriculum materials depend upon structures and connections within and across lessons to help students engage in meaningful learning. Teachers need a great deal of support in order to understand those structures and connections so that they do not do harm to the basic design intentions underlying the curriculum when they inevitably make modifications to the materials to suit the demands of their local contexts.

In the previous chapter, I presented findings based on my data analysis. In this chapter, I first examine whether the results support the hypotheses for my research questions and provide possible explanations for the results. I then discuss the implications that may be drawn from this study for the design of supportive environments that aim to help teachers understand the coherence of curriculum materials and make better modification decisions when enacting inquiry-oriented curricula. Finally, I provide possible directions for future research.

5.1. Discussion of findings for research questions

Overall, the results support my hypotheses for the research questions of this study stated in Chapter Two. I organize this section of my discussion by the three research questions in this study.

5.1.1. Research question 1: How does the amount of teaching experience relate to teachers' understanding of curricular coherence?

The findings indicate that more experience with project-based science units does not contribute to deeper understanding of curricular coherence on its own. In addition, better understanding contributes only to estimation of simpler curricular coherence, and not to a better estimation of more complex curricular coherence, such as the connections between lessons.

These findings support my hypothesis that simpler curricular coherence are easier to recognize and teachers were better able to identify them during their examination of the curriculum materials without support from scaffolds. In contrast, more complex elements of curricular coherence, such as the relative coverage rates of connections between lessons, are difficult for teachers to perceive when they do not have access to information about curricular coherence.

It is important to note that more experience teaching project-based science units does not contribute to deeper understanding of curricular coherence by teachers. This finding contradicts my hypothesis. On their own and without scaffolds, teachers do not have an understanding of more complex elements of curricular coherence, whether or not they have prior experience with inquiry-based curriculum units. The findings suggest that the complexity of curricular coherence is not easily grasped by merely teaching these units, even teaching them multiple times.

There are several possible reasons for the situation that teachers do not form a better understanding of more complex elements of curricular coherence despite their amount of experience with teaching project-based science units. First, teachers might have been focused on addressing standards, especially content standards, instead of connections between lessons (Remillard, 2005). When teachers use innovative curriculum units that tie lessons together with both content and inquiry standards, they may not know how to make sense of these types of curriculum materials. Second, the representations currently used in printed curriculum materials may not sufficient to express deeper design intent such as more complex elements of curricular coherence. It is possible to demonstrate the connections between lessons and the coverage rates of standards and connections of the original curriculum unit. However, it is more complicated to represent the changes of coverage rates of deeper design intent as the consequence as teachers making changes. Third, current curriculum materials may not provide enough support for reflection about designers' deeper intentions when teachers plan and enact the units. Being able to use a tool and to reflect on experience of using this tool helps people internalize the ideas embedded in the tool. As a result, teachers do not have rich opportunities to improve their understanding of deeper design intent when they enact curriculum units.

5.1.2. Research question 2: What are the roles of software scaffolds in helping teachers consider more complex elements of curricular coherence when they modify curriculum units?

Scaffolding for examining different aspects of unit structures helped teachers consider higher levels of curricula coherence. First, scaffolding features for showing standards, connections, and the number of standards and connections covered by a lesson were used by teachers to identify the advantages and disadvantages of including and excluding lessons in their modifications. Second, scaffolding for showing the relative coverage rates and details of coverage rates for standards and connections were mainly used by teachers to identify strong and weak coverage rates of standards within modified units. Third, scaffolding features for showing changed coverage rates of standards and connections were mainly used to identify the improved and the worsened coverage that resulted from their modifications.

It is interesting to note that teachers focused on different aspects of unit structures when they examined strong and weak coverage rates of standards. When checking for strong coverage, teachers focused most on the overall coverage rates of content standards. When checking for weak coverage, they focused primarily on lesson connections through an inquiry standard, which is also the perspective they focused on most for the worsened coverage rates of standards and connections. These differences might result from teachers' intention to make sure content standards are well covered and to have certain coverage rates of lesson connections through each inquiry standard. Another reason might be that teachers know more about content coverage and therefore were not surprised by the consequences of lesson selections on content coverage.

In addition, when checking strong and weak coverage, teachers referred to all levels of unit structures, except for connections between lessons by content standards (one of the advanced-level unit structures). One potential reason teachers did not refer to this perspective might be that they think the coverage rates of content connections are more under control therefore they focused on other aspects less familiar to them.

Weak coverage rate draws teachers' attention. One possible reason for this is that teachers may not want to have weak coverage in their modified units and that the visualized representation for the relative coverage rates of standards and connections made it easier to identify weak coverage. Therefore, when they noticed weak coverage, they attended to it and checked whether there is something they did not consider by looking for more information.

Teachers also identified significantly more changed coverage in the with-scaffolds situation than in the without-scaffolds situation. This serves as evidence that the visual representations made it easier for teachers to identify the improved and the worsened coverage rates as a consequence of the changes they made to the unit.

5.1.3. Research question 3: When teachers make changes in curriculum units with the assistance of the software scaffolds, how do they reflect on their understanding of curricular coherence and their curriculum modification strategies?

Scaffolding features for examining different aspects of unit structures were used for distinct types of modification practices and teachers considered more complex elements of curricular coherence when the scaffolding features were present. The findings indicated that scaffolds for identifying strong and weak coverage helped teachers clarify their understanding by considering more types of unit structures. Next, scaffolds for identifying advantages and disadvantages of including lessons helped teachers select lessons by considering more complex elements of curricular coherence. Finally, scaffolds for identifying strong and weak coverage rates for standards and connections helped teachers evaluate their modifications by considering more complex elements of curricular coherence.

It is worth noting that teachers sometimes skipped the time consuming "contextualization" lessons in the without-scaffolds situation. Contextualization is a critical strategies that helps students construct integrated knowledge (Krajcik et al., in press; Linn, Clark, & Slotta, 2003). With the PERT software tool, teachers were able to see the connections to other lessons from a lesson that builds contextualization for students, and choose to keep it.

In this study, two strategies were used to encourage reflection during curriculum planning. The first strategy was to create opportunities in which teachers could identify the weakness in their understanding of curricular coherence. This strategy encouraged teachers to look for more details of curricular coherence and clarify their understanding. Previous studies also found that comprehension or expectation failures can initiate self-explanations (Chi, Bassok, Lewis, Reimann, & Glasser, 1989; White, 1993).

Although teachers did reflect on their understanding and modification strategies, they did not pay much attention to the text prompts, which was the other strategy for encouraging reflection. One of the reasons that teachers did not use this feature much may be that the prompts were shown in the upper right corner on the screen. The passive representation of prompts was not effective in reminding teachers to reflect on their modification practice. When teachers put most of their attention on the information in the three tabs, these prompts might not be treated as the main focus of their activity (Quintana, Krajcik, & Soloway, 2002). Other researchers have also indicated that it is difficult to get people to reflect on their learning experiences with text prompts. For example, prompts for reflection with specific directions were avoided by students in a science activity (Davis, 2003).

Although teachers did not use the text prompts much, they actually did engage in a type of reflective thinking when they conducted the lesson selection activities. The reason for this might be that they followed the similar prompts provided as part of the instructions for the lesson selection activities. These findings suggest that teachers are able to reflect on the process of curriculum modification and may not need consistent prompts when they work on curriculum modification tasks.

5.2. Implications

I organize this section by discussing how this study may inform curriculum designers or research on the design of supportive environments that help teachers to make decisions about curriculum implementation in their local context that are coherent with respect to designers' intentions.

First, existing approaches for helping teachers make sense of the complex curricular coherence may not be sufficient. The findings of this study indicate that teachers do not have a solid understanding of more complex elements of curricular coherence (i.e., higher levels of unit structures) of the curricula featured in this research, even though some of the teachers have extensive experience with them. Even with units that come with rich resources for curriculum implementation (technologies, educative curriculum materials, and professional development) teachers still have difficulties capturing the complex ideas of coherence within the curriculum units. They tend to consider simpler elements of curricular coherence when they make decisions for their modifications.

Currently, teachers acquire information about design intent mainly through the learning performance tables and description of connections between lessons that are embedded in individual lessons in curriculum materials (Krajcik et al., 2006), or through other communication with curriculum developers, such as through professional development. However, this type of representation or communication appears to be not enough to support teachers to be aware of the effects of modifying curriculum on more complex elements of curricular coherence. The findings of this study indicate that although some teachers know how to estimate coverage using the learning performance table attached in curriculum materials, they did not have much better understanding of higher-level unit structures than those who did not know this table. The concept of curricular coherence may be so complex that teachers cannot easily apply their existing teaching knowledge to make sense of curriculum materials from this perspective. Curriculum designers may benefit from providing more educative features in the curriculum materials related to curricular coherence so that teachers can learn more from their experience using these curriculum materials, or from using systems like PERT as a supplemental tool to support enactment.

Second, In order to help teachers make changes that are congruent with designers' intent and improve their understanding of curricular coherence, curriculum designers should consider providing support that not only shows the details of curricular coherence, but also information useful for making informed decisions. This study demonstrates that, with appropriate support, both experienced and novice teachers are able to consider deeper design intent and use this information in making changes to the unit. Providing support for identifying strong and weak coverage rates of learning goals can help teachers realize what aspects of curricular coherence needs more attention and reconsideration. Providing support for identifying advantages and disadvantages of adding or removing a lesson can help teachers select lessons that better support student learning. Providing improved or worsened coverage of learning goals can help teachers evaluate the consequences of a modification and reflect on their understanding of unit coherence. The implication for the design of curriculum materials and professional development is that the amount of teaching experience is not the only factor that determines whether a teacher can construct a coherent modification. Novice teachers can also grasp the deeper design intent and use it in their modification practices.

Third, the software scaffolds explored in this study can inform the design of future supportive systems that aim to help a larger group of teachers understand curricular coherence and make curriculum modifications congruent with the original design intent. One approach is to embed these software scaffolds in an online professional development system. Online systems can reach more teachers than face-to-face professional development (Chaney-Cullen & Duffy, 1999). In addition, teachers can get access to these software tools whenever they engage in lesson planning. This model has the potential to support teacher learning situated in their daily teaching practice (Blumenfeld et al., 2000; Putnam & Borko, 2000).

Fourth, from a socio-cultural perspective, reflecting on personal understanding of a concept is critical for learning from experience using a tool. Teachers also need support for reflection about their understanding of deeper design intent when they plan and enact curriculum units. In this study, the having teachers predict coverage rates before they see the actual coverage rates of standards and connections encouraged them to clarify their understanding of unit structures. In the process of attempting to accomplish tasks, failure promotes a need to reflect on the outcome, explain unexpected results, and revise newly developing conceptions (Posner et al., 1982; Schon, 1987). The implication for developers of educative curriculum materials and software scaffolds is that scaffolds for reflection should be placed in a more active and situated role so that teachers notice the opportunities to examine their thinking and practice. In addition, strategies for generative learning should be emphasized in order to help teachers identify weaknesses in their understanding of curricular coherence. Interactive models of professional development can engage teachers as active participants and promote higher order cognition, such as understanding curricular coherence (Sprinthall, Reiman, & Thies-Sprinthall, 1996).

This study contributes to the construction of software scaffold design principles for helping teachers understand underlying deeper design intent of curriculum units. In this study, I examined three scaffolding strategies: (1) Providing visualization to help teachers inspect multiple aspects of unit structures; (2) Demonstrating changes in the coverage rates of unit structures as a consequence of lesson or unit modification; and (3) Encouraging reflection. My findings indicate that the scaffolding strategies used for demonstrating complex ideas in other domains can also be useful for helping teachers make sense of higher levels of unit structures and consider higher levels of unit structures when making modifications to coherent curriculum materials. The first two strategies have been used and tested to be successful in helping students making sense of complex concepts in science education (Quintana et al., 2004). More importantly, the results indicate that, with proper support, both novice and experienced teachers can consider higher levels of unit structures in modification practice, thus showing a better understanding of curricular coherence.

The scaffolding strategies studied here could be applied to learning the deeper design intentions of curriculum units for subject matter other than science or instructional models. Although different curriculum units follow various design models, they all address some learning goals for specific content and skills and the elements in a coherent unit are tightly connected. Therefore, the strategies could be helpful for teachers teaching other subject matter or curriculum with different pedagogical goals.

5.3. Limitations

According to scaffolding theory, one important characteristic of scaffolds is that they should “fade” as learners internalize the target performance, otherwise, what you have is only a tool that provides performance support for tasks, but not scaffolding (Pea, 2004). It is possible that the software scaffolds in this study are supports, and not scaffolds. In order to determine fully whether my supports are scaffolds, one would need a study with an iterative design where the scaffolds are not present in later iterations and one could see whether teachers continue to make better decisions in curriculum modification. This study is not designed to allow for that comparison. However, the results show that at least the scaffolds included in PERT do help teachers consider deeper design intent when they make modifications to units, which is an important initial step.

In order to further examine whether these features are scaffolds, I propose several approaches. First, researchers could conduct longer studies in which teachers use the software tools to make modifications to several units so that they have the opportunities to construct their understanding from different perspectives (Bransford & Schwartz, 1999; Spiro & Jehng, 1990). Second, it might be beneficial to conduct quasi-experimental studies to test the difference between two groups of teachers in their understanding of deeper design intent and the effect of scaffolds on their modification practice. Third, researchers may consider recruiting a larger group of participating teachers and conduct quasi-experimental studies to compare the difference between teachers in the with-scaffolds and without-scaffolds situations. Larger samples would enable researchers to obtain higher power and more choices in analysis of the data.

5.4. Future directions

Tighter connections should be built between printed curriculum materials and software-based scaffolds or other types of support in order to create integrated distributed scaffolding for teachers (Puntambekar & Kolodner, 2005). Uncovering deeper design intent is complex and the coverage of learning goals in a curriculum unit changes in subtle ways as teachers add or remove lessons. The scaffolds examined in this study can provide teachers with more dynamic representations than existing paper-based educative curriculum materials. In comparison to information provided through face-to-face workshops, the software scaffolds are more capable of providing proximal support to teachers that is situated in their daily practice (Putnam & Borko, 2000). In addition, the supports examined in this study can also be used for demonstrating coherence across a series of interconnected units (Krajcik et al., in press). With these advantages, scaffolds such as those in PERT can serve a larger population of teachers and be a vehicle for supporting larger scale implementation (Fishman, Marx, Blumenfeld, Krajcik, & Soloway, 2004) of coherent curriculum materials. Teachers can use these tools as part of their daily work. Finally, the software scaffolds can be used to build a platform in which curriculum designer share their ideas. Novice curriculum designers can learn from experienced designers by examining cases of curriculum design and seeing how their changes or additions affect the overall goals for coherence as specified by expert curriculum developers.

5.5. Concluding remarks

In general, the scaffolding strategies examined in this study helped teachers develop an understanding of the curriculum modification practices that preserved the coherence in the curriculum based on their own situational constraints and personal preferences (Blumenfeld et al., 2006; Krajcik, Blumenfeld, Marx, & Soloway, 1994). In other words, teachers moved toward "warranted practice" where they integrated practical concerns with theoretical knowledge (Richardson, 1990). The findings of this study indicate that teachers need more help than they currently receive in order to make sense of the complex ideas of curricular coherence.

The findings of this study can contribute to our understanding of ways to help teachers to be aware of the effects of modifying curriculum on curricular coherence. First of all, curricular coherence should be made explicit to teachers. Curriculum designers should also provide supports that are useful for making informed decisions. Scaffolds for reflection should be placed in a more active and situated role so that teachers are better able to notice opportunities to examine their thinking and practice.

Establishing shared meaning has been shown to be at the center of successful collaborations (Roschelle, 1992). The software scaffolding strategies explored in this study can be used to help more teachers enact curricula successfully and congruently with respect to design intent in the context of large scale curriculum implementation. With integrated support, my hope is that teachers can develop a deeper understanding of coherent curricula and therefore be better able to support students' development of conceptual understanding in science.

APPENDICES

Appendix A. Content standards covered by lessons in the Stuff unit.

Lessons	Content standards		
	A substance has characteristic properties, such as density, a boiling point, and solubility, all of which are independent of the amount of the sample	Substances react chemically in characteristic ways with other substances to form new substances with different characteristic properties	No matter how substances within a closed system interact with one another, or how they combine or break apart, the total weight [mass] of the system remains the same
1	X		
2	X		
3	X		
4	X		
5	X		
6	X		
7		X	
8		X	
9		X	
10		X	
11		X	
12		X	
13			X
14			X
15			X
16			X

Appendix B. Inquiry standards covered by lessons of the Stuff unit.

Lesson	Inquiry standard							
	Define	Identify	Design Investigation	Conduct Investigation	Analyze & Interpret	Explain	Construct Model	Use Model
1	X	X		X				
2	X		X	X	X			
3	X			X	X			
4		X		X	X			
5							X	X
6						X		
7	X			X		X		
8		X		X		X		
9							X	X
10		X	X	X		X		
11								X
12				X				
13	X	X	X	X		X		
14	X						X	X
15				X		X		
16			X	X				

Appendix C. The connections between lessons by content standards in the Stuff unit.

Lesson	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2	Macro-Micro														
3		Property													
4															
5	Macro-Micro	Macro-Micro	Macro-Micro	Macro-Micro											
6	Property	Property	Property	Property	Property										
7															
8						Property									
9				Model	Macro-micro		Macro-micro	Burning							
10			Dissolve												
11					Model				Model	Macro-micro					
12						Soap and fat									
13									Burning						
14										Property		Macro-micro	Macro-micro		
15		Solubility	Melting point	Density								Soap and fat			
16												Soap making			

Appendix D. The connections between lessons by inquiry standards in the Stuff unit.

Lesson	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2	CI														
3	CI	AI													
4	ID		CI												
5															
6	ID				ID										
7			DE	CI		EX									
8				ID			CI								
9					CM										
10		DI						EX, ID							
11									UM						
12										CI					
13							DE			DI		CI			
14									CM		UM		DE		
15													CI, EX		
16													DI		CI

CI: Conduct investigation; ID: Identify; AI: Analyze & Interpret; DE: Define; CM: Construct model; UM: Use model; EX: Explain; DI: Design Investigation

Appendix E. Interview protocol for the lesson selection activity

First, I showed the teacher the worksheet with lessons of Stuff. Then I walked the teacher through the columns of the worksheet to make sure that they're familiar with it. Next, I showed teachers a piece of paper with the following instruction: "This unit is designed to take 26 class periods to teach. Suppose that a teacher have only 16 weeks because the end of the school is coming up and this teacher omitted some lessons (the grayed lessons). What would be the content standards, inquiry standards, and connections missing in these lessons? Please write down the codes for standards and connections in corresponding columns. Please feel free to ask me any questions you have about the unit or the lessons or anything else as you go."

Appendix F. Survey for experience teaching project-based science curriculum units

1. My name is ____________________________________

2. I have taught science for _______ years.

3. Not including this year, the times I have taught each of the following units are:

◆ Air : ____ times ◆ Communicable Disease : ____ times ◆ Water : _____ times ◆ Helmet : _____ times

◆ Big Things : ___ times ◆ Stuff : ____ times ◆ Survive : ____ times ◆ Smell : ____ times ◆ Light : ____ times

4. Please check the lessons you have read and lessons you have taught before:

Lesson number	Lesson name	I have read	I have taught					
			06-07	05-06	04-05	03-04	02-03	01-02
1	How is this stuff the same or different?							
2	Do fat and soap dissolve in the same liquid?							
3	Do fat and soap melt at the same temperature?							
4	Do fat and soap have the same density?							
5	Why are the properties of a substance always the same?							
6	Are fat and soap the same substances or different substances?							
7	What happens to properties when I combine stuff?							
8	Does acid rain make new substances?							
9	Where did that green substance come from?							
10	Do I always make new substances?							
11	What happens when I see different processes?							
12	How can I make soap from fat?							
13	Does mass change in a chemical reaction?							
14	Why does mass stay the same in a chemical reaction?							
15	Is my soap a new substance?							
16	How does my soap compare or how can i improve my soap?							

Appendix G. Worksheet for lesson selection for Stuff in the without-scaffolds situation.

Select	Lesson	Lesson name	Time	Description	Page number
	1	How is this stuff the same or different?	3	The purpose of this lesson is to motivate students by investigating two unknowns (fat and soap), introduce the driving question of the unit: How can I make new stuff from old stuff? and introduce the concepts of substance and property.	5-18
	2	Do fat and soap dissolve in the same liquid?	1	This lesson extends students' investigations to properties that are not observable directly, but need to be measured with tools or techniques. One purpose is to introduce students to the property "solubility.	19-26
	3	Do fat and soap melt at the same temperature?	2	The purpose of this lesson is to introduce melting point as another property that can provide evidence to help distinguish substances.	27-34
	4	Do fat and soap have the same density?	1	The purpose of the present lesson is to introduce students to another such property, density, which provides more evidence to help distinguish substances.	35-54
	5	Why are the properties of a substance always the same?	1	In this lesson, students use molecular models to visualize a substance at the molecular level. Students use molecular models to help them make connections among their ideas of substances at the macro level and the molecular level.	55-68
	6	Are fat and soap the same substances or different substances?	1	One purpose of this lesson is to use all of the properties students have studied in the last five lessons to show students that they need to use multiple properties to determine whether two items (like fat and soap) are the same substance or different substances.	69-84
	7	What happens to properties when I combine stuff?	2	The purpose of this lesson is twofold: (1) to introduce students to the second learning set of this unit, and (2) to introduce students to the concept of chemical reaction by having them engage in an investigation in which they observe a chemical change.	89-102
	8	Does acid rain make new substances?	2	One purpose of the present lesson is to have students investigate everyday chemical reactions to deepen their understanding of the concept and help connect the chemistry to their daily lives. A second purpose is to introduce word equations for chemical reactions, which represent what happens to the substances in reactions.	103-114
	9	Where did that green substance come from?	1	In this lesson, students learn about how the reaction occurs, and where the green substance comes from, at the molecular level.	115-128

	10	Do I always make new substances?	3	This lesson introduces students to two processes that are not chemical reactions: phase changes and mixing. The purpose of the lesson is to solidify students' understanding of chemical reactions by helping them learn how to differentiate perceptually similar processes that are and are not chemical reactions.	129-142
	11	What happens when I see different processes?	1	Students determine that a chemical reaction is different from mixing because the atoms of the substances rearrange and form different substances during a chemical reaction, while there is no rearrangement of atoms into new substances during mixing.	143-146
	12	How can I make soap from fat?	2	The purpose of this lesson is to return to the fat and soap students investigated and determine how one of these substances (soap) can be made from the other substance (fat).	147-156
	13	Does mass change in a chemical reaction?	2	The purpose of lesson 13 is to introduce the final sub-question and the concepts of conservation of mass, open systems, and closed systems.	161-174
	14	Why does mass stay the same in a chemical reaction?	1	The purpose of this lesson is to explore what is happening during the conservation of mass at the particulate level.	175-184
	15	Is my soap a new substance?	2	The purpose of this lesson is to investigate the soap that students made to determine whether students completed a chemical reaction and produced a new substance.	185-200
	16	How does my soap compare or how can I improve my soap?	1	This activity involves students in designing and conducting their own experiments to test the quality of their soap versus commercial brand bar soap	201-208

Appendix H. Sample worksheet in the without-scaffolds situation.

Coverage rates of content standards

	Content standards		
	Substance and properties	Chemical reaction	Conservation of mass
Coverage by your modified unit (%)			

Coverage rates of inquiry standards

	Inquiry standards							
	Define	Identify	Design Investigation	Conduct Investigation	Analyze & Interpret	Explain	Construct Model	Use Model
Coverage by your modified unit (%)								

Appendix I. Sample worksheet in the with-scaffolds situation.

Coverage rates of content standards provided by PERT

	Content standards		
	Substance and properties	Chemical reaction	Conservation of mass
Coverage by your modified unit provided by PERT (%)			
Your estimation – PERT value			
Mark to check for details in PERT			

Coverage rates of inquiry standards provided by PERT

	Inquiry standards							
	Define	Identify	Design Investigation	Conduct Investigation	Analyze & Interpret	Explain	Construct Model	Use Model
Coverage by your modified unit provided by PERT (%)								
Your estimation – PERT value								
Mark to check for details in PERT								

Appendix J. Teacher consent form

January, 2007

Dear Teacher:

This letter it to invite your participation in a research study about a software tool, "The Planning, Enactment, and Reflection Tool (PERT)." This research is being conducted by the University of Michigan and is funded by the National Science Foundation. The objective of this research is to understand ways in which features in this software help teachers enact inquiry- and standards-based curriculum units. Your participation in this research will help to answer an important question related to professional development that shapes the design of future software for professional development in science education. In order to participate in this study, it is required that you commit to participating in a 90-minute interview including using the software and tasks. More details about the activities involved in this research are provided below.

<u>Benefits and Risks of Participation</u>

Your participation in this study may benefit others. By participating you will be contributing to a better understanding of how to make professional development both effective and efficient. This greater understanding of curriculum enactment and design principles for effective learning tools will be valuable to the entire teaching and professional development community. There are no known risks to you or your students as a result of your participation in this project.

<u>Procedures</u>

By electing to participate in this research project, you agree to allow us to gather information about your teaching of project-based science units, and your modification strategies and knowledge related to the teaching of these units. To gather this information, we will use interview, short surveys, and think-aloud tasks. These interviews and tasks will be audio and video taped. We will not record your teaching in your classrooms. You respond in this study as individuals, not as employees of your school.

All data gathered as part of this project will be kept confidential, stored in a secured facility at the University of Michigan, and destroyed five years after the completion of the project. At no point will your name ever be released as a participant in this project, nor will information about you or your teaching ever be identifiable in our reporting of results related to this study.

Your participation in this research project is completely voluntary. If you do not wish to participate, please advise the person who presented this form to you, and no further interactions related to this project will occur. You may elect to withdraw from this project at any time. Upon notifying the researchers of your desire to withdraw, all data provided by you will also be destroyed. Your decision to withdraw will have no material effect upon you (but you may not receive the gift card). We hope that you will participate in this project, though you may choose to stop participating whenever you wish.

The foremost use of the information we gather in this project will be to understand and improve software and professional development. This information will also be used in the preparation of research papers, conference presentations, and the preparation of further grant proposals related to this work.

If you agree to participate in this study, you will receive the following benefits: you will receive a $30 gift card as a thank you for the time required to provide the researchers with information about your teaching during the course of this study.

Should you have questions regarding your rights as a participant in research, please contact the Behavioral Sciences Institutional Review Board, 540 East Liberty Street, Suite 202, Ann Arbor, MI 48109, 734-936-0933. If you have any questions about this work, please contact Hsien-Ta Lin (734-647-4225, or htlin@umich.edu). Thank you for your consideration of this project.

Sincerely,

Hsien-Ta Lin

Ph.D. Student, School of Education, University of Michigan

==

Please check the appropriate options, sign and return to Hsien-Ta Lin:

I DO ________

I DO NOT ________

… consent to participate in this project, including data collection.

I DO ________

I DO NOT ________

…consent to being audio- and video-taped as part of this project.

Your name: _________________________

Your signature:___________________________

Date: ___________

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