INVESTIGATING ONE SCIENCE TEACHER'S INQUIRY UNIT THROUGH AN INTEGRATED ANALYSIS: THE SCIENTIFIC PRACTICES ANALYSIS (SPA)-MAP AND THE MATHEMATICS AND SCIENCE CLASSROOM OBSERVATION PROFILE SYSTEM (M-SCOPS)

A Dissertation

by

DAWOON YOO

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

DOCTOR OF PHILOSOPHY

August 2011

Major Subject: Curriculum and Instruction

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Approved by:

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ABSTRACT

Investigating One Science Teacher's Inquiry Unit through an Integrated Analysis: The Scientific Practices Analysis (SPA)-Map and the Mathematics and Science Classroom Observation Profile System (M-SCOPS). (August 2011)

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Since the 1950s, inquiry has been considered an effective strategy to promote students' science learning. However, the use of inquiry in contemporary science classrooms is minimal, despite its long history and wide recognition elsewhere. Besides, inquiry is commonly confused with discovery learning, which needs minimal level of teacher supervision. The lack of thorough description of how inquiry works in diverse classroom settings is known to be a critical problem. To analyze the complex and dynamic nature of inquiry practices, a comprehensive tool is needed to capture its essence.

In this dissertation, I studied inquiry lessons conducted by one high school science teacher of 9th grade students. The inquiry sequence lasted for 10 weeks. Using the Scientific Practices Analysis (SPA)-map and the Mathematics and Science Classroom Observation Profile System (M-SCOPS), elements of inquiry were analyzed from multiple perspectives. The SPA-map analysis, developed as a part of this dissertation, revealed the types of scientific practices in which students were involved. The results from the M-SCOPS provided thorough descriptions of complex inquiry lessons in terms of their content, flow, instructional scaffolding and representational scaffolding. In addition to the detailed descriptions of daily inquiry practices occurring in a dynamic classroom environment, the flow of the lessons in a sequence was analyzed with particular focus on students' participation in scientific practices.

The findings revealed the overall increase of student-directed instructional scaffolding within the inquiry sequence, while no particular pattern was found in representational scaffolding. Depending on the level of cognitive complexity imposed on students, the lessons showed different association patterns between the level of scaffolding and scientific practices. The findings imply that teachers need to provide scaffolding in alignment with learning goals to achieve students' scientific proficiency.

DEDICATION

To my husband and daughter, Kildong and Sarah,

for their love and support

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First, I would like to acknowledge Dr. Stuessy for her enormous support and patience throughout the course of my educational journey. She has been a great role model for me as a researcher, a mentor, and an educator. I also wish to express gratitude to my committee members, Dr. Griffing, Dr. Loving, and Dr. Schielack, for their valuable input and effort for this research. Inquiry experience with Dr. Griffing in his lab, Dr. Loving's classes on the foundations of science education, and Dr. Schielack's guidance through the ITS program all inspired me in the process of my research.

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I would never forget how Kildong, my husband, supported me throughout the whole process of this study. Without his sacrifice and prayer, I would never have finished the study. Sarah, my daughter, always has been a cheerleader for me and gave me delight and joy of life. Her way of inquiring about the world as a young learner inspired me to explore my fields of study with curiosity rather than doubt. Finally, I thank the Lord for always guiding me in his way and giving me unconditional love.

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CHAPTER I

INTRODUCTION

Statement of the Problem

The quality of science education has been considered a critical issue in the United States since the report of *A Nation at Risk* (National Commission on Excellence in Education [NCEE], 1983). The report warned that American students could fall behind competitors from other countries if there was no significant improvement in math and science education. To address this concern, policy documents such as *Science for All Americans* (American Association for the Advancement of Science [AAAS], 1990), *Benchmarks for Science Literacy* (AAAS, 1993) and *National Science Education Standards* [NSES] (National Research Council [NRC], 1996) were published to elicit educational reforms at the national level. In common, all these documents made an emphasis on inquiry as an ideal strategy for teaching and learning science.

Because of these national reforms, wide reconsiderations of inquiry have emerged in diverse fields such as science, philosophy and history (Grandy & Duschl, 2007). However, this attention has also caused confusion in characterizing what inquiry is, as scholars in different areas have proposed varied definitions. In addition to the disagreement on the meaning of inquiry, researchers have also questioned the feasibility and effectiveness of the instructional approach in real classrooms. Critics have argued that inquiry-based instruction is an inefficient way to teach science and that it works

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This dissertation follows the style of Journal of Research in Science Teaching.

against natural human cognitive structure (Kirschner, Sweller, & Clark, 2006; Settlage, 2007). Research has also indicated that inquiry had been adopted only in a small portion of current classrooms (Weiss, Pasely, Smith, Banilower, & Heck, 2003). On the other hand, meta-analyses of hundreds of empirical studies have revealed the positive impact of inquiry on student learning (e.g., Bredderman, 1983; Minner, Levy, & Century, 2010; Shymansky, Kyle, & Alport, 1983).

Current literature does not provide detailed descriptions of what inquiry looks like in classrooms. Teachers are often confused about “what inquiry is” and are left to construct their own ways of inquiry instruction (Anderson, 2002). Anderson stated that the line of research discussing the effectiveness of inquiry has already matured. He said that now is the time to investigate the dynamics of inquiry teaching and how it can be brought into classrooms. Therefore, rather than asking whether inquiry works or not, we need to question the types of learning environments where inquiry can work best, kinds of practices inquiry promotes, and various supports and scaffoldings needed for different learners (Hmelo-Silver, Duncan, & Chinn, 2007). To document the impact of inquiry in local settings and encourage other teachers to implement it in their own classrooms, more research investigating inquiry practices in unpredictable classroom environments is required.

The Purpose of the Study

The goal of this study is to provide a detailed description of inquiry when it is implemented in a dynamic and unpredictable classroom setting. To describe how inquiry works in light of the diverse elements present in classroom settings, I propose a new type of system incorporating two different instruments for interpreting classrooms. First, to reveal the types of valued practices inquiry promotes, the Scientific Practices Analysis (SPA)-map was used. Following the National Research Council's recent report (NRC, 2007), this study adopted the NRC's goal of science education: students' achievement in scientific proficiency. Scientific proficiency is attained only through students' active participation in four different types of scientific practices: (1) understanding scientific explanations, (2) generating scientific evidence, (3) reflecting on scientific knowledge, and (4) participating productively in science. In this study, I used the SPA-map to analyze and visualize (1) the scientific practices in which students participated in a series of lessons and (2) the evolution and extension of these practices throughout the whole inquiry unit. Also, the Mathematics and Science Classroom Observation Profile System [M-SCOPS] (Stuessy, 2002) was used to analyze inquiry-based lessons in terms of levels of instructional and representational scaffoldings. As inquiry often require students' high-level cognitive processes, the use of appropriate scaffolding is critical in transforming a difficult task into manageable parts, and therefore lowering the cognitive burden imposed on students. This study also aimed to explore the possible associations of scaffolding with scientific practices.

Conceptual Framework

The framework of this dissertation is based on the most current view of scientific proficiency as the goal of science education. Scientific proficiency can be achieved only through students' participation in diverse types of scientific practices. I argue that optimal inquiry learning environments efficiently support students for the purpose of mastering these scientific practices. Figure 1.1 shows the diagram for the conceptual framework of this dissertation.

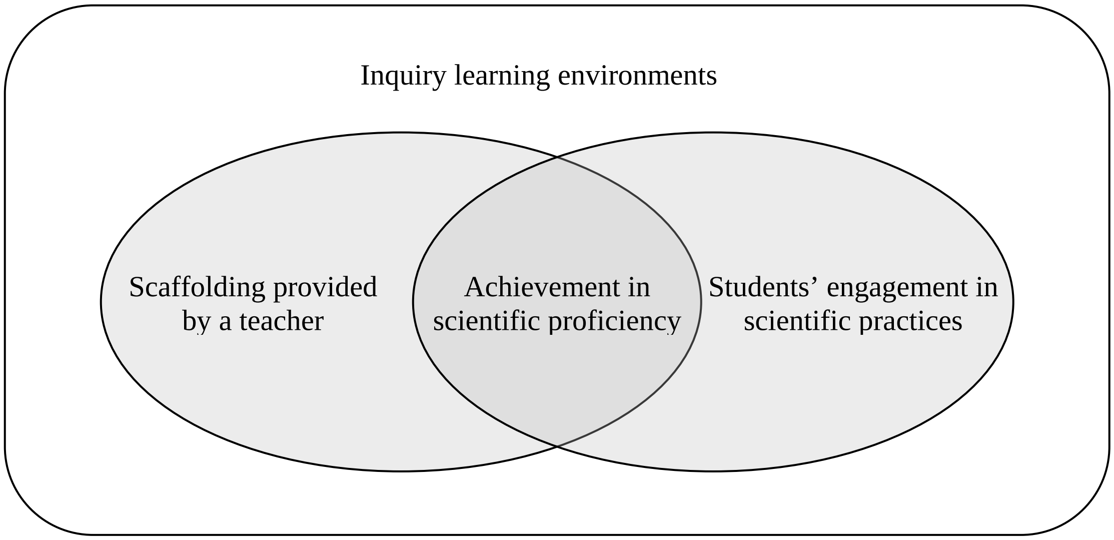


Figure 1.1. Conceptual framework of the dissertation.

Research Questions

Two research studies comprise this dissertation. The first study, which involves the development of an integrated methodology for inquiry lesson analysis, answers these research questions:

1. How can students' participation in scientific practices during inquiry learning be effectively visualized and assessed?
2. How can the association between teacher-provided scaffolding and students' scientific practices be visualized through an integrated analysis?

The second study, which provides a detailed description, analysis and interpretation of one teacher's inquiry classroom, answers these research questions:

3. What did one teacher's implementation of an inquiry unit look like in a 9th grade biology class in terms of provided scaffolding and promoted scientific practices?
    (1) In what kinds of scientific practices did the students participate in each lesson?
    (2) What levels of instructional and representational scaffolding were provided in each lesson?
    (3) How did the levels of students' engagement in scientific practices and scaffolding change as the inquiry unit progressed?
    (4) How were the kinds of students' engagement in scientific practices related to the levels of instructional and representational scaffolding provided by the teacher during the inquiry unit?

Definition of the Key Terms

Many educational terms used in this dissertation are associated with multiple meanings in different contexts. Therefore, key terms used in this dissertation are clarified below:

Inquiry: The definition of inquiry used in this dissertation mainly follows the statement from NSES (NRC, 1996). According to NSES, inquiry is a multifaceted activity involving students' authentic science research. In education, the concept of inquiry is not only confined to teaching strategies but also imply scientific habits of mind and cognitive skills students need to acquire to fulfill inquiry. From a constructive perspective, the meaning of inquiry is achieved through an individual's unique learning processes (Johnston, 2008; Keys & Bryan, 2001). Therefore inquiry can occur in different forms depending on contexts.

Inquiry unit: In this dissertation, the term "inquiry unit" is used to describe the series of inquiry-based lessons that are sequentially organized under a coherent theme. Etheredge and Rudnitsky (2003) provided a guideline to develop an inquiry unit and the procedure includes seven steps: (1) considering students' background, (2) creating/describing the system of variables, (3) designing an initial immersion experience, (4) generating researchable questions, (5) conducting the research, (6) designing a consequential task, and (7) assessing understanding.

Scientific proficiency: NRC (2007) defined the goal of science education as achieving students' scientific proficiency, which allows students to understand and evaluate scientific information and make informed decisions. The framework of scientific proficiency is based on a view that science is not only a body of knowledge but also a process that continually extends, refines and revises the knowledge system of science.

Scientific practices: To be proficient in science, students need to master certain types of scientific practices. NRC (2007) categorized these scientific practices into four different types. To describe the intertwined and mutually supportive nature of these categories, these practices were named "strands of scientific proficiency"

(NRC, 2007, p. 36). The four strands include: (a) students' understanding of scientific explanations, (b) generating scientific evidence, (c) reflecting on scientific knowledge, and (d) participating productively in science.

Scaffolding: Kuhn and Dean (2008) defined scaffolding as a complex construct used in science instruction to assist students with complicated problem solving processes. Scaffolding can occur through diverse forms such as providing strategic guidance, presenting a conceptual model, dividing a difficult task into parts or setting up appropriate goals to lower the cognitive loads of students (Quintana et al., 2004). Also, scaffolding can be brought either by teachers or more knowledgeable peers.

Instructional scaffolding: In this dissertation, the term instructional scaffolding presents the level of student-centeredness in instructional strategies employed by the teacher. Lower-levels are teacher-directed while higher levels are student-initiated. More specifically, higher levels of instructional scaffolding are associated with students having more opportunities to independently investigate subjects and discuss their own ideas based on what they learn in class.

Representational scaffolding: In this dissertation, the term representational scaffolding presents the complexity level of the information students receive or act on. The representational information provided to students can be in the form of symbols (e.g., chemical structures and mathematical equations), pictures (e.g., diagrams and photo images) or objects (e.g., models and computers). Overall, the use of representations can promote students' sense-making processes (Quintana et al., 2004). Lower levels require students to replicate information while higher levels require students to generate and test new ideas.

Significance of the Study

Currently, we have only a few instruments developed for the purpose of characterizing inquiry-based lessons. Often, analysis of inquiry that use traditional tools take only a snapshot of a lesson, which can cause misunderstandings about the nature of inquiry occurring in classrooms. For example, the inquiry mode of teaching is often considered as minimally guided instruction when actually an inquiry-based lesson is filled with well-organized teacher scaffoldings. To better characterize inquiry-based lessons and their impact on student learning, an integrated methodology was developed and applied in this dissertation. The methodology is also expected to assist teachers when they design and implement inquiry-based lessons and provide researchers a goal-aligned measure to analyze science classrooms.

Organization of the Dissertation

The dissertation is composed of five chapters. Chapter I states the problem in current science education. The chapter also presents the purpose, guiding research questions and the significance of the study. Chapter II provides a review of previous literature with emphasis on inquiry in science education. The historical background and current status of inquiry in classrooms were reviewed as well as the accumulated body of empirical studies that have investigated inquiry practices in diverse settings. Chapter III and Chapter IV present two independent but connected research papers. Chapter III answers the first two research questions by describing a methodology developed to analyze inquiry-based lessons. The chapter also provides justification for how this methodology would address the research purpose stated in Chapter I. In response to the third research question, Chapter IV describes the application of the methodology in the context of a prolonged inquiry unit. Finally, Chapter V presents the conclusion of the dissertation with reflection on the process and discusses implications for further studies.

CHAPTER II

REVIEW OF THE LITERATURE: TEACHING SCIENCE AS INQUIRY

Introduction

The use of inquiry in contemporary science classrooms has been minimal, despite its long history and wide recognition. Barriers for implementing inquiry are varied including insufficient resources, conflict with existing curricula, lack of time, and limited facilities. The most formidable obstacles imposed on teachers, however, are the complexities of implementing inquiry-based practice in diverse school settings. This mode of teaching requires teachers to develop specific strategies that engage students to learn scientific concepts through meaningful experiences that are similar to what scientists do in the laboratory. Additionally, inquiry teaching requires teachers to change even their perceptions and attitudes about science teaching (Crawford, 2000).

To promote lasting and successful transition from traditional lecture to inquiry instruction, more teachers' voices are required in the reform process. As a way to increase teachers' input on reform efforts, Keys and Bryan (2001) suggested greater emphasis on branches of educational research pertaining to teachers' beliefs, knowledge, and practices of inquiry. In this context, to add to the body of knowledge in inquiry research as it relates to teachers, I argue that comprehensive analysis of practices designed by teachers are required in order to reveal teachers' views towards inquiry. My desire to look more closely into inquiry classrooms and learn more about teacher perceptions motivated this study.

The literature review of this study consists of three sections. The first section provides a brief overview of inquiry. Specifically, I reviewed the history of inquiry to provide an understanding of the concept of inquiry in a historical context. Because of the continuous debates regarding its definition, I reviewed the existing definitions of inquiry and then described the most up-to-date and well-established ones provided in recent literature. I also present the challenges of inquiry implementation and possible reasons for discrepancies between goals and realities. The lack of teacher voices emerged as a critical problem regarding inquiry-related reform processes. Therefore, the second section focuses mainly on reviewing research about teachers' beliefs and knowledge about inquiry, and how one should approach these views. Finally, the third section describes the characteristics of teacher-designed inquiry practices in relation to students' scientific proficiency. Based on previous research, I also discussed the various ways to analyze inquiry classrooms. The organization of the literature review with associated concepts and relationships is shown in Figure 2.1.

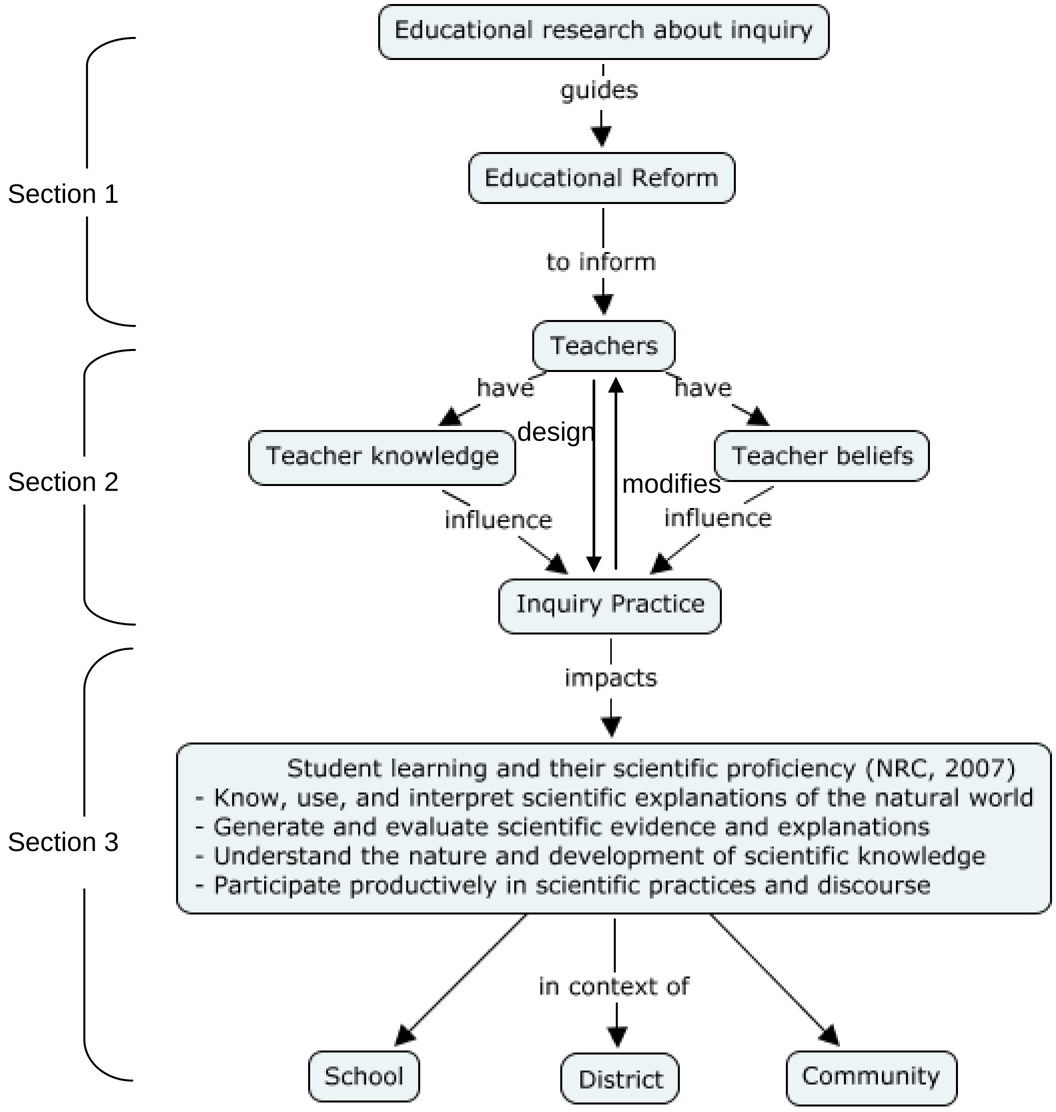


Figure 2.1. Concept map delineating the concepts and relationships associated with the three sections.

Inquiry in Science Education

History of Inquiry

The National Science Education Standards (NSES) define scientific literacy as students' ability to understand the natural world and use appropriate scientific processes in making informed decisions in today's high-technology world (National Research Council [NRC], 1996). To improve scientific literacy for all students, continuous efforts have been made in the area of science education. Recently, more emphasis has been placed on "learning by doing" rather than "cook book science," cooperative learning over individual learning and conceptual understanding over the acquisition of factual knowledge (see Table 2.1).

At the center of these discussions to advance science education, inquiry has always been considered a "good way of learning and teaching science" (Anderson, 2002). Indeed, since the late 1950s, inquiry has been one of science educators' most important goals (Deboer, 1991). Most recent reform efforts calling for inquiry in science classrooms reflect the enthusiasm and efforts of science educators that have prevailed for the past decades (American Association for the Advancement of Science [AAAS], 1990; NRC, 1996).

Table 2.1

Changing Emphases for Teaching (NRC, 1996, p. 52)

Less emphasis on	More emphasis on
Treating all students alike and responding to the group as a whole	Understanding and responding to individual student's interests, strengths, experiences, and needs
Rigidly following curriculum	Selecting and adapting curriculum
Focusing on student acquisition of information	Focusing on student understanding and use of scientific knowledge, ideas, and inquiry processes
Presenting scientific knowledge through lecture, text, and demonstration	Guiding students in active and extended scientific inquiry
Asking for recitation of acquired knowledge	Providing opportunities for scientific discussion and debate among students
Testing students for factual information at the end of the unit or chapter	Continuously assessing student understanding
Maintaining responsibility and authority	Sharing responsibility for learning with students
Supporting competition	Supporting a classroom community with cooperation, shared responsibility, and respect
Working alone	Working with other teachers to enhance the science program

Inquiry as a teaching strategy originated with early philosophers such as Socrates, Plato, and Aristotle, who first laid the foundation for rational inquiry. The current concept of inquiry in education, however, was first specified by Dewey (NRC, 2000), who emphasized the aspect of science as a way of thinking rather than a collection of factual knowledge. Moreover, Dewey first recommended adding the concept of inquiry into the K-12 science curriculum (Dewey, 1910 as cited in Barrow, 2006). He encouraged science teachers to use inquiry as a teaching strategy and suggested six steps in the scientific method: (1) sensing a perplexing situation, (2) clarifying the problem, (3) formulating a tentative hypothesis, (4) testing the hypothesis, (5) revising with rigorous tests, and (6) acting on the solution. In this model, students become more actively involved in learning, while teachers serve more as facilitators than instructors. In particular, Dewey stressed the need for research problems to relate to students' experiences and intellectual capability so that the learning experience is more meaningful. Dewey's thoughts about science as inquiry profoundly influenced subsequent decades of educators and therefore became the basis for future educational reforms in science education (Abd-El-Khalick et al., 2004).

In the 1960s, national science curriculum reforms were conducted involving 20 large-scale curriculum development projects such as the Physics Sciences Curriculum Study (PSSC) and Biological Sciences Curriculum Study (BSCS). Following Schwab's (1960) description of science education as "enquiry into enquiry," the National Science Foundation (NSF) curricula focused more on providing an "authentic" science experience that developed students' intellectual growth as active learners with advanced processing skills. At the time, most textbooks presented a mere "rhetoric of conclusions," making Schwab's idea that students needed to undertake inquiries for themselves rather profound (Bybee, 2000). As a result, BSCS biology, which was partly designed by Schwab, is considered one of the most successful high school curricula ever (Bybee, 2000). These curricula, however, also contained some flaws. The primary flaw was that they were driven by theories of teaching rather than theories of learning (NRC, 2007). The proposed learning cycle of exploration, conceptual invention and application, without much consideration given to students' prior knowledge and ideas, ignored the role of students as active learners and teachers as facilitators (NRC, 2007).

In the 1980s, nation-wide standards-based reforms emerged in response to *A Nation at Risk* (NCEE, 1983), which declared a crisis in America's educational foundations. As the AAAS noted in *Science for All Americans*, the shared goal of these reforms was to improve scientific literacy among all citizens (AAAS, 1990; NRC 1996). One reform document was the NSES which provided standards in coordination in the areas of content, instruction, assessment, and professional development (NRC, 1996). Currently, NSES is regarded as providing the most comprehensive statement on teaching science as inquiry. By suggesting what students should know and be able to do by grade 12, the standards emphasized the significance of inquiry in achieving scientific literacy for all students. NSES not only stressed the need for students to understand the nature of scientific inquiry, but also recommended that students be taught to conduct scientific inquiry.

Definition of Inquiry

Though inquiry has been regarded as an essential element of science education for more than 50 years, confusion and disagreement still linger in how to define the term. While the term "inquiry" is widely used in the field of education as well as in daily life, it often implies different meanings in different contexts. The most common use of the word "inquiry," as found in Merriam-Webster, is "a systematic investigation or examination into facts or principles" (Merriam-Webster online). However, a recent review of symposium papers by Grandy and Duschl (2007) revealed that many different terms or phrases were associated with the meaning of inquiry. Grandy and Duschl pointed out that widespread reconsideration of inquiry in diverse fields such as education, philosophy and history of science caused a proliferation of different meanings and interpretations of inquiry. Therefore, even in academia, there was a lack of agreement in characterizing inquiry and its main elements, which has further widened the gap between educational research and practice (Abrams, Southerland, & Evans, 2007).

In education, the term “inquiry” has been used in at least three different contexts. First, inquiry has been described as a tool for gaining greater understanding of scientific concepts and principles, as well as the methods and processes that scientist use. Second, inquiry has meant a set of cognitive abilities and process skills that students need to master. Finally, inquiry has been understood as a pedagogical approach for facilitating students’ learning about the scientific method and developing their own abilities (NRC, 1996). Because the concept of inquiry pertains to these diverse perspectives of science teaching and learning, previous studies have often shown different approaches for defining and describing inquiry.

Bonnstetter (1998) stressed the meaning of inquiry as scientific abilities and skills by arguing that school science curricula should encourage students to engage in authentic inquiry, comparable to that of real scientists. He categorized the levels of inquiry as ranging from traditional hands-on to student research, depending on teacher and student directedness in each inquiry process. Chinn and Malhotra (2002) described inquiry as a set of cognitive abilities that students need in order to develop scientific skills. In line with Bonnstetter, these authors categorized the levels of inquiry, but from different perspectives. Based on students' cognitive processes, Chinn and Malhotra contrasted the authentic inquiry form with the simple inquiry task, which is more prevalent in contemporary classrooms. Etheredge and Rudnitsky (2003) described inquiry as an understanding of the nature and origin of scientific knowledge. They used "story" to let teachers articulate what they mean by inquiry to achieve shared understanding. Then they provided guidelines for developing inquiry units with emphasis on the dynamic nature of inquiry. Many other researchers regarded inquiry as a type of teaching approaches. For instance, Barman (2002) defined inquiry as a kind of teaching strategy intended to build students' individual process skills. Moyer, Hackett, and Everett (2007) also saw inquiry as one of teaching methods and suggested specific steps for "inquirize" activities: planning, exploring, engaging, explaining, extending, applying, and evaluating.

In some cases, researchers presented relatively open-ended views for inquiry rather than strict parameters. Keys and Bryan (2001) stated that while there is no specific definition of inquiry, its meaning tends to be understood by individual participants. By arguing that inquiry is not a single, specific teaching method, Keys and Bryan suggested the adoption of "multiple modes and patterns of inquiry-based instruction" that create rich and meaningful learning experiences for students. Anderson (2002) extended the context-dependence of inquiry by differentiating inquiry into three different domains: (1) inquiry as a descriptor of scientific research, (2) as a mode of student learning and (3) as a type of teaching. Newman et al. (2004) also emphasized the dynamic and context-dependent nature of inquiry by stating that each instructor and each student need to construct their own working definition when they engage in inquiry within a constructivist paradigm.

Different definitions of inquiry have often hampered its effective research and implementation. Newman et al. (2004) argued that inconsistent definitions of inquiry in the science education literature lead students and instructors of science methods to face dilemmas during the study of inquiry. Barrow (2006) pointed out that there is a need for science teacher educators to reach consensus about the nature of inquiry, because not doing so is likely to result in confusion, in both pre-service and in-service situations. Grandy and Duschl (2007) also stressed the need for a consistent view of inquiry among educational researchers. Therefore, it seemed reasonable to me to first describe and establish what inquiry means in this study, before discussing the implementation and influence of inquiry in science classrooms. Though inquiry is a complicated term and easily entangled in many different perceptions due to its dynamic and context-dependent nature, some non-negotiable and indispensable elements should be present across all inquiry-related research, teaching, and learning. Table 2.2 summarizes these essential elements and possible variations (NRC, 2000). Based on these elements, many researchers argue that we should be able to establish certain consensus on inquiry.

Table 2.2

Essential Features of Classroom Inquiry and Their Variations (NRC, 2000, p. 29)

Essential features	Variations			
1. **Learner engages in scientifically oriented questions**	Learner poses a question	Learner selects among questions, poses new questions	Learner sharpens or clarifies question provided by teacher, materials, or other source	Learner engages in question provided by teacher, materials, or other source
2. **Learner gives priority to evidence in responding to questions**	Learner determines what constitutes evidence and collects it	Learner directed to collect certain data	Learner given data and asked to analyze	Learner given data and told how to analyze
3. **Learners formulate explanations from evidence**	Learner formulates explanation after summarizing evidence	Learner guided in process of formulating explanations from evidence	Learner given possible ways to use evidence to formulate explanation	Learner provided with evidence and how to use evidence to formulate explanation
4. **Learner connects explanations to scientific knowledge**	Learner independently examines other resources and forms the links to explanations	Learner directed toward areas and sources of scientific knowledge	Learner given possible connections	
5. **Learner communicates and justifies explanations**	Learner forms reasonable and logical argument to communicate explanations	Learner coached in development of communication	Learner provided broad guidelines to use sharpen communication	Learner given steps and procedures for communication

More ----------------------Amount of learner self-direction--------------------Less
Less --------------Amount of direction from teacher or material-------------More

NSES is thought to provide the most recent consensus on “what is inquiry” in its current state. Therefore, the definition and characteristics of inquiry in this study will follow the one from NSES (NRC, 1996), however, with particular attention to the dynamic nature of inquiry. NSES does not provide an explicit operational definition for inquiry (Abd-El-Khalick et al., 2004). Instead, NSES provides extensive description of what inquiry looks like, what students need know about it, and how teachers should teach and assess students. NSES describes inquiry as “a multifaceted activity that involves a process of exploring the natural world, making discoveries, and testing those discoveries for deeper understanding” (NRC, 1996). Therefore, inquiry-based instruction is usually associated with scientific processes such as formulating original scientific questions, designing an investigative procedure, conducting an experiment using appropriate technologies, and evaluating and communicating the findings (NRC, 2000). These essential features need to be considered in three different contexts: scientific habits of the mind, learning abilities, and teaching strategy (Anderson, 2002). Based on the NSES description of inquiry, I believe that the participation in inquiry, regardless of one’s positions in teaching, learning or researching, needs to make its own way in getting to the essence of inquiry. In other words, participants in inquiry need to construct their own definition and continuously refine their method of doing inquiry. As inquiry is not a simple approach to learning or teaching, but rather a goal in the process of making sense of new understandings, we need to be aware that the meaning of inquiry can shift among people and across places and over time.

Challenges of Inquiry

Many educators have been attracted to the study of inquiry since Dewey introduced it as an ideal way of learning in the early 1900s. In 1996, the NSES (NRC, 1996) included inquiry as one of the important learning goals for K-12 students, and along with this national reform, there has been increasing movement towards the adoption of inquiry in teaching practice. The scholarly literature has provided evidence that the use of inquiry in science education encourages students to attain greater academic achievement and deeper understanding of scientific concepts (O'Neill & Polman, 2004). Moreover, scientific inquiry has been shown to promote learning by low achieving students and students from diverse backgrounds (Cuevas, Lee, Hart, & Deaktor, 2005; Palincsar & Brown, 1992).

Contrary to the fact that inquiry was a key issue during the second half of 20th century, it has yet to become a standard practice in science classrooms. In fact, the reverse is true. Many studies have revealed that most teachers do not apply scientific inquiry in their classrooms (Anderson, 2002; Costenson & Lawson, 1986; Marlow & Stevens, 1999; Wallace & Kang, 2004; Welch, Klopfer, Aikenhead, & Robinson, 1981; Wells, 1995). Muscovici (2000) revealed that the majority of teachers taught science primarily from the textbook. Weiss, Pasley, Smith, Banilower, and Heck (2003) noted that only a small percentage of science lessons focused on the use of inquiry; inquiry was used most often at the elementary school level (15%) and less at the middle school level (9%) and high school level (only 2%). Windschitl (2003) also demonstrated that half of the pre-service teachers in his study did not implement inquiry teaching even after attending a workshop on scientific inquiry. Even in classes where inquiry takes place, a study found that types of inquiry were usually limited to structured inquiry rather than guided or authentic inquiry (Tobin, Tippins, & Gallard, 1994). Data from the student side also underscore the lack of inquiry in classrooms today. According to a survey from U.S. Department of Education, the majority of 12th grade students reported that they had “never” or “hardly ever” designed or conducted their own investigations (U.S. Department of Education, 1999). As already noted, even though the importance of inquiry has been understood for several decades, challenges and obstacles still exist in implementing inquiry in actual instruction. What could be the reasons for this widening gap between research and practice?

The debate over whether inquiry is beneficial – or even possible given current educational conditions – has been continuous. According to Bonnstetter (1998), inquiry can be divided into five types depending on the levels of student-teacher interactions and participation: (1) traditional hands-on, (2) structured, (3) guided, (4) student-directed, and (5) student research. Authentic scientific research is usually regarded as a very beneficial form of inquiry for students (Edelson, 1998). However, debate persists over whether students can develop sufficient skills to engage in authentic scientific research. Opponents argue that student research is not possible in current school environments, because scientific inquiry is a complex activity that requires professional with highly specialized and advanced expertise, performing elaborate procedures using expensive equipments (Dunbar, 1995; Galison, 1997; Giere, 1988 as cited in Chinn & Malhotra, 2002; Friedrichsen, 2008). Some researchers have argued that inquiry is not appropriate in teaching essential facts and knowledge to students, since inquiry instruction is a model without any systematic instruction or meaningful emphasis on scientific facts (Kirschner et al., 2006). Settlage (2007) even concluded that open-inquiry with authentic student research is nothing but a myth. He encouraged his colleagues to tackle problems that can be solved rather than unattainable goals.

Even though we have advocated the increased use of inquiry in education, we recognize that challenges remain regarding its implementation. Edelson (1998) presented five challenges that must be overcome to support inquiry learners: motivating students, establishing accessibility of investigation techniques, considering students' background knowledge, facilitating students' management of extended activities, and dealing with learning context constraints. Newman et al. (2004) listed seven dilemmas of teaching inquiry mainly from teachers' point of view: varying definitions of inquiry, the struggle to provide sufficient inquiry-based science-learning experiences, perceived time constraints, determining instruction versus pedagogy instruction and instructors' and students' lack of inquiry-based learning experiences, and grade versus trust issues with students. Anderson (2002) extended the concept of challenges beyond a classroom level by noting the technical, political and cultural dilemmas that teachers and learners may face when implementing inquiry.

Among all these issues mentioned above, the very first challenge teachers confront when implementing inquiry is to understand "what inquiry is." Teachers who are unclear on the matter can introduce confusion when translating and applying inquiry into practice. Mere understanding of inquiry, however, does not ensure successful inquiry teaching (Wee, Shepardson, Fast, & Harbor, 2007). Teachers need to develop the ability to design and implement inquiry units suitable for their own classrooms. The kinds of instructional problems teacher will face include difficulties in relating inquiry activities to existing curricula and standardized tests, and a lack of resources. Some models have been developed since the 1970s to guide inquiry instruction, however, they tend to be more lesson-based than unit-based, and they focus primarily on completing experiments rather than testing explanatory models, which may eventually impede students' meaningful engagement in the inquiry experience (NRC, 2007).

Along with these instructional challenges, teachers also need to address their own perceptions of inquiry. Sometimes, when teachers' perceptions of inquiry are based on previous knowledge and experiences, they do not match those of the researchers. Then this discrepancy can cause confusion (Crawford, 1999). In addition, a lack of experience and negative or uncertain perceptions of inquiry on the part of both teachers and students can interfere with teaching and learning. Research has found that many science teachers view inquiry as difficult to manage, time and energy consuming, and only possible with competent students (e.g., Blumenfeld, Krajcik, Marx, & Soloway, 1994; Costenson & Lawson, 1986; Welch et al., 1981). Teachers often think students or even they themselves are not sufficiently prepared for inquiry instruction. Some teachers believe that inquiry can impede teaching more knowledge and facts and thus, could possibly lead to less achievement on state-mandated tests. A variety of issues emerging from different aspects of inquiry practices are shown in Figure 2.2 (Anderson, 2002; Edelson, 1998; Newman et al., 2004).

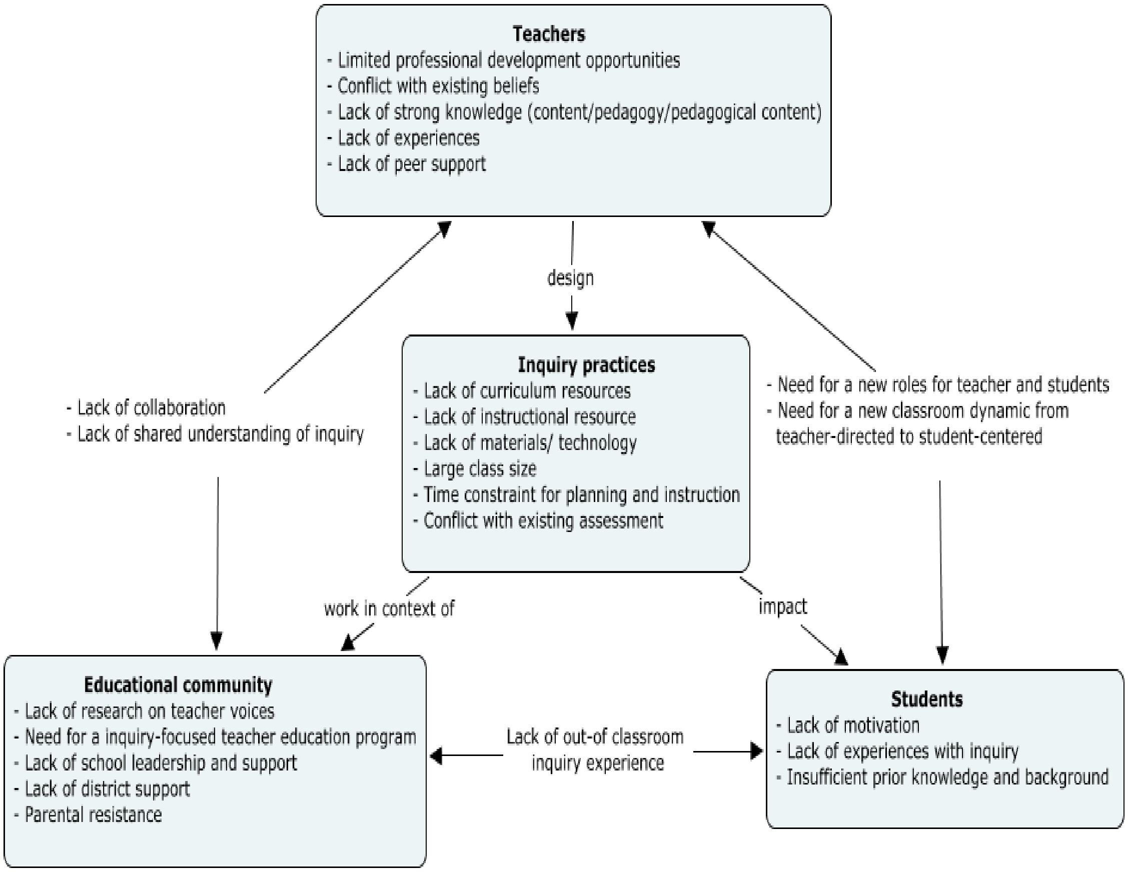


Figure 2.2. Challenges of inquiry (adapted from Anderson, 2002; Edelson, 1998; and Newman et al., 2004).

I believe that many of these debates, whether about the feasibility of inquiry or problems with implementation, likely originate from a misunderstanding about the nature of inquiry in contexts of school science. Johnston (2008) argued that perceiving inquiry as a teaching tool would only serve to distract and frustrate many future teachers. He asserted that inquiry should be understood as a teaching goal or a process to be learned. In accordance with Johnston’s argument, Anderson (2002) stated that the solution for most of these issues lies in the hands of teachers. Before bringing inquiry into the classroom, a teacher needs to understand and be able to conduct inquiry on his or her own terms. Teaching science as inquiry requires teachers to develop their own approaches for students to engage in creating authentic problems, conduct research, and develop a personal understanding of scientific concepts. This means that teachers must embrace numerous new roles, such as motivator, diagnostician, guide, innovator, experimenter, researcher, modeler, mentor, collaborator, and learner (Crawford, 2000). Teachers’ competence, especially a strong knowledge of and positive attitude toward inquiry, is essential for inquiry implementation. While competency alone may not guarantee the success of inquiry teaching, it is more likely that incompetent teachers will not be able to engage students in a meaningful inquiry experience.

Teachers’ Views of Inquiry

Research Agenda for Teacher-Focused Reform

Successful transition into the mode of inquiry teaching and learning in science classrooms first and foremost requires teachers to have beliefs that they are capable and confident in the inquiry process. Achieving this goal calls for a new approach for educational reform that emphasizes close connections among teacher educators, researchers and teachers. Researchers need to share clear definitions of inquiry while teacher educators assist prospective and in-service teachers in understanding the essence of inquiry and applying this understanding in the classroom. Most of all, as classroom instructors, facilitators, and guides, teachers should play a central role in designing, implementing, and assessing reform efforts. Current reform efforts, however, are designed and directed primarily by researchers.

One big obstacle in teacher-focused reform efforts is the lack of sufficient information on teachers' beliefs, knowledge and practices. While much research has been conducted regarding how students learn through inquiry, very little is known about teachers' perceptions or their teaching practices. To ease the gap and achieve lasting reform, Keys and Bryan (2001) proposed more research in the following domains: (a) teacher beliefs about inquiry; (b) the teacher knowledge base for implementing inquiry; (c) teacher inquiry practices; and (d) student science learning from teacher-designed, inquiry-based instruction including conceptual knowledge, reasoning, and nature of science understandings. Each of these domains, especially teacher beliefs and knowledge which are known to be least developed, needs more attention and research. In addition to this knowledge, I propose that research connecting these different areas and investigating their interrelations is most important.

Teachers' Knowledge and Beliefs of Inquiry

Researchers in diverse fields inclusive of anthropology, social psychology, and philosophy, have sought to understand the nature of knowledge and beliefs, and their correlation with actions (Richardson, 1996). In educational research, teachers' knowledge and beliefs have received significant attention as important factors in understanding their acceptance of new ideas and, consequently, the impact of those ideas on classroom practices (Bohning & Hale, 1998). First, teachers' knowledge about teaching comes from their education and experiences, both in and out of the classroom. Knowledge is described as an empirically based, non-emotional, and rational concept (Gess-Newsome, 1999). For science teachers, knowledge consists of their understanding about science content as well as curricular and pedagogical content. Again, pedagogical content knowledge is framed in terms of knowledge of science curricula, instructional strategies, understanding of students, and assessment of scientific literacy (Shulman, 1986). The conception of how that information is established or changed within the arena of science is another type of knowledge. What teachers know of the subject, the nature of science, and student learning combine to influence their choices of lesson design and flow (Crawford, 2007).

Teachers' beliefs are another important factor. Beliefs, like knowledge, are formed throughout teachers' lives through their personal experiences and background. Beliefs, however, are quite different from knowledge in that they are highly subjective and have a significant emotional component (Gess-Newsome, 1999; Richardson, 1996). When a person confronts a particular situation, beliefs towards that situation form attitudes, and then these attitudes are shown as actions that project a person's decisions and behavior (Pajares, 1992). In short, people tend to act based on what they believe (Lumpe, Haney, & Czerniak, 2000). For this reason, beliefs are regarded as one of the best indicators for decisions and judgments people make in their lives (Bandura, 1997). According to Ford (1992), there are two different types of beliefs: capacity and contextual. Capacity beliefs pertain to one's ability to perform specific goals, while contextual beliefs refer to the kinds of beliefs one holds about environmental factors (Lumpe et al., 2000). Together, these two types of beliefs significantly influence how teachers interpret knowledge, conceptualize teaching tasks, and enact their teaching decisions in classrooms (Bryan, 2003).

Knowledge and beliefs about teaching are closely related and work together to influence instruction (refer to Figure 2.3). Some researchers argue that knowledge is a subset of beliefs, while others maintain the opposite. Often, knowledge and beliefs are regarded as synonymous (Martin, 2008). To describe the tangled relationship between knowledge and beliefs, Crawford (2007) proposed the term “views.” Teachers’ views are a key factor in their decision to interpret a curriculum, design lessons, and interact with students. The role of teachers’ views is even more critical in inquiry instruction. Crawford (2007) stated that teachers’ knowledge and beliefs are critical for “creation of inquiry classrooms in which students develop in-depth understandings of how scientists develop understandings of the world.” Cronin-Jones (1991) also commented that teachers’ views play a pivotal role when implementing a new curriculum. Even though the recent reform of science teaching is clearly stipulated, teachers may not implement it without first developing strong beliefs about this new type of instruction (Yerrick, Parke, & Nugent, 1997). Therefore, one can easily understand the challenges teachers encounter when they are required to adopt inquiry – a concept that lacks a clear definition and prescription – into their lessons.

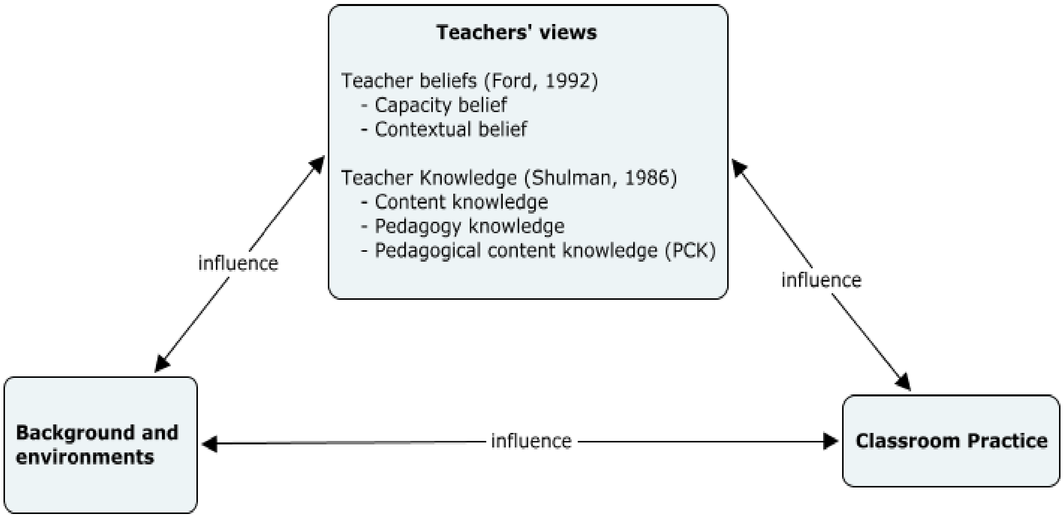


Figure 2.3. Impact of teacher beliefs and knowledge on inquiry practice (adapted from Bandura, 1986; Ford, 1992; Shulman, 1986).

The difficulty lies in the fact to date that we know little about the interrelation between teachers' views and practice (Bryan, 2003). Previous research revealed that teachers require in-depth content knowledge to implement inquiry lessons successfully (Anderson, 2002; NRC, 1996; T. M. Smith et al., 2007; Ward, 2009). Based on these findings, many of current teacher preparation and training programs are focusing more on improving teachers' content knowledge. However, the attention paid to developing a deeper understanding of scientific inquiry and understanding teachers' beliefs has been minimal (Keys & Bryan, 2001). Furthermore, there has not been significant discussion of the impact of these views for practice and possible changes to these views across time. For inquiry instruction, however, even a well-established and extensive knowledge base is likely to be insufficient. To fully adopt inquiry into instruction, teachers need belief systems that are open and reflective and allow teachers to easily align their views with constructive inquiry teaching.

Changing teachers’ beliefs is not a simple endeavor (L. K. Smith & Southerland, 2007). Bryan and Tippins (2005) described how the complex and nested nature of beliefs makes it difficult for teachers to change their beliefs. As these beliefs are established even before teachers entered into the profession, Bryan and Tippins proposed that teachers’ views need to be explicitly assessed as early as possible in their careers, Even though teachers can grow to hold positive views of inquiry, more often, other beliefs related to instruction can lead to conflict (Wallace & Kang, 2004). Therefore, a line of research explicitly focusing on teachers’ knowledge and beliefs as well as the interplay between the two, and their impact on teacher-designed inquiry practices, is greatly needed. Furthermore, these relationships need to be understood in the context of daily teaching practice, which can be very diverse and dynamic.

Classroom Analysis of Inquiry Practice

The Need for a Closer Look at Inquiry Practice

Inquiry instruction is typically described as “hands-on science,” “real world science,” or “doing science.” Though many inquiry practices involve hands-on activities or the use of technology, these are merely part of the overall process. More importantly, our view of inquiry lessons need to go beyond what teachers and students are doing, and focus more on how and why they are doing these things (Brooks, 2009). For this reason, in addition to teachers’ beliefs and knowledge, another major area that would benefit from greater attention is the diverse modes of inquiry practice designed and implemented by the teachers themselves (Keys & Bryan, 2001). Compared to the amount of research on student learning, research on teachers' roles and impact in implementing inquiry has been scarce indeed. In addition, previous research generally was conducted independently by teachers and researchers rather than through collaboration from both sides. For instance, data on teacher practice tend to come from teachers' own writings, without much researcher involvement. In other cases, researchers fail to include teachers' voices (Keys & Bryan, 2001).

While the national standards describe what inquiry should look like in classrooms, the current literature provides little information on how teachers should actually conduct inquiry. Because of the discrepancy between an "anticipated" and "achieved" curriculum, teachers have implemented inquiry instruction in ways that are wildly inconsistent (Gates, 2008), sometimes to the point of not meeting the criteria for inquiry instruction. Additionally, some teachers believe their practice to be inquiry-based when it is not in actuality (Yerrick et al., 1997). It is possible that teachers adopt only certain traits of inquiry, or follow procedures superficially, without changing their core beliefs.

The best way to understand inquiry in a school science context is to visit a classroom where inquiry practice is occurring (NRC, 2000). Good and Brophy (1997) explained that practice is the projection of what teachers think, know, and believe. In this respect, classroom observation and analysis have a two-fold purpose. For researchers, it brings more in-depth information about teacher beliefs and knowledge as well as an updated understanding of current practice. For teachers, it can enhance their selfawareness and reflective thinking, as the lack of awareness of everything that goes on in the classroom can hinder their effectiveness. In other words, researchers can understand better about subjectivity of the classrooms – the teachers' own knowledge and beliefs that drive the classrooms – while teachers can see their classrooms through the lens of objectivity (Good & Brophy, 1997). Furthermore, continuous communication between researchers and teachers in the process of analysis could maximize the benefit for both parties while decreasing the gap between research and practice.

Inquiry practices are relatively complicated and often involve long-term projects. Classroom analysis of inquiry teaching and learning environments is critical for understanding teachers' perception and instruction as well as their impact on student learning. In particular, in addition to the recent trend of research describing long-term inquiry projects, more reports on mundane events in real-life classrooms are needed, as teachers need clear and specific visions of "what if" in implementing inquiry (Crawford, 2000). Through classroom analysis, the value of inquiry needs to be demonstrated in local and culturally diverse settings to promote wide application of inquiry in current science classrooms. The accumulated body of research and evidences will lead to design principles that are common across contexts (Puntambekar, Stylianou, & Goldstein, 2007).

What Do We Need to See From Teacher-Designed Inquiry Lessons?

In this study, the focus of analysis is on instructional elements present in day-to-day events of teacher's inquiry instructions. With social and physical settings, instructional elements are major factors that comprise classroom practices. Specifically, instructional elements refer to factors such as instructional content, materials, class time, activities, and the application of technology. The flow of instruction with the incorporation of these factors through the unit as a whole is also regarded as a major instructional element. Additionally, I want to investigate inquiry teaching practices with greater attention placed on how these elements assist the student learning in a framework of scientific proficiency model suggested by NRC (2007).

Compared to the traditional instructional method of teacher-directed lessons focusing on factual knowledge, inquiry-based classrooms are open systems that provide students with possibilities for authentic research experiences from multiple resources. Inquiry classes are dynamic, interactive, and diverse in nature. In inquiry lessons, students become active operators of their own learning, while teachers serve as facilitators. The characteristics of inquiry lessons are quite different from didactic lessons and, therefore, accompany different teaching strategies (Puntambekar et al., 2007). For instance, one key aspect is to allow students extended time for “grappling” with – or making sense of – data using their own reasoning (Crawford, 2007). Furthermore, inquiry lessons encourage students to communicate their findings so that they can reflect on their own learning. These aspects of scientific practice are often disregarded in traditional classrooms. In light of these differences, when we see inquiry lessons, it is important to notice how teachers support students by their design of an optimal inquiry learning environment. Diverse factors such as teachers’ choice of materials, organization of activities, and their perceptions about student learning can be targets of investigation.

As mentioned above, the transferability of research results will be even more increased when more studies are conducted in diverse contexts. Previous literature revealed that we need more research in middle and high school inquiry-based instructions, especially with teacher-designed curricular (Keys & Bryan, 2001; U. S. Department of Education, 1999; Weiss et al., 2003). Therefore, I put more emphasis on reviewing research conducted in secondary classrooms that emphasized teacher-designed inquiry practices. Depending on the focus of their research, previous studies have adopted various strategies to find out different characteristics in teacher-designed inquiry classes.

Crawford (1999; 2000) conducted a series of case studies to see how teachers used the inquiry method to engage students and to identify the factors supporting or constraining teachers’ abilities to design and conduct inquiry lessons. Detailed descriptions revealed that successful inquiry involves collaboration between teachers and students, teachers who can model scientists, and development of student ownership in the learning process. Schneider and associates (Schneider, Krajcik, & Blumenfeld, 2005) analyzed the inquiry implementation of four teachers in terms of accuracy, completeness, opportunities, similarity, instructional supports, sources, and appropriateness. The authors then compared how the teachers presented scientific ideas and supported student learning, and whether the instruction was consistent. Findings indicated that teachers were generally consistent in their inquiry enactments with suggested curriculum. However, teachers who spent class time with more focus on small-group work, and continued to use suggested instructional supports turned out to be more consistent with curriculum intentions. Puntambekar et al. (2007) compared how two teachers structured the activities in a unit and facilitated classroom discussion. The results showed that, depending on teachers' use of inquiry, the same curriculum can be applied differently and cause significant differences in the learning outcomes of students belonged to those two classes. The authors concluded that teachers need to integrate inquiry activities coherently to help students make meaningful connections between concepts. Table 2.3 provides a list of example researches with their foci of analysis.

Another factor that needs to be considered in relation to teachers' inquiry practices is student learning. As stated in *Science for All Americans* (AAAS, 1990), the most important goal of science education is to increase students' scientific literacy. Recently, the NRC (2007) provided a newly defined description of what it means to be proficient in science. According to the definition, scientific proficiency consists of four different but intertwined strands that must be considered as a whole. To achieve scientific literacy, students need proficiency in all four areas: content, process, argument, and social interaction. These factors can be described as students' ability to:

(1) Know, use, and interpret scientific explanations of the natural world.
(2) Generate and evaluate scientific evidence and explanations.
(3) Understand the nature and development of scientific knowledge.
(4) Participate productively in scientific practices and discourse. (p. 37)

Table 2.3

Examples of Research Conducted in Secondary Classrooms for Teacher-designed Inquiry Practice

Author	(a) What did they see?		(b) How did they see it?	
	Research topic	Focus of analysis	Research design	Data analysis
Crawford (2007)	Investigating five teachers' beliefs about teaching science and their ways to teach inquiry	Each teacher's levels of inquiry implementation and their mentors' stances towards inquiry	Multiple case method/ cross case comparison	An inductive method (Erickson, 1986) and strategies suggested by Creswell (1998) and Merriam (1988)
Ladewski et al. (2007)	Exploring the role of inquiry and reflection in shared sense-making in an inquiry-based science classroom	The process of developing shared sense-making among the teacher and students	An interpretive case study comprised of "telling" mini-cases	A theoretical model of shared sense-making, Conversation analysis (Psathas, 1995) and an analytical framework were used to examine teacher-student interactions
Puntambe-kar et al. (2007)	Understanding the role of teachers when they facilitate student learning for deeper conceptual understanding.	Teachers' facilitation of classroom discussion and their impact on student learning	Mixed method design	Incorporation of the data from video-taped classroom analysis with qualitative coding scheme with quantitative student data
Schneider et al. (2005)	Examining classroom enactment in comparison to the intent of the materials	Three aspects of enactment – presentation of science ideas, opportunities for student learning, and support to enhance the learning opportunities	Qualitative video analysis	Iterative qualitative analysis with first coding scheme developed to capture three aspects of enactment and final coding designed to assess eight instructional aspects

Table 2.3 continued

Author	(a) What did they see?		(b) How did they see it?	
	Research topic	Focus of analysis	Research design	Data analysis
Wallace & Kang (2004)	Investigating six high school teachers' beliefs on inquiry teaching and their relationship with classroom practice	Teachers' beliefs about science learning and purposes of inquiry in relation to their implementation of inquiry	An interpretive multiple within-case study	Beliefs profiles created through iterative coding process from an ethnographic perspective
Wee et al. (2007)	Studying the impact of a professional development program on teachers' understanding of inquiry and their inquiry teaching practices	Teachers' understanding and ability to design inquiry lessons	A qualitative design	Inductive analysis adopting multiple data from inquiry analysis tool (IAT), concept maps, open-response assessments, and site-visit
Windschitl (2003)	Studying the impact of pre-service teachers' research experience for their thinking and eventual classroom practice	Pre-service teachers' conceptions of inquiry related to the way they conduct and interpret their own independent inquiry	A multiple-case study	Incorporation of participants' written descriptions and interviews into cross-case analyses to assess patterns of interaction between their conceptions and experiences regarding inquiry

The NRC (2007) stressed that this model moves beyond a focus on the dichotomy between content knowledge and process skills. These strands of proficiency represent learning goals for students as well as a broad framework for curriculum design. The process of achieving proficiency in science involves all four strands. Because none of these strands is independent or separable, an advance in one strand supports an advance in the others. In conclusion, to promote students' understanding of science, it is important to design learning opportunities that address all four strands.

Compared to the lack of research on teachers' views and inquiry practices, there has been quite a bit of research regarding the impact of inquiry on student learning (Keys & Bryan, 2001). Based on these studies, inquiry could be expected to be powerfully influential in promoting student learning. However, there are also arguments that the impact of inquiry shown in the literature, in many cases, has been superficial or even fictional (Settlage, 2007). More concrete and detailed evidences of inquiry practices and their positive impact on student learning outcomes are needed at this time. In particular, when analyzing inquiry practices, the relationship with students' learning should be addressed in the framework of the scientific proficiency model (NRC, 2007).

Simple observation tools and assessments may not be able to meet the needs to ascertain the ways in which scientific proficiency is achieved and accumulated in inquiry instruction. As current curricula and assessments often contain numerous disconnected topics, we need more attention on how students' learning of scientific ideas are connected and enhanced in a sequence of inquiry. To analyze teachers' inquiry sequence with regard to students' scientific literacy, a more systematic and comprehensive instrument is required to look into inquiry classrooms and extend the insight.

How Do We See It? - Tools for Classroom Analysis

Though the NRC (2007) clearly framed the goals of science education with four intertwined strands, we still do not know exactly how to support teachers and students in achieving these goals. Ladewski, Krajcik, and Palincsar (2007) mentioned that only a few theoretical or analytical tools exist to characterize the process of inquiry in naturalistic classroom contexts. Therefore, Ladewski at al. argued that we need to develop a vision of inquiry first, and then develop a tool that can differentiate inquiry from other types of learning, describe students' learning progressions, and characterize teacher-students interactions in inquiry classrooms.

Classroom analysis requires an identification of the strategy that will most appropriately suit the purpose of the research (Wragg, 2002). Numerous strategies exist for effective classroom observation. Inquiry-based lessons are usually more student-centered with relatively large portions of the class period spent in independent research. Traditional classroom observation systems that focus on teacher effectiveness by mainly counting events may not be appropriate for inquiry classes. Therefore, previous research conducted to characterize inquiry practices has had a tendency to use multiple resources with diverse strategies (see Table 2.3). As shown in Table 2.3, in many recent studies, researchers conducted in-depth qualitative case studies. Based on diverse data (i.e., video-taped classes, formal and informal interviews, reflection journals, student test data), researchers tried to explore teachers' use of inquiry and their impact on student learning. In particular, these researches showed significant differences in ways of revealing findings. For instances, Wallace and Kang (2004) created profiles for each teacher to contrast their beliefs and inquiry practices. Puntamebekar et al. (2007) represented teacher-student discourse in the form of a matrix.

As shown in these studies, to analyze the dynamic and complex nature of inquiry lessons, a system that can focus on multiple aspects of inquiry teaching is required. Along with lesson structure, another important evaluation factor is an understanding of the process of knowledge building and the interactions between teachers and students. Because the four strands of scientific literacy are neither separable nor independent, students use them in concert when they engage in a scientific task (NRC, 2007). However, there is also evidence that the strands can be assessed separately (Gotwals & Songer, 2006). For this reason, in my study, two different instruments were used to provide diverse perspectives in capturing and interpreting complex features of classroom inquiry activities. Through a mixed method design, Mathematics and Science Classroom Observation Profile System (M-SCOPS) and Scientific Practices Analysis (SPA)-map were integrated from the beginning stage of the experimental design to the final analysis and interpretation (Creswell, 2008).

The M-SCOPS (Stuessy, 2002) is an observation system designed to describe complex activities in science classes. By translating transcripts into visual profiles, M-SCOPS provides information about the content and flow of the lessons as well as their complexity and student-centeredness. In addition, M-SCOPS focuses on the student learning process by measuring changes in student activity. By providing the kinds of information students are receiving and acting on for each segment of instruction, as well as recording teacher and student behavior, M-SCOPS scripts provide a more complete view of “interactivity among teachers and students with instructional material and technologies” (Stuessy, 2002). Especially, M-SCOPS makes it possible to translate observational scripts into visual profiles that show the patterns of instructional strategies at a glance. M-SCOPS can be used in diverse contexts: to describe learning environments, correlate instructional patterns with academic performances, and enhance classroom teaching practices of science teachers. In this study, M-SCOPS data revealed the classroom information about context and content, flow, student-centeredness, and cognitive complexity of the lessons.

The SPA-map, the other instrumentation in this study originated from a concept map. Concept mapping is a kind of visual organizer that can represent relationships between ideas or concepts. Since being introduced by Novak and Gowin (1984), concept mapping has received continuous attention and now is considered the most effective meta-cognitive tool in science education (Mintzes, Wandersee, & Novak, 1997). Nesbit and Adesope (2006) mentioned that the number of publications referring to concept maps or knowledge maps has greatly expanded since 1985. They reported that more than 500 peer-reviewed articles, mostly published since 1997, have made reference to the application of concept or knowledge maps in education.

Concept mapping has been widely employed in a variety of fields including education, business, medicine, and software development, because it is effective in revealing the organization of complicated knowledge. Particularly in education, the concept map is known to be useful for nearly every part of the educational process, from student learning, designing curricula, planning instruction, and evaluation. To date, however, the use of concept mapping has been limited primarily to the fields of planning, instruction, and assessment, rather than for classroom observation research purposes. In this study, concept mapping will be used not only as a learning strategy and collaboration tool, but also to visualize and represent the types of scientific practices addressed in each lesson, thus re-named as the SPA-map. More specifically, the maps will focus on levels of knowledge, their interconnectedness, and the organization of scientific concepts in each lesson. Overall, the accumulated maps will reveal the patterns and flow of the scientific information and processes students had participated across the entire inquiry unit.

These two instruments focus on different aspects of the inquiry sequence. When woven together, however, an integrated analysis reveals more than these two tools can provide separately. They are expected to provide the researcher with a more holistic view of inquiry activity in the science classroom and to elucidate complex relationships that exist between classroom activity and science information in a prolonged sequence of lessons. In addition, the gained knowledge will support in-service teachers as they plan inquiry instruction and inform administrators to provide coordinated support.

Conclusion

The fact that inquiry has not become a common practice in science classrooms despite its wide recognition by science education reformers tells us that there are some disconnects. The major gap found from previous research was the lack of teacher input in the process of reform efforts. As national reform efforts, mainly conducted by federal agencies with top-down strategies, appear to have reached their limits, more attention is needed to study local contexts as a key for effective school change. Various factors that comprise local settings include classroom teachers, students, their activities and environments (Ball & Cohen, 1996; L. K. Smith & Southerland, 2007).

Especially, more research on teachers in relation to their beliefs, knowledge, and their practice of inquiry is required. Inquiry lessons, which allow students to pose their own questions, design and conduct research, require efficient teachers to support and guide them. Compared to lecture- and text-based classes, the teacher's role in inquiry lessons becomes doubled in some ways. Teachers must possess extensive knowledge on the scientific subject matter, approach their teaching tasks with positive and open-minded beliefs, and have abilities to effectively implement well-designed lesson plans. In reality, these burdens often frustrate teachers who plan to implement inquiry. Sometimes these burdens can make teachers follow the wrong concept of inquiry. Research on teachers' inquiry practices, their knowledge, beliefs and practice, will provide teachers' voices in the process of reform efforts.

Currently, there is a significant body of research regarding student learning outcomes within inquiry lessons. However, we need more research on teacher-designed inquiry lessons and their application in real classroom environments. Similar inquiry curricula can be applied differently by various teachers in particular contexts. Accumulated results on the application of inquiry curricula in diverse settings by different teachers will reveal certain design principles that can promote inquiry learning across the contexts. Especially, the research on inquiry practice in relation to students' scientific proficiency will prove the practical value of inquiry as a pedagogical approach as well as a learning goal.

CHAPTER III

DEVELOPMENT OF AN INTEGRATED SYSTEM FOR INQUIRY LESSON ANALYSIS

This study describes a method for analyzing inquiry lessons from multiple perspectives. The method integrates two instruments, the Scientific Practices Analysis (SPA)-map and the Mathematics and Science Classroom Observation Profile System [M-SCOPS] (Stuessy, 2002) for the purpose of better understanding “what happens” in science classrooms. The method was applied to video data obtained from one teacher’s inquiry lessons. The SPA-map revealed the types of scientific practices (National Research Council [NRC], 2007) present in each lesson, while the M-SCOPS revealed the content and flow of the instruction with information on levels of student-centeredness (i.e., instructional scaffolding) and use of representational content (i.e., representational scaffolding). Combined, these two instruments were used to produce visual profiles highlighting salient features of inquiry-based lessons. This paper describes (1) the development process and features of the SPA-map, (2) the use of the SPA-map in combination with the M-SCOPS, and (3) two examples that apply the SPA-map and the M-SCOPS to analyze lessons. The potential of the integrated system in visualizing and assessing the impact of inquiry on student learning is also discussed. This integrated method may help teachers design and reflect on their lessons and assist researchers in characterizing inquiry lessons in accordance with national standards that advocate scientific proficiency as an ultimate goal of science education.

Introduction

National reform documents from the 20th century, such as *Science for All Americans* (American Association for the Advancement of Science [AAAS], 1990) and *National Science Education Standards* [NSES] (NRC, 1996), emphasized the need for adopting inquiry teaching in science classrooms. Contrary to continuous attention, however, inquiry has not become a standard practice in science classrooms (Anderson, 2002; Costenson & Lawson, 1986; Marlow & Stevens, 1999; Wallace & Kang, 2004; Welch, Klopfer, Aikenhead, & Robinson, 1981; Wells, 1995). Current literature provides little information on how teachers should actually conduct inquiry in classrooms. This lack of information is considered a critical obstacle in implementing inquiry lessons.

To promote wide adoption of inquiry, Keys and Bryan (2001) proposed research of teacher-designed inquiry in a naturalistic context of diverse classrooms across both subjects and grade levels. While a body of research on diverse modes of inquiry instruction could provide teachers with a clear understanding of how to bring inquiry into classrooms, at the current state, few tools exist that are designed specifically for analyzing inquiry lessons (Ladewski, Krajcik, & Palincsar, 2007).

In inquiry-based lessons, where students' initiatives are maximized with dynamic interaction, traditional tools for classroom observation and data analysis are not able to capture the essence of inquiry. To explore the dynamic nature of inquiry in a classroom, I developed a new method with a comprehensive approach. The system was designed to investigate inquiry practices with attention on student learning in a framework of the scientific proficiency model (NRC, 2007). This model proposes that scientific proficiency can be achieved through students' active and frequent use of scientific practices and that the role of teachers is to provide an optimum learning environment where students engage in diverse types of scientific practices. I designed the integrated method to assist teachers' design of effective inquiry curricula and to help researchers analyze teacher practices with goal-aligned measures.

Background

Current Views on Inquiry Teaching

NSES (NRC, 1996) describes inquiry as "a multifaceted activity that involves a process of exploring the natural world, making discoveries, and testing those discoveries for deeper understanding" (p. 23). Compared to traditional teacher-directed instruction, inquiry teaching is more dynamic and interactive in nature. Authentic science research allows students to become actively involved in learning by designing their own research questions and experiments. Also, students participate in social interactions with peers as scientists do in their laboratories.

Based on these unique characteristics, inquiry has been expected to be effective in promoting students' scientific literacy. Several meta-analyses have reported positive results for inquiry on student learning. Shymansky, Kyle, and Alport (1983) reviewed 105 experimental studies involving "new science curricula" that emphasized the nature, structure and process of science, integrated laboratory activities as an integral part of the class, and focused on higher cognitive skills and appreciation of science. Their results revealed significant achievement of students when they were involved in these new science curricula. Another meta-analysis study conducted by Bredderman (1983) synthesized 57 studies to assess the effectiveness of activity-based elementary science programs. Based on the results, Bredderman estimated 10 to 20 percentile units of increase with student performance in case of wide adoption of these programs. Especially, the results revealed that disadvantaged students would benefit more than other students from these inquiry-oriented programs.

More recently, Schroeder, Scott, Tolson, Huang, and Lee (2007) conducted a meta-analysis on 62 selected studies published from 1984 to 2004. The goal of the analysis was to identify the effectiveness of alternative teaching strategies including questioning, manipulation, enhanced materials, assessment, inquiry, enhanced context, instructional technology, and collaborative learning. The result revealed that these teaching strategies, all permeated with inquiry, had significant impacts on student achievements. Also, Minner, Levy, and Century (2010) conducted a meta-analysis to investigate the impact of inquiry-based instructions on K-12 student learning using 138 studies conducted from 1984 to 2002. Their findings indicated a clear and positive influence of inquiry teaching for students, in comparison to other teaching strategies that relied more on passive techniques. The influence was most evident in students' conceptual understanding.

Negative voices also exist. Kirschner, Sweller, and Clark (2006) criticized inquiry teaching as a strategy that works against natural human cognitive structure. They discussed the number of studies dealing with inquiry to conclude that there was no body of research supporting minimally-guided inquiry instruction. According to the authors, the impact of learning can be maximized when students take the advantage of direct guidance. Settlage (2007) also criticized inquiry as an inefficient teaching strategy. He stated that the positive results of inquiry shown in the literature were superficial or even fictional in some cases. Overall the opponents of inquiry instruction state that there is not sufficient evidence supporting positive impacts of inquiry on student learning.

However, these critiques of inquiry may have originated from misunderstandings of the complex nature of inquiry. Hmelo-Silver, Duncan, and Chinn (2007) argued that Kirschner et al. (2006) misunderstood the nature of inquiry as minimally guided, when actually it is a highly scaffolded type of instruction. With several levels of scaffolding provided by a teacher, inquiry allows students to learn in complex domains with less cognitive burden (Hmelo-Silver et al., 2007). Also, Johnston (2008) argued that Settlage (2007) underestimated inquiry as a kind of teaching tool. He emphasized that inquiry should be viewed as a scientific endeavor itself and also a goal to be accomplished.

The Use of Scaffolding in Inquiry Teaching

Scaffolding is a specialized instructional support designed to help students' learning processes when students face difficult or unfamiliar tasks (Kuhn & Dean, 2008). As inquiry lessons usually require students to engage in complex tasks such as experimental design and problem-solving, diverse forms of scaffolding are needed to help students with their cognitive process.

Quintana et al. (2004) listed various scaffolding strategies that can promote students' inquiry learning including: (1) the use of representations that bridge learners' understanding, (2) the organization of tools and artifacts around the discipline, (3) the use of representations that allow learners to inspect the data from multiple points of views, (4) the provision of structure for complex tasks, (5) expert guidance about scientific practices, (6) skills for automatics handling of routine tasks, and (7) the facilitation of ongoing articulation and reflection. Through these diverse forms, scaffolding can lower the cognitive loads imposed on students and promote their inquiry learning.

Puntambekar and Koloner (2005) stated that scaffolding can be employed anywhere across instructional materials, scientific process, social interaction and learning environments. Also scaffolding can be provided by teachers, peers or learner themselves. Research indicated that different forms of scaffolding are needed to best facilitate different types of population (Hmelo-Silver et al., 2007). Therefore, more research is required to reveal how various types of scaffolding work and where they should be placed in complex inquiry learning environments (Kuhn & Dean, 2005).

Inquiry as a Strategy to Achieve Scientific Proficiency

Contrary to the wide recognition of inquiry, there is still confusion and disagreement on what inquiry is (Grandy & Duschl, 2007) and whether it is beneficial for student learning (Johnston, 2008; Kirschner et al., 2006; Settlage, 2007). To discuss the effectiveness of inquiry in classrooms, we first need to clarify the objectives of science education achieved by inquiry instruction (Anderson, 2002). NSES (NRC, 1996) describes the goal of science education as helping students develop scientific knowledge and thinking skills, so they can understand the natural world better and use appropriate scientific processes to make informed decisions. To achieve scientific literacy for all students, NSES emphasize the importance of inquiry for K-12 students. However, NSES does not specify how inquiry can address the element of scientific literacy, and consequently it caused confusion among teachers and researchers.

Recently, NRC (2007) published newly defined objectives of science education under the umbrella term, “scientific proficiency.” Although the NRC adopted a different term, the notion of scientific proficiency shares many commonalities with scientific inquiry as a goal of science education, except for the fact that scientific proficiency provides more emphasis on the aspects of science as a social enterprise (Liu, 2009; Michaels, Shouse, & Schweingruber, 2008). According to NRC (2007), scientific proficiency can be achieved through students’ active participation in four different types of scientific practices. To describe their intertwined nature, these practices are called “strands of scientific proficiency” (NRC, 2007, p. 36). The four strands include: (a) students’ understanding of scientific explanations, (b) generating scientific evidence, (c) reflecting on scientific knowledge, and (d) participating productively in science. While the strands are described as independent, they are also mutually supportive. Therefore development in one strand is expected to enhance proficiency in the other strands.

Because of the confusion regarding inquiry, Michaels et al. (2008) proposed to use the term “scientific practices” as precursors of scientific proficiency. By using a more inclusive term, the scope of discussion can be extended, instead of limiting discussion to “inquiry,” which these authors claimed was just a part of scientific practices. They also stated that focusing on scientific practices and placing inquiry practices in a broader context would reveal more effectively when and why inquiry works.

Table 3.1 compares essential elements of inquiry (NRC, 2000) with the four strands of scientific practices (Michaels et al., 2008; NRC, 2007). As shown in this table, even though inquiry is only a specific type of scientific practice, inquiry practices necessarily embed all four strands of scientific practices. Contrary to the traditional view of science presenting a dichotomy between content knowledge and process skills, inquiry instruction encourages students to become involved in authentic research with a concrete understanding of the topic (NRC, 2007). For this reason, scientific practices defined by NRC (2007) would far better characterize the complex nature of inquiry as a model moving beyond the traditional views of science.

Table 3.1

The Juxtaposition of Essential Elements of Inquiry (NRC, 2000) with the Four Strands of Scientific Proficiency (Michaels, et al., 2008)

Elements of Inquiry	**Strand 1** Learners know, use, and interpret scientific explanations of the natural world.	**Strand 2** Learners generate and evaluate scientific evidence and explanations.	**Strand 3** Learners understand the nature and development of scientific knowledge.	**Strand 4** Learners participate productively in scientific practices and discourse.
Learners engage in scientifically oriented questions.	Scientific questions come from learners' prior knowledge and curiosity for natural world (NRC, 2000, p.46).	Scientific questions lead learners to participate in empirical investigations and using data to develop explanations (NRC, 2000, p. 24).	Learners recognize the value of explanations in generating new and productive questions for research (Michaels et al., 2008, p. 20).	By sharing their explanations, learners can have an opportunity to use these explanations in work on new questions (NRC, 2000, p. 27).
Learners give priority to evidence in responding to questions.	Using evidence, learners can connect current knowledge with proposed new understanding (NRC, 2000, p. 26)	Learners use evidence to develop and evaluate explanations about how the natural world works (NRC, 2000, p. 25)	The evidence is subject to questioning and further investigation (NRC, 2000, p. 26)	By sharing their explanations, learners can examine evidence together (NRC, 2000, p. 27)
Learners formulate explanations from evidence.	Learners build explanations upon the existing knowledge base (NRC, 2000, p. 26)	Learners design and conduct scientific investigation to construct and evaluate knowledge claims (Michaels, et al., 2008, p. 19)	Learners build explanations upon the existing knowledge base (NRC, 2000, p. 26)	In sharing their explanations, learners can identify faulty reasoning, point out statements that go beyond the evidence, and suggest alternative explanations (NRC, 2000, p. 27)

Table 3.1 continued

Elements of Inquiry	**Strand 1** Learners know, use, and interpret scientific explanations of the natural world.	**Strand 2** Learners generate and evaluate scientific evidence and explanations.	**Strand 3** Learners understand the nature and development of scientific knowledge.	**Strand 4** Learners participate productively in scientific practices and discourse.
Learners connect explanations to scientific knowledge	Learners' explanations should be consistent with currently accepted scientific knowledge (NRC, 2000, p. 27).	Learners recognize that predictions or explanations can be revised on the basis of seeing new evidence (Michaels, et al., 2008, p. 20)	Learners evaluate their explanations in light of alternative explanations (NRC, 2000, p. 27)	Sharing explanations can fortify the connections between students' existing scientific knowledge and their proposed explanations (NRC, 2000, p. 27).
Learners communicate and justify explanations.	Students recognize that there may be multiple interpretations of the same phenomena (Michaels, et al, 2008, p. 20).	Learners understand appropriate norms for presenting scientific arguments and evidence (Michaels, 2008, p. 21)	Sharing explanations can fortify the connections between students' existing scientific knowledge and their proposed explanations (NRC, 2000, p. 27).	Like scientists, learners benefit from sharing ideas with peers, building interpretive accounts of data, and working together to discern which accounts are most persuasive (Michaels, et al., 2008, p. 21)

Research Agenda for Inquiry

In response to critics arguing that no concrete evidence exists to support the effectiveness of inquiry (Kirschner et al., 2006; Settlage, 2007), more research has been conducted to reveal the positive impact of inquiry on student learning. Furthermore, after the continued debate on the effectiveness of inquiry instruction, current researchers argue for the need to move on to the next level: developing ways to understand the dynamics of inquiry and describing how inquiry can be brought into the classroom (Anderson, 2002; Keys & Bryan, 2001).

Inquiry is a multifaceted activity that involves extended student research with complex scaffolding. Therefore, Wilson, Taylor, Kowalski, and Carlson (2010) stated that diverse measures need to be adopted to reflect multiple learning goals of inquiry and to avoid possible biases in the analysis of inquiry-based classroom enactments. Furthermore, Grandy and Duschl (2007) stated that teaching science as inquiry without the chance to engage students in scientific practices could not ensure their understanding on “a core component of the nature of science.” Thus, inquiry practices need to be evaluated in terms of its goal, which is a students’ scientific proficiency. By viewing inquiry activities as scientific practices, the impact of inquiry on student learning would be more clearly characterized in terms of scientific proficiency which is an ultimate goal of science education.

Research Questions

Research questions that guided this study include:

1. How can students’ participation in the strands of scientific practices during the process of inquiry learning be effectively visualized and assessed?
2. How can the association between teacher-provided scaffolding and students’ scientific practices be visualized through an integrated analysis?

Conceptual Framework

Science lessons consist of instructional elements such as content, material, class time, and application of technology. Teachers and students both participate in these elements for the purpose of achieving students' scientific proficiency. To obtain a more complete view of understanding complex science lessons, two instruments were used in this study. The SPA-map and the M-SCOPS serve as instruments to represent knowledge and skills in science lessons created by participants and to provide multiple perspectives in capturing features of inquiry practices.

The SPA-map shows students' involvement in scientific practices: an indicator for students' scientific proficiency. The M-SCOPS shows the content and flow of instruction as well as information about instructional and representational scaffolding existing to support learning in the lessons. Two instruments with different perspectives were integrated in this study to produce visual profiles showing the types of instructional patterns related with particular scientific practices (see Figure 3.1).

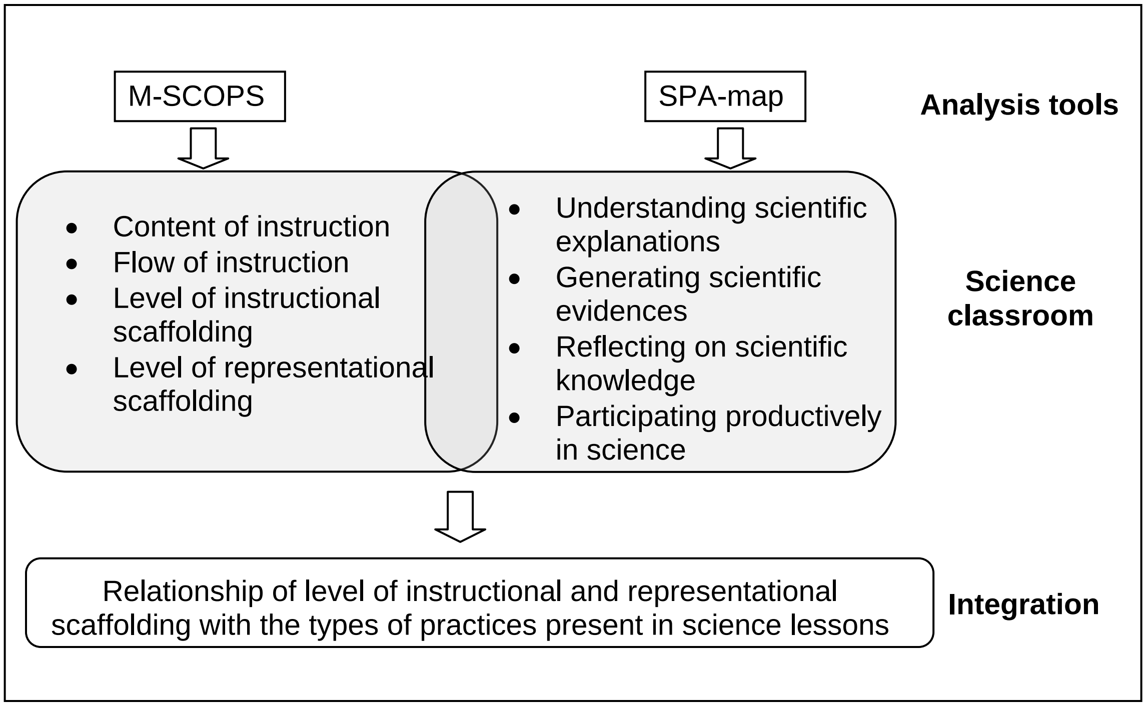


Figure 3.1. Conceptual framework of the integrated system.

Methodology

Analysis Using the Scientific Practices Analysis (SPA)-Map

A. Origin of the SPA-map. The format of the SPA-map originated from concept maps designed to graphically represent ideas or concepts. The concept map was introduced by Novak and Gowin in 1984. Since then, it has been used in various fields to effectively reveal organizations of complex cognitive structures. In the field of education, the concept map has been considered to be the most effective meta-cognitive tool (Mintzes, Wandersee, & Novak, 1997) applied to diverse processes, from designing instruction to assessing student learning. Different from previous approaches which used the concept map as a learning and teaching strategy, this study adopted the format of the concept map to create a new research tool, the SPA-map, which represents different scientific practices present in science lessons.

A traditional characteristic of the concept map is its hierarchical structure. However, the SPA-map does not have a hierarchy. Instead, the SPA-map is composed of four sections that equally represent each strand of scientific practices. Only within the strands, the structure of hierarchy can be applied. The four strands of scientific practices are closely related and therefore usually occur together (NRC, 2007). In this study, however, each practice is identified and mapped separately for the purpose of analysis (Gotwal & Songer, 2006). Included with the four separate maps are cross-links, which mark connections within/between the four strand maps to identify intertwined relationships between strands. Overall, the accumulated maps over several days can reveal the patterns and flow of the scientific practices across an entire inquiry unit.

B. Development of a rubric: Identification of scientific practices. To identify different scientific practices present in science lessons, I constructed a rubric based on the framework for scientific proficiency (Michaels et al., 2008; NRC, 2007). Items for the rubric were selected using recent literature published by the NRC (Michaels et al., 2008; NRC, 1996; NRC, 2000; NRC, 2007) that emphasize inquiry as an ideal way of teaching science. As such, many items in the rubric share commonalities with the essential elements of inquiry as defined by the NRC (2000). The goal of the rubric was to provide a reproducible and comprehensive description of scientific practices embedded within each of the four scientific proficiencies. Furthermore, other researchers and teachers can use the rubric as a focal point to discuss and reflect on what they see in science classes. A series of formal and informal meetings with other educational researchers were held in the process of building the rubric. The final version of the rubric is shown in Appendix A. Next to the list of descriptions for scientific practices, there is a space called “practice example” where actual examples of scientific practices observed in a lesson are described. These examples turn into concepts in a SPA-map.

C. Achieving an inter-rater reliability of the rubric. To achieve a sufficient level of inter-rater reliability for the rubric, four rounds of meetings were conducted with other education researchers. The meetings were held consecutively about one month apart in a same manner. In the first meeting, a panel of five researchers gathered to watch a 30-minute video clip of a science teacher’s inquiry lesson. As training for using the rubric, the members were asked to read selected literature that explained the theoretical framework of the scientific proficiency model (Michaels et al., 2008; NRC, 2007). A brief introduction and explanation of the rubric was provided before the meeting. After watching the video, the members were asked to recall the kinds of scientific practices they recognized in the video clip. Based on this preliminary analysis and provided feedback, I revised the items and format of the rubric.

In the second of four meetings, the revised rubric with more descriptive items was provided to the same researchers. After watching a 30-minute video clip from a different lesson by the same science teacher, the members were asked to check scientific practices found in that clip. After a whole-group discussion, the level of agreement achieved by the members was 81.2% with a kappa value of 0.63 (n=5). A third meeting followed and resulted in a level of agreement measured at 89% with a kappa value of

0.78 (n=5). Through these first three meetings, the format of the rubric became more close-ended with an increased number of categories and detailed descriptions for each category. Finally, in the fourth meeting, a sufficient level of reliability was achieved with 93% of agreement with a kappa value of 0.87 (n=4). Table 3.2 shows the final reliability score of the rubric.

Table 3.2

Scores of Inter-rater Reliability for the Rubric (n=4)

Strand of scientific practice	Percentage of overall agreement (%)	Fleiss' kappa[1]
Strand 1: Understanding scientific explanations	87.5	.74
Strand 2: Generating scientific evidence	91.7	.83
Strand 3: Reflecting on scientific knowledge	90.0	.80
Strand 4: Participating productively in science	100.0	1.00
Overall	93	.87

Note. [1]The inter-rater agreement was measure by Kappa's coefficient (Fleiss, 1971).

D. Transformation into the SPA-map. Once an inquiry lesson is observed and coded into the rubric, the SPA-map is constructed with identified scientific practices. As with any concept map, individual scientific practices in the SPA-map are marked as concepts and linked by phrases to explain relationships between concepts. After completing a SPA-map for each strand of scientific practices, cross-links within and between different types of scientific practices are identified (see Figure 3.2). For the SPA-maps shown in the application section of this paper, the process outlined here was conducted by the author, but the map was shared with other researchers for confirmation and feedback.

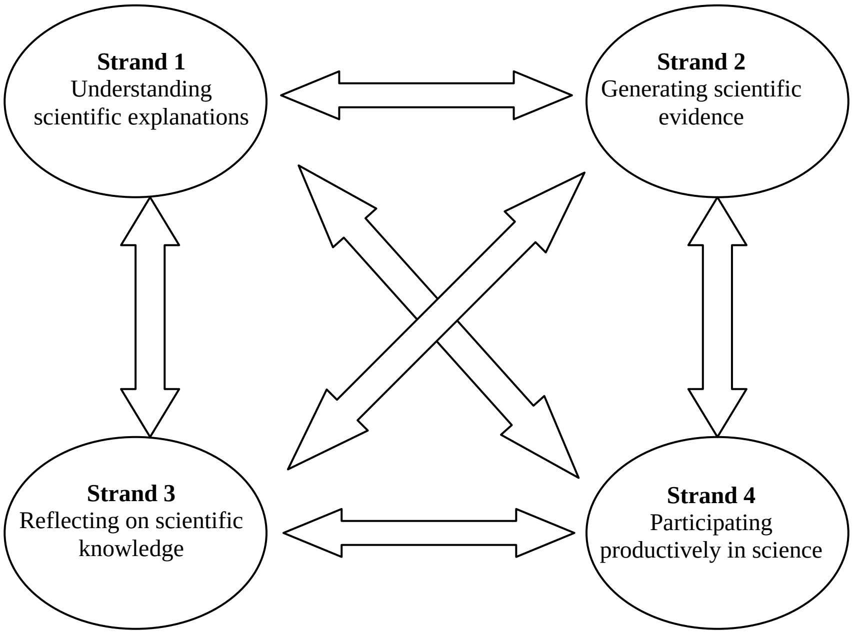


Figure 3.2. Organization of the SPA-map.

E. Interpretation. After completing SPA-maps for multiple lessons, overall patterns of the maps can be compared using a scoring process. Each strand of the SPA-map is scored separately following a rubric (see Table 3.3). I adapted the scoring rubric from two types of methods originally developed by two research teams (Kinchin & Hay, 2000; Novak & Gowin, 1984). When Novak and Gowin (1984) first proposed concept mapping as a useful educational tool, they also suggested a scoring system, which became the basis for many other scoring strategies (Liu, 1994; Lomask, Baron, Greig, & Harrison, 1992; Rice, Ryan. & Samson, 1998; Ruiz-Primo, 2000; Wallace & Mintzes, 1990). Their measurement was analytic, mainly based on counting the number of valid propositions, hierarchy, cross-links and examples. In contrast, Kinchin and Hay (2000) questioned the validity of a numerical system for scoring concept maps. They claimed that a quantitative system cannot thoroughly capture the scope and depth of a concept map and threatens the constructive learning process of students. As an alternative, they proposed a qualitative approach to the analysis of a concept map. Because they regarded a knowledge structure to be more holistic, Kinchin and Hay judged the overall structure of the maps (i.e., linear, spoke, or net structure) in order to identify the levels of student understanding.

More recently, Yin, Vanides, Ruiz-Primo, Ayala, and Shavelson (2005) added two more types of possible concept map structures (i.e., circle and tree) to Kinchin and Hay's categories (2000). In this study, considering the nature of the SPA-map, which contains four small-size maps instead of one big map with more complicated structure, the map structures are divided into three levels: (1) low level with linear-type maps, (2) medium level with circle, spoke- or tree-type maps, and (3) high level with net-type maps. According to Kinchin and Hay, the net structure of concept map implies that meaningful learning occurred in student cognition. The net structure of the SPA-map, therefore, becomes indicative of a more systematic and substantial experience with a scientific practice.

Both quantitative and qualitative scoring systems were partly adapted in this study to assess levels of scientific practices shown in the four different parts of the SPA-map. The analytic category measures the complexity and connectivity of maps to identify scientific practices in each lesson. Also this category shows how the practices within/between the strands are connected to each other. On the other hand, the holistic category evaluates the structure of the map to explore in what ways scientific practices expand beyond the core concepts and skills. Relative comparison of the maps based on analytic and holistic standards would lead to the categorization of overall high, medium, and low levels of scientific practices.

Table 3.3 shows the scoring rubric that combined both analytic and holistic categories. First, to analytically assess the level of particular strand, the number of concepts and level of hierarchy in each strand map were counted. According to the numbers, that strand would be evaluated as low, medium or high level and therefore scored with 1, 2, or 3 points, respectively. Second, to holistically assess the level of particular strand, the structure (i.e., whether the map is linear, spoke, or net) of each strand map is reviewed and given a score of 1, 2, or 3. Adding all the scores decides the overall level of the strand. The standards for the scoring rubric can be revised based on reiterative comparisons across the lessons. When applied to a different series of lessons, the standard deciding levels of strand maps according to the number of concepts and hierarchy are subject to change until all concerns of conformity across lessons are satisfied.

Table 3.3

The Rubric Developed to Score Each Strand of the SPA-map

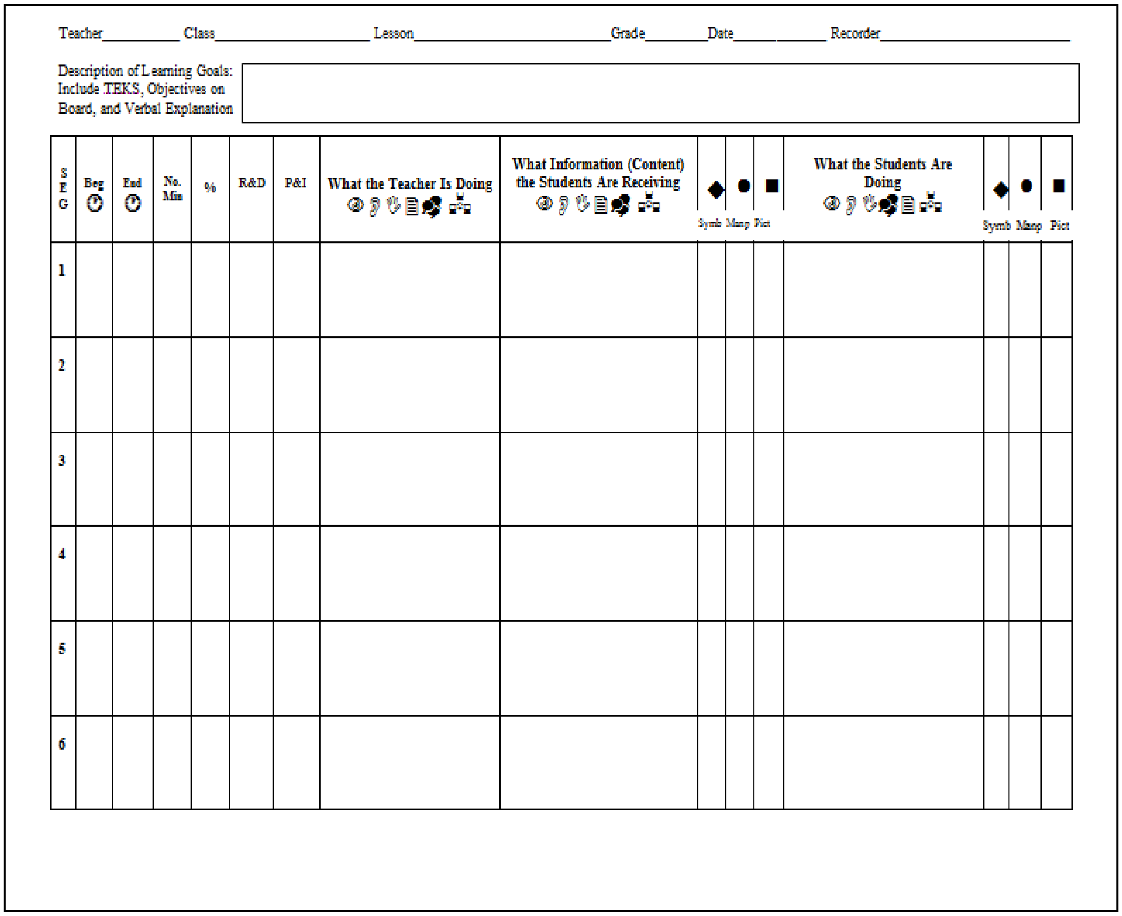
Type of assessment	Criterion	Level	Score
Analytic	Number of concepts	Low	1
		Medium	2
		High	3
	Level of hierarchy	Low	1
		Medium	2
		High	3
Holistic	Structure	Linear	1
		Spoke	2
		Net	3
Overall level	Low, Medium or High		

Analysis Using the Mathematics and Science Classroom Observation Profile System (M-SCOPS)

The other instrument used in this study is the M-SCOPS, designed to be used in complex mathematics and science classrooms to describe learning environments and find correlations between instructional input and student actions (Stuessy, 2002). M-SCOPS profiles reveal interactivity among teachers and students with instructional materials and technologies. Inquiry-based lessons are usually student-centered with large portions of the class periods allocated for independent student research (Etheredge & Rudnitsky, 2003). Therefore, instead of traditional classroom observation strategies that focus on a teacher's instruction, the M-SCOPS captures both the teacher's and students' activities as well as interactions between them.

In this study, the M-SCOPS provides multiple dimensions of information to facilitate in-depth understanding of the observed classroom. First, the M-SCOPS script has three columns that present information on "what the teacher is doing," "what information the students are receiving," and "what the students are doing" (see Figure 3.3). The information in these columns presents instructional content and context.

Second, in the M-SCOPS script, a lesson is segmented according to changes in student activities. Therefore, the number of segments in one lesson notifies the frequency of changes in student activities. By examining how segments change, the information of how the lesson flows from the beginning to the end can also be obtained. For example, one can see the flow of the lesson if it becomes more student-centered or teacher-directed.



Teacher__________ Class____________________ Lesson__________________________ Grade________ Date_____________ Recorder__________________________

Description of Learning Goals: Include TEKS, Objectives on Board, and Verbal Explanation

SEG	Beg	End	No. Min	%	R&D	P&I	What the Teacher Is Doing	What Information (Content) the Students Are Receiving	◆ Symb	● Manp	■ Pict	What the Students Are Doing	◆ Symb	● Manp	■ Pict
1															
2															
3															
4															
5															
6															

Figure 3.3. A scripting sheet for the M-SCOPS (Stuessy, 2002).

Third, the M-SCOPS reveals levels of instructional scaffolding provided in a lesson. As shown in Figure 3.3, there are three sections for inputting codes in the M-SCOPS script. The first set of codes (see Appendix B) titled “R&D” and “P&I” provides information on the level of student-centeredness. The code for instructional scaffolding strategies is composed of two paired numbers. These two numbers imply a teacher’s direction and students’ performance and initiatives respectively. As the level of instructional scaffolding increases, the second number in the code, which indicates student-centeredness, would also increase. In one lesson, there are multiple segments that can present different levels of scaffolding. For the purpose of cross comparison with other lessons, the levels of instructional scaffolding in each lesson are averaged considering the number of segments and allocated time. As a result, representative level for each lesson can be determined among low, medium and high levels of student-centeredness.

Finally, representational scaffolding describes levels of representational content students receive or act on during a lesson. Three different sources of content are described as symbols (e. g., verbal information, mathematical or chemical equations), pictures (e.g., images or diagrams), and objects (e.g., 3D models or plants). In the M-SCOPS script (see Figure 3.3), the second and third set of codes provide information on the level of representational scaffolding. Levels range from 1 to 6 according to the complexity of provided content. A detailed description for each level is shown in Appendix C. In a same manner with instructional scaffolding, for the purpose of the integrated analysis with the SPA-map using multiple lessons, the levels of representational scaffolding in a lesson are averaged considering the number of segments and allocated time for each segment. As a result, a representative level of low, medium or high can be determined.

Based on information from the script, the M-SCOPS transforms codes into visual profiles presenting a lesson as segments of instruction, with the level of instructional and representational scaffolding for each segment. For the integrated methodology developed for this study, only the levels of instructional and representational scaffolding were selected and integrated with the SPA-map.

Integration of the SPA-map with the M-SCOPS Profile

After completing a SPA-map and a M-SCOPS profile for each lesson, I constructed a hexagon profile for the integrated analysis (see Figure 3.4). In the six-sided hexagon, the representative levels of instructional and representational scaffolding from the M-SCOPS mark the top two points. The remaining four points present the four strands of scientific practices, respectively. Depending on their levels, each point can be located in one of three positions that indicate low, medium or high levels. Once all six points are plotted, a line connects each of the six points to create a profile which represents the associations between the six measured elements.

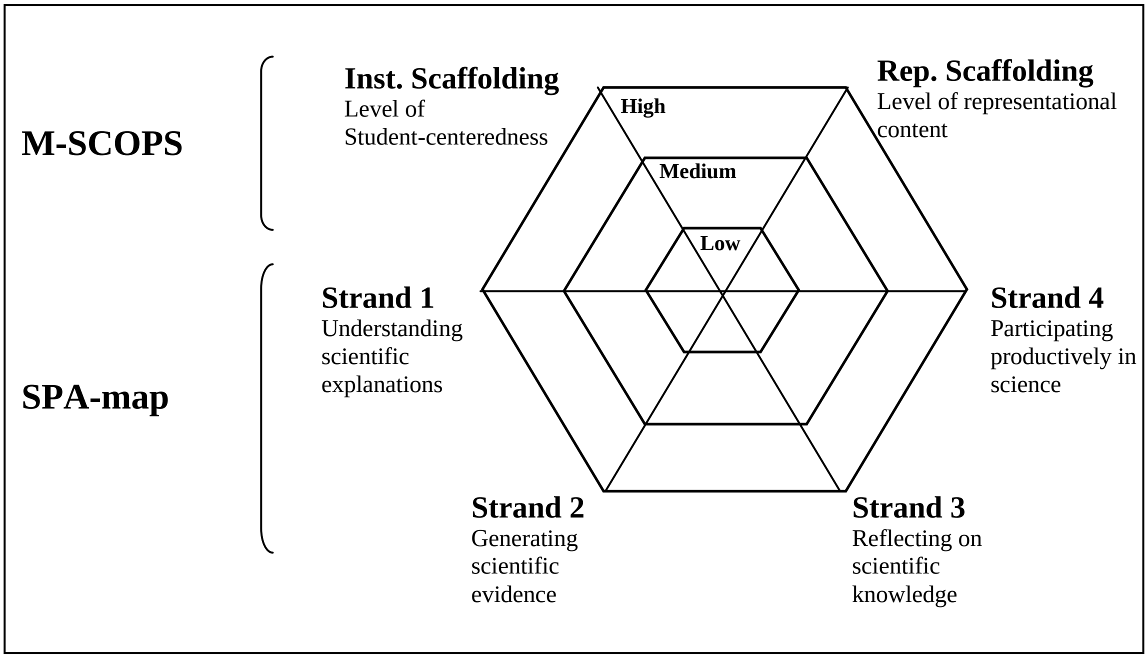


Figure 3.4. Organization of the hexagon profile.

Application of the Methodology for Inquiry Lessons

In this section, the methodology is described in context of two inquiry-based lessons. These lessons were parts of an inquiry unit one teacher had implemented for 10 weeks in a high school biology science classroom.

Background

A. The participant. The teacher had 22 years of teaching experience at the time she participated in this study. Her classroom enactment occurred as a result of her engagement in a professional development program for two years. The program focused on teachers' engagement in authentic science research in laboratories with university scientists and enrichment in educational knowledge through lectures and support from education researchers. Through this two-fold professional development experience, the teacher developed an inquiry-based instructional unit, which was implemented it in her own classrooms during the academic school year.

B. The classroom. The teacher implemented an inquiry unit titled, "Cultivating Scientists through Plant Inquires" in a ninth grade biology class. The implementation covered a 10-week period. In the beginning of the unit, the students received mutant plants with unknown traits. During the unit, the students conducted research projects to figure out traits of the mutants as compared to wild type *Arabidopsis*. Within this overall learning goal provided by the teacher, the groups of students came up with their own specific research questions and designs.

Two lessons from the implementation period were chosen in this study to provide examples of how the SPA-map and the M-SCOPS is used to analyze science classrooms. The classroom where she taught these lessons consisted of 17 high school students, composed of 10 males and 7 females. There were 2 Hispanic students and 3 special education students in this class. Located in a rural area of Texas, the school had approximately 32% economically disadvantaged students and 13% ethnically diverse students, with a total 276 students.

Lesson I – A Model Activity

A. Description of the lesson. This lesson was conducted in the first week of the implementation period. In the beginning of the unit, the students were mainly involved in exploring genetics concepts before they started working on plant experiments. Therefore the lessons were relatively teacher-directed with more emphasis on delivering factual knowledge. The goal of the lesson described here was to provide the students with opportunities to engage in a model activity so that they can understand the function and structure of the cell. By learning the features of the cell using a model, the students also learned that real organisms in nature can be studied with models.

The teacher began the lesson by asking students questions concerning a shoebox on each table. Four to five students sat on a same table and shared a shoe box. She then explained what a model was and how cells and chromosomes could be represented as shoeboxes with paper strips in each box. After the teacher provided basic directions for the model activity, the students started to work on the shoebox to explore its content.

Based on the information shown on the paper strips, the students were asked to figure out what kinds of traits they would expect from their shoebox cell. A worksheet composed of eight questions guided the student activity and subsequent discussions. During this activity, the students participated in a teacher-guided whole group discussion to talk about how models are similar or dissimilar from the objects they represent. The students obtained a glimpse of the information on the plant project through this discussion. The teacher closed the lesson by checking student answers on the worksheets and asked a review question to gauge students' understanding.

B. The SPA-map analysis (within class analysis). As the lesson was conducted in the beginning of the implementation, a significant amount of time was spent on students' learning scientific concepts, which served as background knowledge for the subsequent student projects. To elicit more student-operated learning, the teacher designed the shoebox model activity. Therefore, instead of a typical two-dimensional diagram of the cell, the students could explore hands-on materials as a model for the cell. As shown in the SPA-map (Figure 3.5), this activity was a highlight of the lesson in the way it involved all four strands of scientific practices. Without the shoebox activity, the SPA-map of this particular lesson would have seemed quite knowledge-intensive with most concepts distributed in the strand 1 map.

Overall, the level of strand 1 practices (i.e., understanding scientific explanations) was very high when it was compared to other strands of scientific practices. The activity introduced in this lesson was a relatively simple hands-on activity that did not involve any type of designing or conducting research activities. Therefore, I assessed the level of strand 2 practices (i.e., generating scientific evidence) as medium.

However, the activity helped the students to engage in higher-level thinking, such as reflection and representation. The model activity encouraged the students to reflect on how models represent nature but also how they are different from real organisms. These discussions became an indication of medium level of strand 3 practices (i.e., reflecting on scientific knowledge). When compared to other strands, the level of strand 4 practices (i.e., participating productively in science) was lowest because the lesson involved only a small portion of student discussion. Besides, the discussion was highly teacher-guided rather than student-initiated. However, the teacher did note that this lesson was the first in which students actually sat in small group. Though the group work the students had participated on this day was minimal (i.e., sharing the shoe box and participating in informal discussions when students were working on the worksheet), the new seating arrangement also worked out as an introduction for the plant project, in which they would sit in groups for 10 weeks.

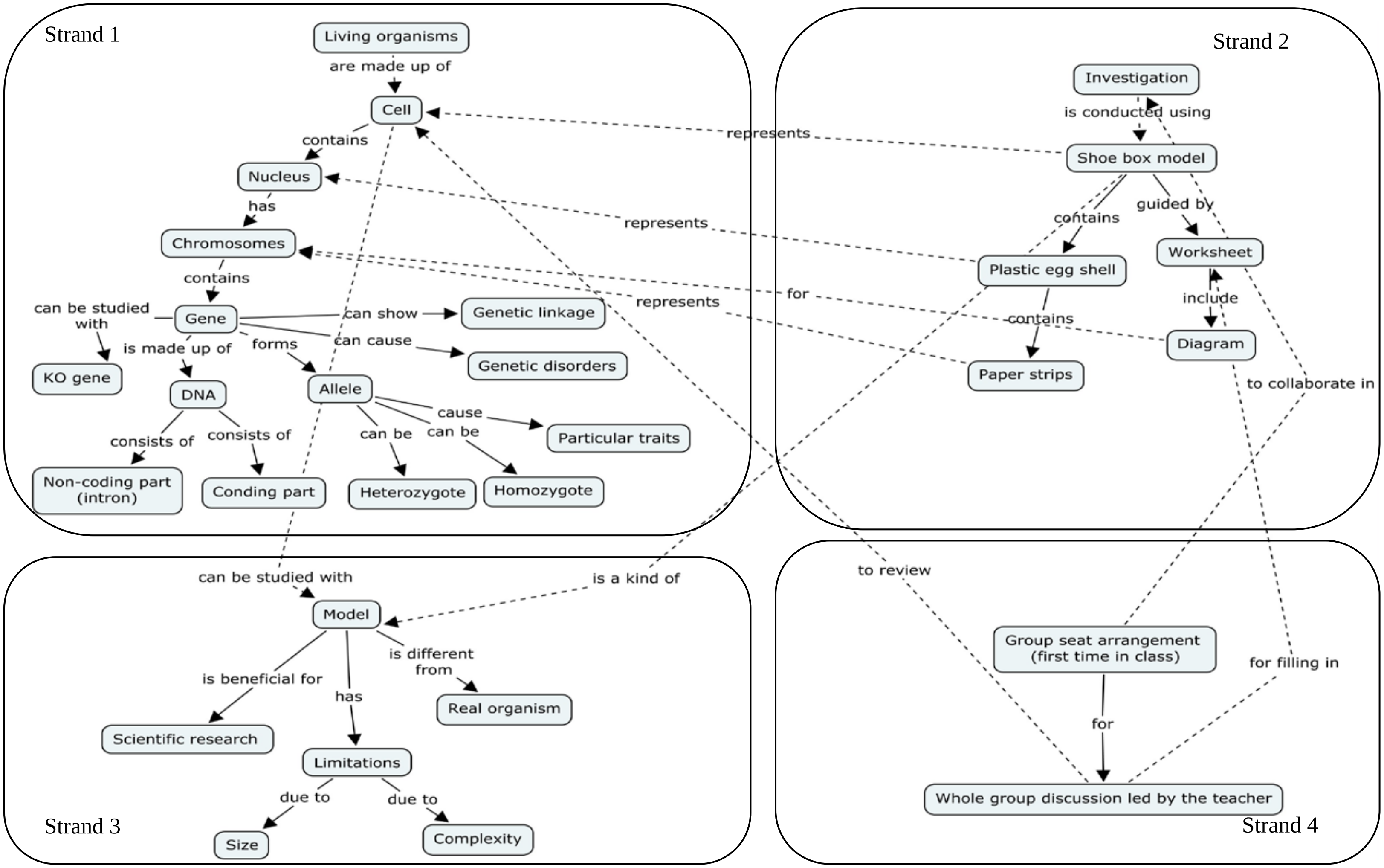


Figure 3.5. The SPA-map of Lesson I.

C. The M-SCOPS analysis. This 47-minute lesson consisted of 7 segments where 42% of the instruction time was spent in hands-on activities or whole group discussions (segments 4, 5 and 7). The remaining time (58%) was teacher-directed instruction (segments 1-3 and 6). As shown in the M-SCOPS profile (Figure 3.6), the lesson alternated between direct instruction and whole group discussion which imply 5-1 and 4-2 levels of instructional scaffolding, respectively.

Analysis of the symbols, mostly words in the case of this lesson, revealed that the teacher and the students were engaged in “replicate” level of representation when the teacher gave the students the direct instruction on cells. The students were also engaged in higher order thinking such as “transform” when they discussed models as different representational system of real organisms. To make the connection between cell models and natural cells, the students worked with objects (i.e., shoeboxes and paper strips) for about half of the lesson period (52%). For approximately one-third of the lesson period, the students received or acted on pictorial content mainly in the form of diagrams. The teacher and the students drew diagrams of cells and chromosomes to represent their understanding. The objects and diagrams used in this lesson also allowed students’ engagement in higher order thinking at the “transform” level.

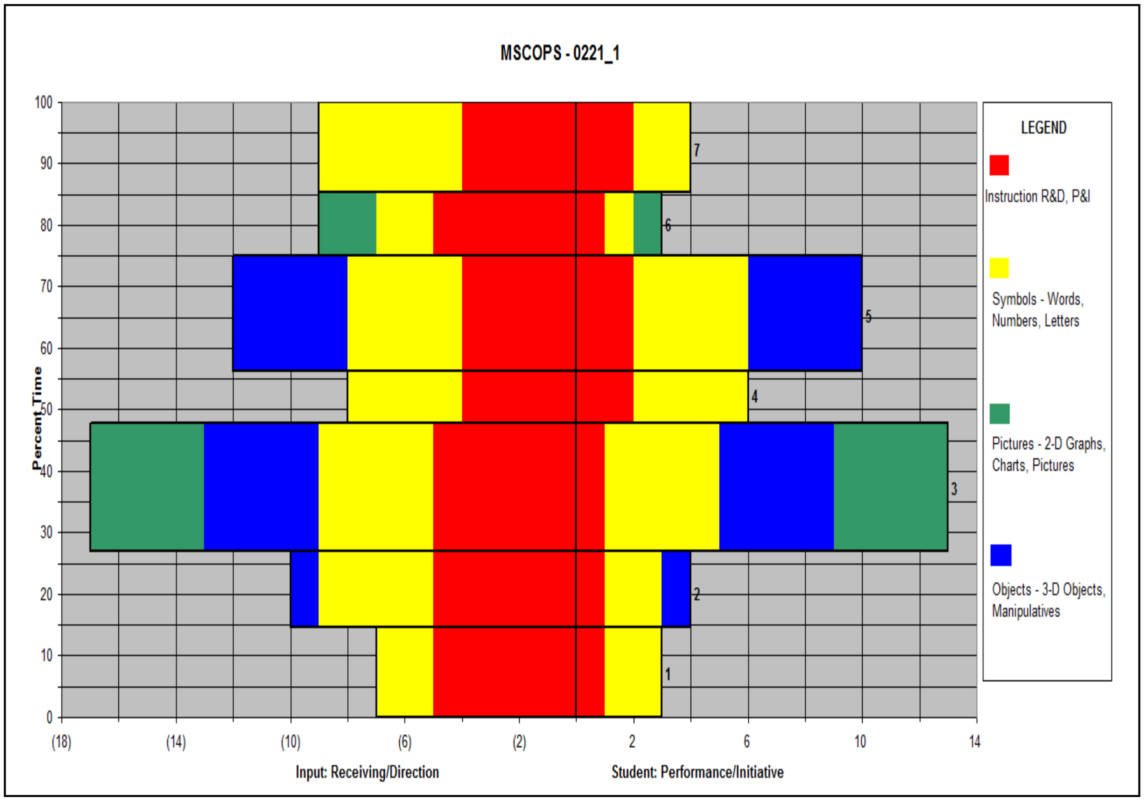


Figure 3.6. The M-SCOPS profile of Lesson I.

D. Integration of the two instruments. The hexagon profile of Lesson I (see Figure 3.7) revealed a low level of instructional scaffolding as the teacher directed the lesson for most of the period. During the direct instruction, the teacher delivered many scientific concepts indicating students' engagement in a high level of strand 1 practices. However, the students had fewer opportunities to be involved in strand 4 practices. Analysis of strand 2 and 3 practices revealed medium levels of student engagement. Through the model activity and whole group discussions, a medium level of representational scaffolding was provided to students.

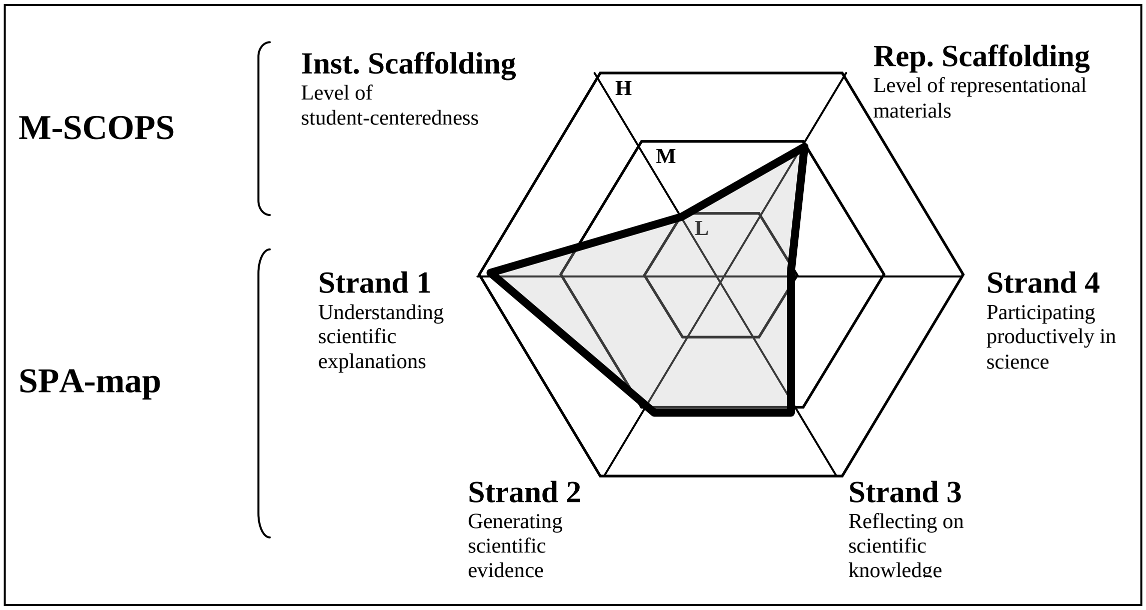


Figure 3.7. The hexagon profile of Lesson I.

Lesson II. Data Analysis in the Computer Lab

A. Description of the lesson. Lesson II was conducted in the seventh week of the inquiry unit that lasted for 10 weeks. At this time, the students were in the middle of data analysis. Including this lesson, about one third of the whole implementation was conducted in a computer lab with similar instructional patterns. The students spent large amounts of time in independent research under minimal supervision except for a short introduction and closure provided by the teacher. Though all the groups and students showed different levels of progress, they generally used computational tools for analysis, and presentation such as *Image J, Excel*, and *PowerPoint.* The students also searched for information on the web while working on data analysis. The teacher's role at this stage was limited to a facilitator and technical support. However, she always gave useful guidance and direction to anyone in need of help.

B. The SPA-map analysis (within class analysis). In this lesson, as input of new information was limited to students' web searches, the level of strand 1 practices was rated a medium level. In contrast, the level of strand 2 practices was very high as the students worked in the computer lab using computer software such as *Excel* and *Image J*. To analyze and interpret data, the students used multiple resources to edit images, review movies and create tables. Based on the analyzed data, the students reflected on their original research questions and hypotheses (thus causing their participation in strand 3 practices). The teacher also encouraged the students to discuss possible revisions they could make to their projects. However, the frequency of occurrence for strand 3 practices was low. Through the most of the lesson period, the students worked in groups to analyze data and discuss their opinions, which indicated high level of strand 4 practices. Particularly, the students collaborated in lab work according to their assigned roles as a leader, a tech person, a protocol person, or a plant-caring person. Based on their experiences with plants from different points of view, each member shared their opinions and contributed to the analysis. Figure 3.8 shows the SPA-map of this lesson.

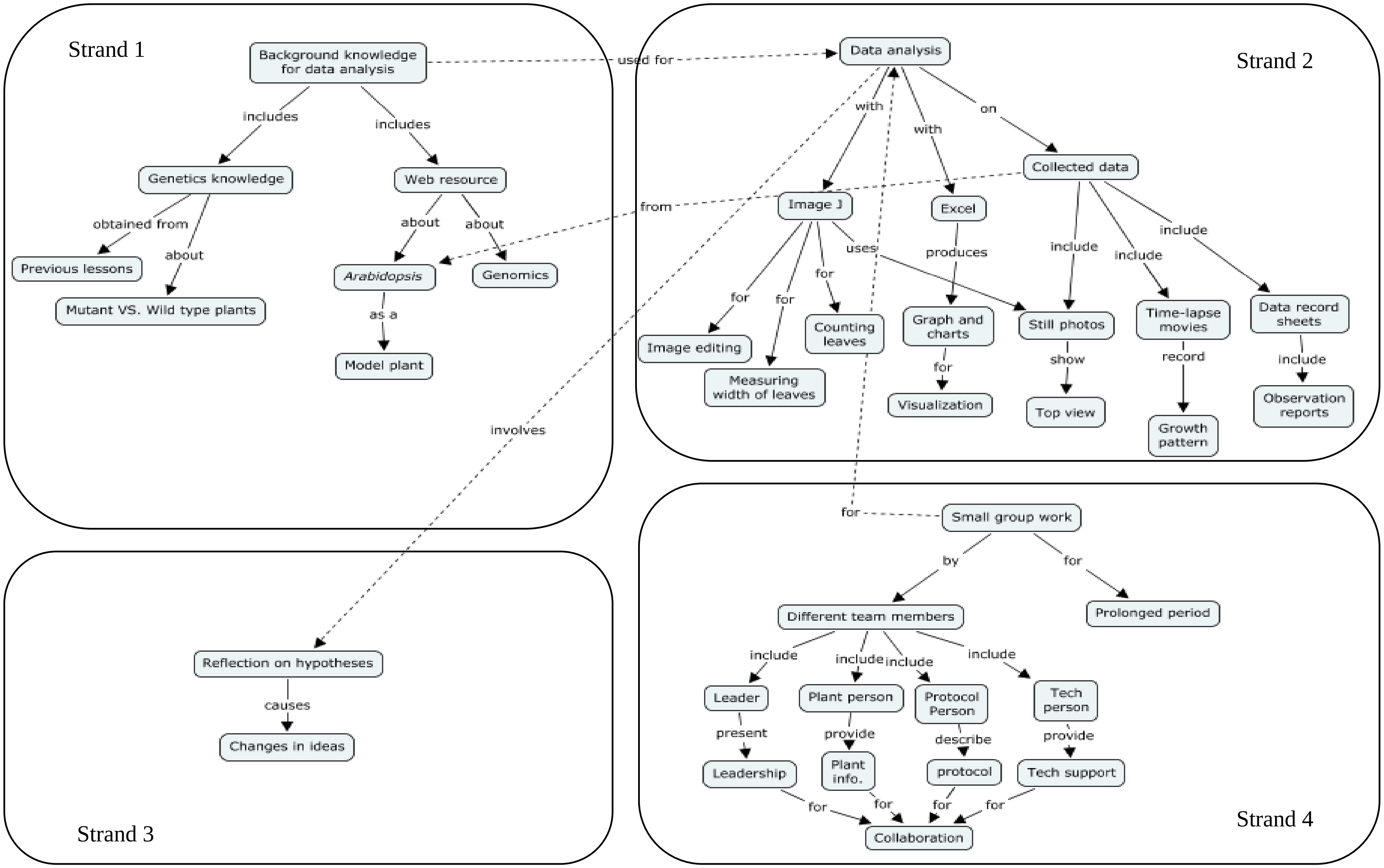


Figure 3.8. The SPA-map of Lesson II.

C. The M-SCOPS analysis. This 52-minute lesson consisted of three segments with most time (87%) spent on student research with a 1-5 level of instructional scaffolding (segment 2). Short periods (14%) of teacher-directed instructions with a 5-1 level of instructional scaffolding opened and closed this lesson (segments 1 and 3). The M-SCOPS profile is shown in Figure 3.9.

In the process of student research, the teacher did not provide any type of direct instruction. However, the students obtained new content from multiple sources, which included peers, websites, and collected data. As symbolic content, the students communicated information through group discussion and received information from websites and handouts provided by the teacher. This information helped the students to engage in a higher order thinking level of 5 (connect) while they discussed alternatives points of view, explained relationships in a system, and developed explanations.

Computers served as an important medium in this lesson by providing a mixed form of representations. In addition to the collected data such as movies and images, the students obtained more images from the web. *Image J* and *Excel* were used to manipulate these data. Analyzed data were transferred into tables and charts for visual representation. Overall the students were involved in a level 4 (transform) of higher order thinking using these objects and pictorial content.

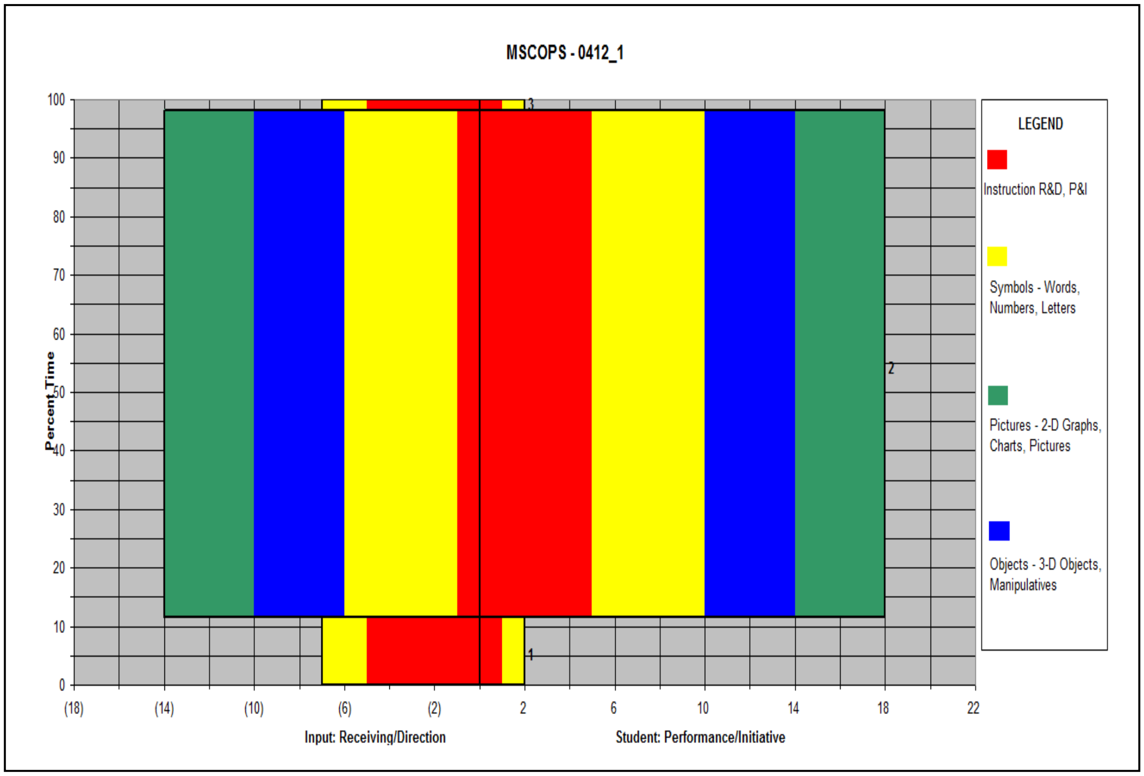


Figure 3.9. The M-SCOPS profile of Lesson II.

D. Integration of the two instruments. The hexagon profile revealed that the level of instructional scaffolding in Lesson II was very high. Student-centered instructional strategies involved a high level of strand 4 practices. The students also experienced a high level of strand 2 practices by analyzing and interpreting data, which engaged the students in using diverse form of representational content at a high level. The level of strand 3 practices was relatively low in this lesson, showing no significant association with other elements indicating higher levels. See Figure 3.10 for the hexagon profile of this lesson.

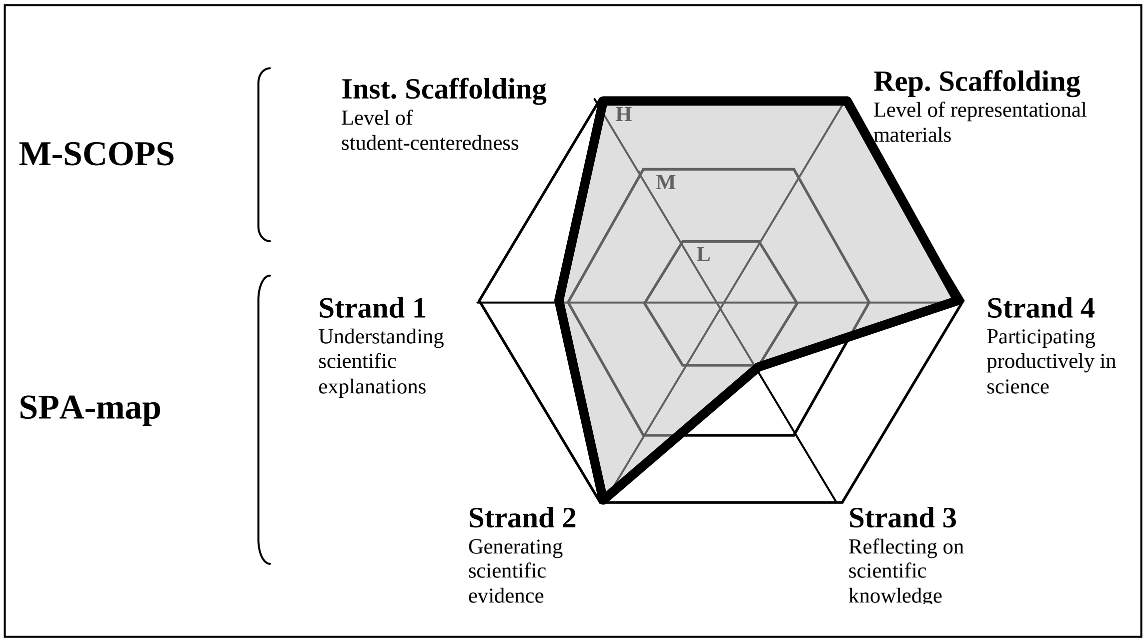


Figure 3.10. The hexagon profile of Lesson II.

Interpretation of the Two Lessons

The results from the analysis of the two inquiry lessons through the SPA-maps and the M-SCOPS revealed the following four points. First, though these two lessons had quite different characteristics, both hexagons showed a positive association between levels of instructional scaffolding and strand 4 practices. In the case of student-centered instruction (Lesson II), the students had opportunities for strand 4 practices such as discussing, arguing, and presenting their ideas to peers. In contrast, in the teacher-directed lesson (Lesson I) with lower instructional scaffolding, the students had fewer opportunities to work in groups and communicate with peers.

Second, the hexagon profiles for two lessons also show a positive association between levels of representational scaffolding and strand 2 practices. It should be noted that inquiry does not necessarily accompany the use of representational tools. However, I find it difficult to think of inquiry instruction without multiple representations embedded in every phase of the inquiry cycle. Previous research studies have revealed that technology or hands-on activities with mixed representations can enhance the effectiveness of inquiry (Hubbell & Kuhn, 2007). From the analysis of these two lessons, it was assumed that higher representational scaffolding would promote the level of strand 2 practices. However, analysis of more lessons is needed to see a clearer pattern within a complete unit of instruction.

Third, the levels of strand 3 practices in both lessons (Figures 3.5 and 3.8) were not high and revealed weaker connection (i.e., less cross-links between strands) with the other strands. The NRC (2007) pointed out that strand 3 practices, which indicate reflecting on scientific knowledge, are often a less robust yet critical element of scientific practice. The teacher may consider finding a way to connect strand 3 practices with other strands by directly stating the nature of science (i.e., a connection with strand 1 practices) or letting students discuss their own reflections (i.e., a connection with strand 4 practices).

Fourth and finally, the two lessons analyzed revealed few connections between different strands of scientific practices. Ideally, the four strands of scientific practices should be presented in meaningfully integrated ways for effective student learning. For example, high levels of strand 1 practices without strand 2 practices may indicate that a teacher enacted didactic instruction in which students would not be active operators of their own learning. High levels of strand 2 practices without strong foundations from strand 1 practices might indicate that the students were working on a hands-on activity with little opportunity for deep conceptual change. Though it may not be easy to design one lesson with all four strands at high levels, teachers would be able to design curriculum units so that students have opportunities to gradually experience and develop scientific practices over a longer period of time to assure inter-connections between the four proficiencies.

Implication

Researchers emphasize the need to study inquiry within the context of real classroom environments to have vivid descriptions of what teachers and students experience (Crawford, 2007; Krajcik et al., 1998). This paper introduces a methodology useful in analyzing science classrooms, especially those in which inquiry teaching and learning occur.

What we need in science classrooms is to teach “science as practice.” To make it possible, we need to know how and what types of practices are being taught in classrooms. For teachers, the SPA-map and the M-SCOPS can serve as tools to visualize classroom activities and distinguish particular activities that address scientific proficiency, which is an ultimate goal of recommended science instruction. By visualizing inquiry lessons in terms of scientific practices, the methodology introduced in this study may help teachers design and assess their own lessons with more focus on providing opportunities and scaffolding appropriately for students to grow in their scientific proficiency.

For researchers, analyzing inquiry lessons from the perspective of scientific practices may help them to discuss inquiry in a broader context. Johnston (2008) argued that inquiry needs to be perceived as a process to be learned rather than as a teaching tool. By focusing on the practices in which students engage within inquiry lessons, the method is expected to help researchers reveal more clearly why and when inquiry is effective (Michaels et al., 2008). However, research investigating a prolonged sequence of inquiry is required to see the clearer patterns and flow of scientific practices and their associations with instructional elements within the bigger picture of instruction.

CHAPTER IV

CHARACTERIZING A SERIES OF INQUIRY-BASED LESSONS USING AN INTEGRATED SYSTEM

After a long period of research on the feasibility and effectiveness of inquiry, the focus of research is moving to understand the dynamics of inquiry and to identify the necessary supports for inquiry in unpredictable classroom settings (Anderson, 2002). More specifically, research questions focus on the optimal learning environments for inquiry, scaffolding systems needed for diverse learners, and types of valued practices that inquiry can promote (Hmelo-Silver, Duncan, & Chinn 2007). Following the current trends of research, the purpose of this study is to analyze one science teacher's series of inquiry-based lessons using a system incorporating two instruments: the Scientific Practices Analysis (SPA)-map and the Mathematics and Science Classroom Observation Profile System (M-SCOPS). Ten representative lessons were chosen from a prolonged inquiry unit for analysis. I used the SPA-map to characterize the lessons in terms of students' involvement in four types of scientific practices and the M-SCOPS to analyze the instructional and representational scaffolding present in the lessons. Integration of these two instruments through hexagon profiles revealed the pattern and flow of the inquiry-based lessons across the unit. Findings imply that teachers need to incorporate all four types of scientific practices and a variety of lesson designs in instruction to achieve students' scientific proficiency.

Introduction

For the past several decades, inquiry has been associated with “a good way of teaching and learning science” (Anderson, 2002). However, a review of literature reveals that few teachers adopt inquiry approaches in their classrooms (Wells, 1995; U. S. Education, 1999). Diverse problems such as varying definitions of inquiry, conflicts with standardized tests, and insufficient time and resources were identified as challenges by teachers. Most of all, due to the lack of thorough guidelines, teachers are often left to create their own images of inquiry and construct their own way of implementing inquiry (Anderson, 2002).

In inquiry teaching, the teacher’s role is highly critical in guiding students through authentic science research experiences. Puntambekar, Stylianou, and Goldstein (2007) revealed that two teachers’ different implementations of inquiry on a same subject unit resulted in significant differences in students’ learning outcomes. Crawford (2007) also examined six intern teachers who were trained in the same professional development environment and revealed they showed different spectra of inquiry implementation – from traditional lectures to open inquiry – in their classrooms. Researchers argue that detailed descriptions of inquiry on how one should bring it and what it will look like in dynamic classrooms may help teachers in designing and implementing inquiry.

Accumulated research conducted in the daily events of inquiry occurring in regular classrooms would provide a more specific vision of “what if” for teachers when they face numerous barriers in inquiry teaching. This study attempts to reveal the dynamics of inquiry through one case of an inquiry unit conducted in one high school classroom. By showing how inquiry was conducted, how it influenced student learning in terms of scientific practices, and how it was scaffolded, the result would provides teachers with an example of what inquiry looks like in a naturalistic context.

Background

Diverse Forms of Inquiry Practices

Inquiry is a complex educational approach addressing students’ scientific thinking and learning as well as teachers’ pedagogical strategies. Because of its context-dependent nature, inquiry presents various forms in classrooms and they are called “inquiry spectrum” or “inquiry continua” (Germann, Haskins, & Auls, 1996; Windschitl, 2003). Bonnstetter (1988) argued that that school science curricula should encourage students to engage in an authentic inquiry, comparable to that of real scientists. Therefore, depending on the students’ levels of independence, Bonnestetter described inquiry as an evolutionary process ranging from traditional hands-on activities to independent student research. In the lowest level of inquiry, students participate in cook-book experiments following only a teacher’s directions. As the levels go up, students are encouraged to come up with their own research questions, experimental designs, and finally conduct independent research.

Chinn and Malhotra (2002) described various forms of inquiry that could occur in classrooms, according to students' cognitive processes. They contrasted the authentic inquiry with lower level of inquiry tasks such as included simple experiments, simple observations, and simple illustrations. These simple inquiry tasks are more prevalent in current classrooms, but they could not fully engage students in higher level cognitive processes as real scientists do. To promote authentic reasoning processes of students, Chinn and Malhotra proposed different strategies for inquiry tasks such as free hands-on inquiry, computer-simulated research, and evidence evaluation. They then discussed the strengths and limitations of each strategy.

Implementation of inquiry is still an issue for many teachers. Wells (1995) claimed that even simple forms of inquiry were not widely adopted in current classrooms. For open inquiry such as independent student research, researchers doubt if it is even feasible in classroom environments (Chinn & Malhotra, 2002, Friedrichsen, 2008, Settlage, 2007). Though the differences among diverse forms of inquiry seem deceptively minor on the surface, those different approaches could bring significant changes in students' practices (Windschitl, 2003). High-level inquiry would more effectively promote students' creativity and problem-solving skills. However, these approaches are challenging for both teachers and students due to designing difficulties and higher cognitive loads. To assist students with the complicated cognitive processes of inquiry, diverse types of scaffolding need to be distributed in instructions.

Scaffolding in Inquiry Practices

Kuhn and Dean (2008) defined scaffolding as a complex construct that provides cognitive, motivational and environmental situations for students to facilitate their problem solving processes. Generally, scaffolding can promote student learning in three ways: scientific process, social interaction, and conceptual models. First, scaffolding can improve student learning through scientific process. Kolodner et al. (2003) argued that scaffolding can help students by connecting science activities with actual reasoning process. Hmelo-Silver et al. (2007) also stated that scaffolding can lower students' cognitive loads by changing complicated tasks into more manageable and accessible forms. Second, scaffolding can promote student learning through their social interaction. Social interaction can enable students to perform a complex scientific task by allowing them to take parts and collaborate with each other. In doing so, students can engage in varied experience (National Research Council [NRC], 2007). Researchers argue that students can perform much better when they form "a community of learners" where students engage in collaborative research and learn from each other (Brown & Campione, 1994; Vygotsky, 1989). Third, instructional design embedded with conceptual models can help student to more clearly understand science concepts. For example, students can easily recognize the patterns of data through visualization tools such as graphical representation and computer simulation (NRC, 2007).

Moreover, these different ways of scaffolding usually work together and enhance one another. Quintana et al. (2004) listed various kinds of scaffolding and how they interact in a context of student learning. To promote students' understanding in sense-making processes, scaffolds such as representations, language, and artifacts can be used. Expert guidance can promote process management of students. Ongoing articulation and reflection, which is essential for the whole process of investigation, can be encouraged with journals or peer-group discussion (Quintana et al., 2004).

In terms of where scaffolds need to be placed, they can be distributed anywhere within the instructional materials, scientific process, social interaction and learning environments either by teachers or students (Puntambekar & Kolodner, 2005). Though scaffolding plays a critical role in inquiry teaching, more research is required to reveal how various types of scaffolding work and where they should be employed in complex inquiry learning environments (Kuhn & Dean, 2005).

Previous Research on Inquiry Practices

To investigate diverse forms of inquiry with embedded scaffolding, researchers have tried to develop effective methods of analyzing inquiry practices. Crawford (1999, 2000) conducted case studies to examine teachers' inquiry lessons and found factors that supported or constrained their teaching abilities. Her results revealed that teachers need to collaborate with students and model scientists to make inquiry lessons successful. Schneider, Krajcik, and Blumenfeld (2005) used a qualitative video analysis to compare four teachers' inquiry lessons with regard to their accuracy, completeness, opportunities, similarity, instructional support, sources, and appropriateness. Their findings indicated that teachers who focused on small-group work and used suggested instructional supports were more consistent with curriculum intentions. Using a mixed method research design, Kuhn and Dean (2008) investigated both regular and academically disadvantaged students to see how inquiry experiences improved conceptual knowledge. Kuhn and Dean noted that scaffolding, especially when introduced in the early phases of inquiry, significantly improved students' knowledge.

These studies suggested that a same curriculum can be applied in different forms and produce significant differences in the learning outcomes of students, depending on the teacher's use of inquiry. To clearly reveal how inquiry can be effectively incorporated in naturalistic classrooms where curriculum, policy, teachers and professional development opportunities all interact (NRC, 2007, p. 253), researchers have called for more research in local and diverse classroom environments (Keys & Bryan, 2001; Krajcik, Marx, Bass, Fredricks, & Soloway 1998), especially in high school levels where least amount of research had been reported (U.S. Department of Education, 1999; Weiss, Pasley, Smith, Banilower, & Heck, 2003).

Recently, the NRC (2007) proposed to use the inclusive term "scientific proficiency" when discussing effective science teaching. By focusing on the goals of science education, the NRC argued that we can avoid excessive debates on the meaning of inquiry. The NRC also states that scaffolding can promote student learning by structuring students' experiences with the elements of scientific practices. For example, scaffolding can make students perform complex scientific practices by providing them with divided or simplified aspects of the practice first. Also, scaffolding can make students understand and evaluate the scientific process in more explicit ways. However, more research is required to reveal the effective ways to distribute scaffolding in diverse instructional design to support students' engagement in scientific practices.

Research Questions

The guiding question that framed this study was, “What did one teacher’s implementation of an inquiry unit look like in a 9th grade biology class?” More specifically, this study provides a rich description of inquiry practice as well as its impact on student learning. Specific research questions are shown below.

1. In what kinds of scientific practices did the students participate in each lesson?
2. What levels of instructional and representational scaffolding were provided in each lesson?
3. How did the levels of students’ engagement in scientific practices and scaffolding change as the inquiry unit progressed?
4. How were the kinds of students’ engagement in scientific practices related to the levels of instructional and representational scaffolding provided by the teacher during the inquiry unit?

Context

The Information Technology in Science (ITS) Center for Teaching and Learning hosted a six year-professional development program in a large research-intensive university. The program engaged three cohorts of science and education graduate students as well as in-service science teachers. The purpose of the program was to improve science teaching and learning in secondary schools through the use of scientific inquiry and information technology (Stuessy & Metty, 2007).

Participants

The teacher under current study had 22 years of teaching experience at the time she participated in this study. The teacher had participated in the ITS Program for two years as a member of Cohort III. As a part of the program, the teacher worked in a scientist's laboratory every morning to conduct an authentic science research investigation while being mentored by scientists. In the afternoon, she attended various lectures and seminars to enrich her pedagogical knowledge base and receive support from science educators. Based on this two-fold experience, the teacher developed her very first inquiry instructional unit. She implemented it in her classroom in the following academic year. The scientist and the science educator had continued to provide mentoring to the teacher in diverse forms for the whole period of implementation. The scientist reviewed the teacher's implementation plan, supported required experimental facilities, and even visited the classroom to provide the students with expert modeling. The science educator had several times of meetings with the teacher to assist her with designing, implementing and reflecting on inquiry classes. In the second year of the ITS Program, she also entered into graduate school to pursue her master's degree in education.

The teacher-designed inquiry unit, which was a final product of the ITS Program, was implemented in a 9th grade biology class with 17 high school students (composed of 10 males and 7 females). There were two Hispanic students and four special education students in this population. The school in which the lessons occurred was located in a rural area of Texas. The school had a total of 276 students with 32% economically disadvantaged students and 13% ethnically diverse students.

The Inquiry Unit

The students had participated in a plant project titled “Cultivating Scientists through Plant Inquires” to develop scientific knowledge and skills in context of authentic science research. The students worked with *Arabidopsis* including both mutant and wild type plants to reveal the unknown traits of mutants when they were under different environmental factors. The teacher designed the inquiry unit following Etheredge and Rudnitsky’s guidelines (2003). These guidelines suggest seven phases in developing an inquiry unit including: (1) Considering students’ background, (2) Creating/describing the system of variables, (3) Designing an initial immersion experience, (4) Generating researchable questions, (5) Conducting the research, (6) Designing a consequential task, and (7) Assessing understanding. The teacher originally planned to implement the inquiry unit for three weeks. However, she revised the plan in response to student reaction and considered other factors such as availability of resources and facilities. As a result, the period for the inquiry unit was extended to 10 weeks, which was much longer than the teacher planned in the beginning of the implementation. The calendar for the whole inquiry unit is provided in Appendix D to present the flow of the lessons. As a summarized version, the timeline for major activities held in each week of the unit is shown in Table 4.1.

Table 4.1

Timeline of the Inquiry Unit as Implemented by the Teacher

Week	Learning goals of the week	Stages in developing an inquiry unit[1]
1	Introducing a model plant, Assigning project groups and roles within a group	Consider students' background/ Create and describe the system of variables
2	Designing experiment, Preparing materials, Setting up time-lapse camera for control and experimental plants	Design an initial immersion experience/ Generating researchable questions
3	Collecting data by taking still photos of plants and recording observation results, Receiving teacher instruction on genetics	Conduct the research
4	Continuing student research for data collection with teacher instruction on genetics	Conduct the research
5	Reflecting on collected data with teacher instructions on analysis techniques	Conduct the research
6	Introducing consequential task (final presentation) with teacher instruction on presentation skills	Design a consequential task
7	Conducting student research for data analysis in a computer lab	Conduct the research
8	Continuing student research for data analysis in a computer lab	Conduct the research
9	Preparation for final presentation in groups	Design a consequential task
10	Presenting findings in class	Assess understanding

Note. [1]Adopted from Etheredge & Rudnitsky (2003).

The teacher proposed three explicit learning goals in the design of the inquiry unit: (1) to learn about the nature of science by conducting authentic research, (2) to gain a deeper understanding of genetics concepts, and (3) to use several forms of technology to further both previous goals. The unit incorporated technology so that student projects involve two weeks of experimenting with digital cameras and more than three weeks of data analyses with computer software in the lab. The students used imaging technologies to analyze data and present their findings at the end of the unit. The teacher also adopted technology in a large portion of the instruction for organizing and presenting data. In this unit, the students developed their own researchable questions, designed experiments, and analyzed the collected data. Since there was teacher's guidance for parts of these processes, the lessons in this study were defined as "guided-inquiry instruction" according to Bonnstetter's categories (1998).

The Researcher

As an education graduate students I also participated in the ITS Program as a Cohort III. Through two years of experience at the ITS Program, I could obtain information about how teachers view and implement inquiry in their classrooms. During this period, I could come up with possible research questions, find a teacher that I wanted to collaborate for my study, and build a relationship with her for strong empathy. My role as a researcher took significant part in qualitative aspects of this study. As a human instrument, I observed the lessons and developed the system that I expected to best describe what happened in inquiry lessons. To avoid possible biases based on personal judgment, I adopted multiple sources of evidence with frequent peer debriefing and member check (Yin, 1994).

Methodology

Research Design

This study employed a two-phase mixed-methods design to reveal the dynamic nature of inquiry practices in the context of a naturalistic classroom environment (see Figure 4.1). In phase I, lessons were analyzed using the SPA-map and the M-SCOPS, respectively. In phase II, data from phase I were integrated to find associations between multiple elements, and describe the overall pattern of the inquiry unit.

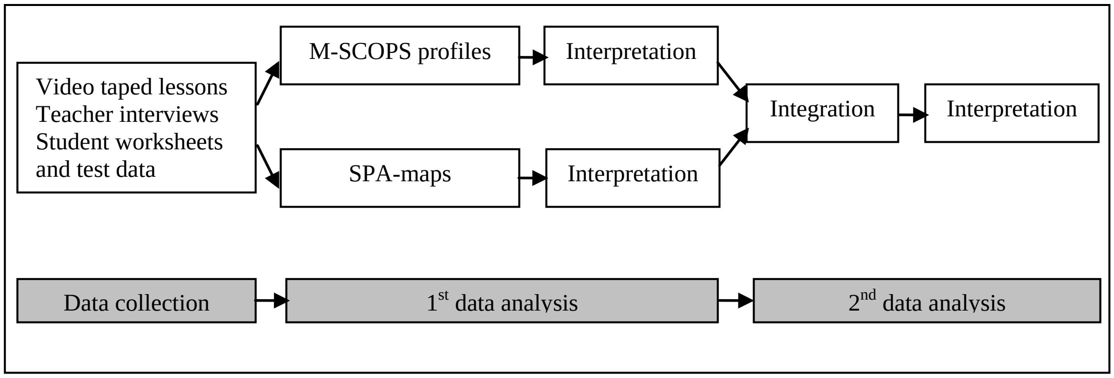


Figure 4.1. Mixed methods design for analyzing lessons during the inquiry unit.

Instruments

A. The Scientific Practices Analysis (SPA)-map. The SPA-map was developed to reveal both the types and levels of scientific practices in which students participated. The SPA-map consists of four major sections representing four strands of scientific practices (see Figure 4.2). The strands of scientific practices include: (1) understanding scientific explanations, (2) generating scientific evidence, (3) reflecting on scientific knowledge, and (4) participating productively in science. Based on the rubric (see Appendix A), classroom observers check the items matching the evidence of scientific practices during face-to-face classroom visits or while observing videotapes of classroom practice. To achieve a sufficient level of reliability with the SPA-map, four meetings were held with other educational researchers to refine the rubric and check the inter-rater reliability. The development process of the rubric is described in Chapter III. Once completed, the items on the rubric become concepts for the SPA-map. Cross-links within each section as well as the links between different sections are added by the observer after completing four sections.

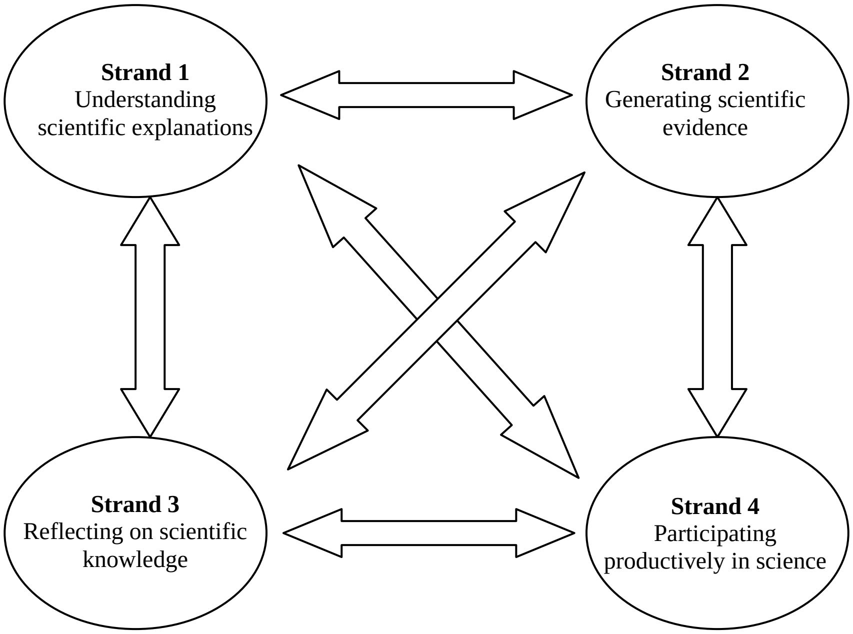


Figure 4.2. A review of the organization of the SPA-map.

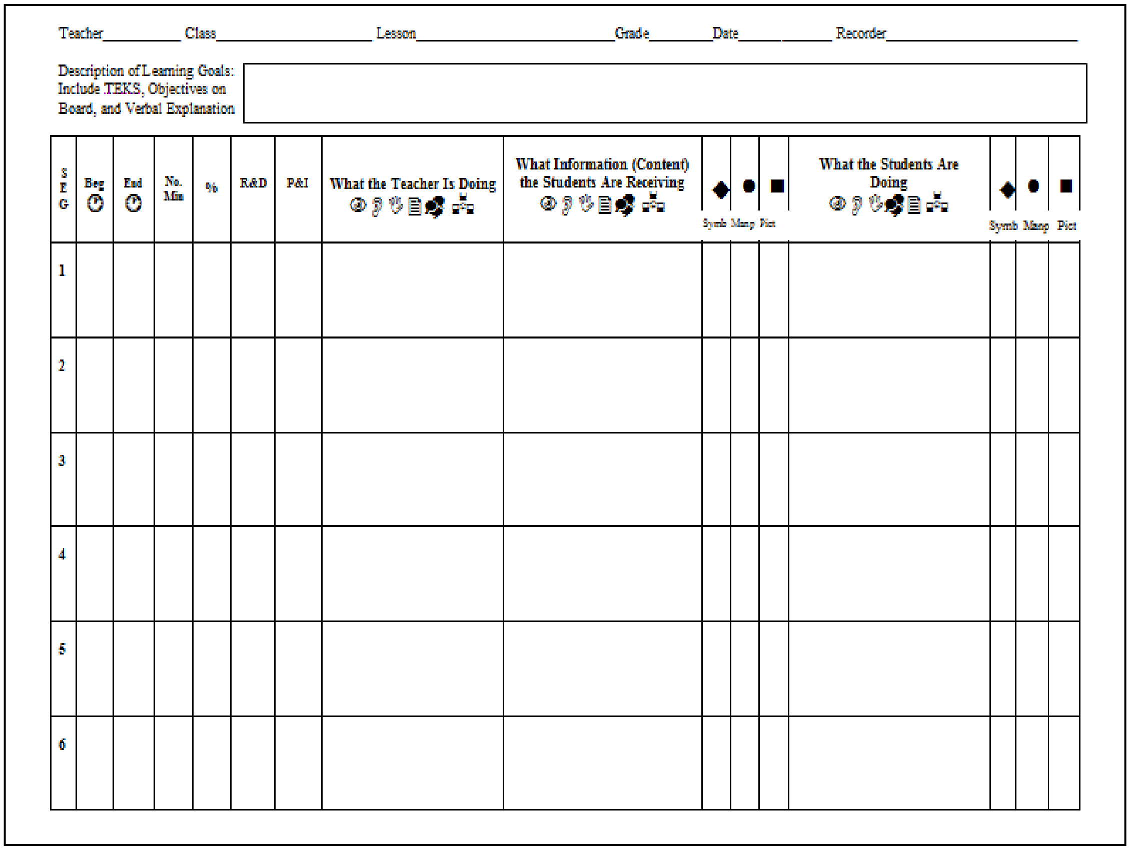
B. Quantification Rubric for the SPA-map. A rubric was created to quantify qualitative data from the SPA-map so that the data can be integrated with M-SCOPS for hexagon profiles. Based on the scheme shown in Chapter III (see Table 3. 3), the standard numbers that decide low, medium and high levels of strands were determined through inductive and iterative cross-comparison across the lessons. In case of the inquiry sequence shown in this dissertation, each strand map was assessed as low when the total score is less than 5 points. Medium level strand map had between 6 to 8 points. To be evaluated as high level, the strand map needed to have more than 8 points (see Table 4.2). However, application of the rubric to a series of lessons in different contexts will results in changes in these standard numbers due to the inductive process of scoring.

Table 4.2

The Rubric Applied to the Inquiry Sequence to Score Each Strand of the SPA-maps

Type of assessment	Criterion	Level	Score
Analytic	Number of concepts	Low (≤ 4 concepts)	1
		Medium (5 – 9 concepts)	2
		High (≥ 10 concepts)	3
	Level of hierarchy	Low (≤ 1 level of hierarchy)	1
		Medium (2 levels of hierarchy)	2
		High (≥ 3 levels of hierarchy)	3
Holistic	Structure	Linear	1
		Spoke	2
		Net	3
Overall Level	Low (3–5 scores), Medium (6–7 scores), or High (8–9 scores)		

C. The Mathematics and Science Classroom Observation Profile System (M-SCOPS). The M-SCOPS is an observation system designed to describe complex teaching and learning activities in a science classroom. Divided into three columns, the M-SCOPS scripts provide information about “what the teacher is doing,” “what information the students are receiving” and “what the students are doing” (Stuessy, 2002). The codes in the script provide information about the level of instructional strategy (i.e., instructional scaffolding) and the complexity of the information being received and operated by students (i.e., representational scaffolding). Then, these scripts with codes can be translated into profiles and tables to create visual representations of (1) content, (2) flow, (3) levels of instructional strategies, and (4) levels of representational scaffolding. Overall, the M-SCOPS scripts attempt to provide a complete view of interactivity among teachers and students with instructional materials and technologies (Stuessy, 2002). A template of the M-SCOPS script and coding sheets for levels of instructional and representational scaffolding are shown in Figure 4.3, Appendices B and C, respectively. To ensure the inter-rater reliability of the M-SCOPS coding process, two of the ten video-taped lessons were watched and coded with one other educational researcher. In M-SCOPS profiles, the lesson is usually composed of multiple segments embedded with different levels of instructional and representational scaffolding. To make the integration with the SPA-map, these levels in a lesson were averaged according to the number of segments and allocated time for each segment to obtain one representative level for each lesson.



Teacher__________ Class___________________ Lesson_________________________ Grade_________ Date_____ _____ Recorder_________________________

Description of Learning Goals: Include TEKS, Objectives on Board, and Verbal Explanation

SEG	Beg	End	No. Min	%	R&D	P&I	What the Teacher Is Doing	What Information (Content) the Students Are Receiving	◆ Symb	● Manp	■ Pict	What the Students Are Doing	◆ Symb	● Manp	■ Pict
1															
2															
3															
4															
5															
6															

Figure 4.3. A review of the scripting sheet for the M-SCOPS (Stuessy, 2002).

D. The Hexagon Profile for Integration. After the completion of analysis, results from both instruments, the SPA-map and the M-SCOPS, were integrated. These two instruments focused on different aspects of inquiry. However, when integrated, the analysis revealed associations among different aspects of inquiry which encompassed both instructional elements and strands of scientific practices. Levels of four strands of scientific practices from the SPA-map were placed on four points of a hexagon. The other two points of the hexagon were marked with scores describing the representative levels of instructional and representational scaffolding examined by the M-SCOPS. A diagram for hexagon profile is shown in Figure 4.4.

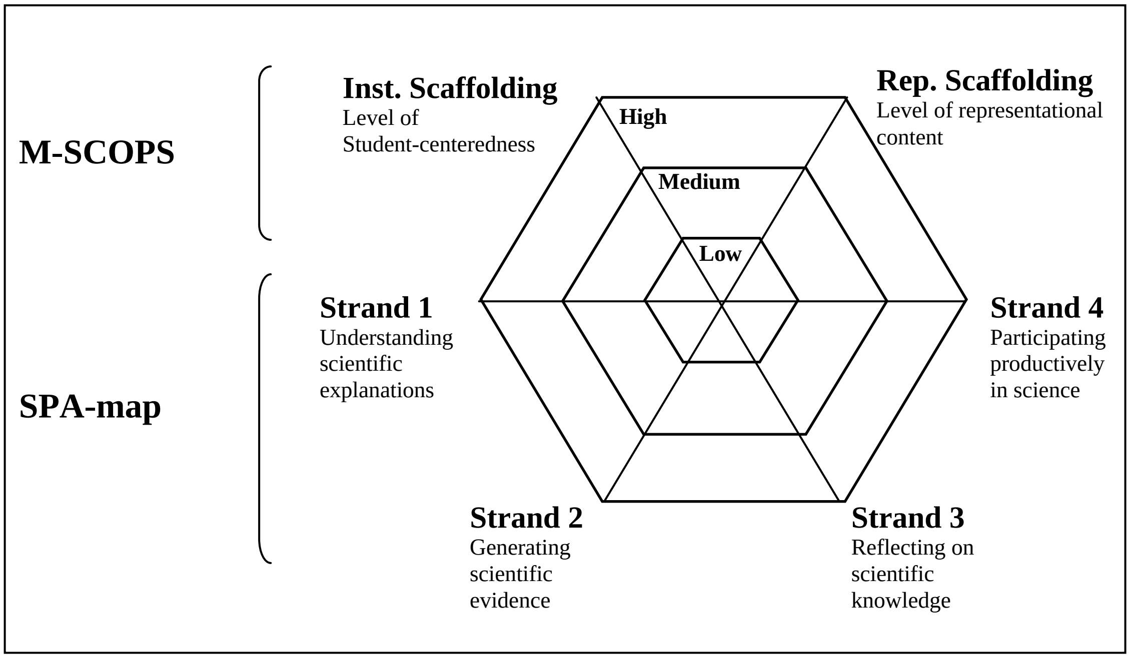


Figure 4.4. A review of the organization of the hexagon profile.

Data Collection

To ensure the validity of data collection procedures, multiple data sources from prolonged observations of classroom were used in this study (Lotter, Harwood, & Bonner, 2007). The data collected for this study came from three sources including the lessons, the teacher and the students. Teacher interviews and students data worked as supplementary materials for classroom observation data which was a primary source of this study. During the 10-week long inquiry unit, 26 visits were made by the classroom observer to attend the teacher’s inquiry lessons. As a non-participant observer, the researcher observed and videotaped 26 lessons. During observation, field notes were made. The field notes were mainly narratives describing classroom events in a chronological order with more emphasis on the aspects of classroom activities that were hardly captured in videotapes (e.g., student conversations in a group, attitudes of students, etc). Before observation, instructional materials such as lesson plans, worksheets, and hand-outs were collected.

Before beginning the inquiry unit, both the teacher and researcher had a formal meeting to discuss the implementation plan and schedule observation dates. During the implementation, before and after each lesson, the researcher had an informal interview with the teacher to obtain additional information. In these conversational interviews, the teacher shared her daily plan, concerns and expectation of student response. After completing the inquiry unit, a series of follow-up interviews were held to discuss and reflect on the lessons. In addition, to determine students' scientific practices in the lessons, student data such as formative and summative assessment results, presentation files, storyboards, and worksheets were collected. These artifacts were used for reference building the SPA-maps and the M-SCOPS profiles.

Data Analysis

Twenty-six lessons from the inquiry unit were observed and videotaped. Ten of these lessons were chosen for in-depth analysis. The lessons were chosen as being primarily representative of the different phases in the inquiry sequence (Etheredge & Rudnitsky, 2003). To validate the process of selection, the researcher reviewed all the videotaped lessons and identified the target lessons.

As the inquiry lesson sequence progressed, the researcher wrote brief vignettes to describe each lesson. Video-taped lessons were then transcribed for further analysis. The transcribed data went through two separate processes to construct SPA-maps and M-SCOPS profiles. First, the researcher developed a rubric (see Appendix A) for the purpose of identifying students' engagement in scientific practices occurring within each lesson. Then data from the rubric were converted into the SPA-map. Video transcripts were the primary data source at this point. However, field notes, teacher interviews and student data were also used to construct accurate and comprehensive maps. Each SPA-map revealed the process of students' development of scientific knowledge and process skills with more focus on four strands of scientific practices. To make relative comparisons, the SPA-maps for 10 lessons were scored based on the number of concepts, levels of hierarchy, and structure of the map (see Table 4.2).

As a second process, based on the field notes and transcript, the M-SCOPS scripts were recorded with codes. The scripts were turned into profiles for visual representation. The M-SCOPS interpreted each video-taped lesson in terms of content, flow, student-centeredness and cognitive complexity. The M-SCOPS profiles and the SPA map data obtained from the lessons were compared and contrasted. Finally, using the hexagon, data from both the SPA-map and the M-SCOPS were integrated and compared. As a result, accumulated hexagon profiles showed the patterns and flow of the levels of scientific practices and scaffolding.

Results

The teacher designed the inquiry unit following Etheredge and Rudnitsky’s guidelines (2003). However, the teacher occasionally revised her instructional plans to better support student learning. To reflect the unique and context-dependant inquiry activities, 10 lessons were selected from different phases of the unit comprising inquiry sequence. These lessons were labeled as Lesson 1 to Lesson 10 (see Table 4.3).

Table 4.3

Description of the Representative Lessons in the Inquiry Sequence

Lesson	Focus of the lesson
1	Conducting a model activity to understand a concept of models in scientific research
2	Getting familiar with *Arabidopsis* through immersion experiences, finding groups and roles, and considering the system of variables
3	Planning and designing experiments
4	Setting up the cameras and plants to begin experiments
5	Learning how to collect data and getting teacher instruction on basic genetics concepts
6	Collecting data and receiving teacher instructions on basic genetics concepts
7	Reviewing collected data, discussing analysis plan, and receiving teacher instruction on how to use diverse analysis tools
8	Conducting independent research in a computer lab for data analysis
9	Working in groups in a computer lab to prepare for final presentation
10	Presenting findings in front of the teacher, the peers and visitors

As shown in Table 4.3, the inquiry phases suggested by Etheredge and Rudnitsky did not linearly occur in this particular sequence. Rather, activities were connected in an iterative format where teacher-directed lessons occasionally occurred in the middle of student-directed research whenever the students faced new concepts or new tools to learn. In the following sections, the results of the study are presented in parallel with the order of the analysis procedure. First, narratives presenting the researcher's holistic impression on the lessons are described. Second, results from SPA-maps and M-SCOPS profiles are discussed. Finally, integrated results for the two tools are presented.

Holistic Reviews of Inquiry Sequence

A. Lesson 1 – A model activity. Lesson 1 was conducted in the first week of the inquiry unit. In the beginning of the unit, the students were heavily involved in exploring genetic concepts before starting their own plant projects. Therefore the lessons were relatively teacher-directed with more emphasis on delivering factual knowledge. The goal of Lesson 1 was to provide the students with opportunities to engage in a model activity to gain understanding of cell as a basic structure of life. Using a model of cell, the students developed knowledge of cell features and understand the role of models in studying organisms in nature.

The teacher began the lesson by asking students what the shoebox on each table would represent. She then explained what a model was and how cells and chromosomes could be represented as shoeboxes and paper strips within each box. After the teacher provided basic directions for the model activity, the students started to work on the shoebox to explore its content. Based on the information shown in paper strips, the students were asked to figure out what kinds of traits they would expect from their own shoebox cell. A worksheet with eight questions was used to guide student activity and discussions. The students also participated in whole group discussions with the teacher. This discussion allowed the students to talk about how models are similar or different from real organisms. The teacher also used this discussion as a chance to introduce the plant project to the students. The teacher closed the lesson by checking students' answers from the worksheet and asking a review question to ensure students' understanding. Overall the students seemed very excited about this new type of science lessons as it was their first time to engage in an inquiry project or any other long-term group projects.

B. Lesson 2 - Introduction for the plant project. The learning goal of this lesson was to understand the characteristics of *Arabidopsis.* The teacher began the lesson by telling students that their project groups and roles within each group were assigned. The decision for the students' roles in each group as a leader, a protocol person, a plant caring person, and a technology support person was made based on the aptitude survey students completed a week before. Then the students received the packet containing introductory information of *Arabidopsis* and general guidelines for the plant experiment. Also, the teacher provided direct instructions about experimental designs, including possible variables, the importance of control, and labeling tips. Based on this information, the students had a chance to discuss their ideas about plant experiments in groups.

C. Lesson 3 - Designing experiments. In this lesson, the students began their investigative procedures by asking questions, formulating hypotheses, and selecting appropriate equipments and technology. The teacher began the lesson by reviewing the content about mutation which was taught in the previous class. As the comparison between mutation and wild-type plants is the most critical task for the project, the teacher revisited the concepts several times to help students connect their projects with the underlying genetic concepts. Then, the teacher distributed the activity worksheet for planning the project. Mostly, the students worked in groups to plan their experiments. They worked with the planning sheet to describe their groups' general question, hypothesis, and required materials for the plant project. In previous lessons, students mainly "received" information about experimental design. However, in this lesson, students really "acted on" designing. More than 70% of this lesson was spent on student-directed activity. Students worked with objects such as plants and experimental tools for around 80% of the lesson duration. There was no evidence of closure.

D. Lesson 4 - Setting up experiments. "Today is the day!" The teacher raised her voice when she started the lesson. In a previous class, the students had a benchmark lesson on how to work with the digital camera through a demonstrative movie. In this lesson, the teacher gave a final review about how to set up plants in a proper position with appropriate labels. The teacher provided the checklists on the board for students to make sure the camera and plants were set up correctly. All groups had four plants in common (e.g., one wild type and one mutant under control condition and one mutant and one wild type under the experimental condition). The students employed different settings, depending on the variables they had chosen (e.g., amount of caffeine in the water, color of light, and intensity of heat). When all groups had their experiments set up and cameras were ready, the time lapse was started. Compared to previous weeks, the students now seemed very familiar with group works and all eager to participate in the project. More than half of the lesson period was spent on student-directed experiments, with some teacher assistance. After all students came back to their seats, the teacher closed the lesson by instructing them about the rules they had to keep in the lab. Also, this was the day students took a short quiz as a formative assessment.

E. Lesson 5 –Learning how to collect data. Once the students set up the time lapse with plants in diverse conditions, they continued to observe the plants every day for the following three weeks. After that time the cameras were removed from the lab. In this beginning phase, the teacher provided data record sheets with instructions on observing plants, taking still photos, and recording the information on the sheet. It took around 15 minutes of this lesson period for students to finish observing and recording (Starting from this lesson, this 15-minute observation period became a routine activity for students until they finish collecting data). Then, the teacher gave direct instructions about the basic concepts related to genetics (e.g., chromosomes, genes, alleles, homozygous, and heterozygous). Mostly, the students just listened to teacher's directions or answered simple questions. The iteration of lab work with instructions seemed appropriate; the students had to understand the genetics knowledge to make sense of their experiments and comply with district policies related to the TAKS test they would take at the end of the semester. How to facilitate different types of activities in one lesson is critical for inquiry teaching. However, in this lesson, the connection between "learning" and "doing" did not seem very clear. In closing the class, the teacher mentioned what students needed to do tomorrow and showed a brief plan for future genetics lessons in closing the class.

F. Lesson 6 – Data collection with teacher instruction on genetics. In this lesson, the expressed learning goal for students was to understand about genetic variations and traits observed in plants. Also, students were expected to understand the vocabulary (e.g., homozygous vs. heterozygous, dominant vs. recessive, phenotype vs. genotype). The students began the lesson by collecting data in the lab. As usual, students took pictures of plants and filled in their data record sheets. Then, the students received feedback from the teacher about their experimental progress. The rest of the lesson focused on teacher-directed instructions about genetics. The connection between student research and teacher-directed instructions appeared more closely linked than in previous lessons. The students occasionally brought up questions and ideas related to their own experiments in response to teacher instructions.

G. Lesson 7 – A benchmark lesson on analysis tools. The goal of this lesson was to provide a springboard for students so that they can work more productively in the computer lab for the following weeks (Etheredge & Rudnitsky, 2003). More specifically, the teacher wanted the students to acquire basic skills with computer software they will need for data analysis in future lessons.

The lesson started with the students taking a final look at their plants in the lab before finalizing data collection. Then, the students learned how to use the analysis tools of Excel and *Image J*. The teacher presented movies and pictures from this class to give the students opportunities to reflect on their own data. It was the first time the students watched the time-lapse movie of their own plants and they were obviously amazed. A long period (about 40% of the lesson period) of whole-group discussion followed to discuss what could be seen from the plants, what was wrong in their experimental settings, and what they needed to know more about using the analysis tools. At the end of the class, the students had an opportunity to review the content they had learned and to ask questions.

H. Lesson 8 - Working in a computer lab for data analysis. This lesson was conducted in the seventh week of the inquiry unit. At this time, the students were in the middle of data analysis. Therefore, most classes were held in the computer lab. Actually, more than 30% of the whole unit was conducted in the computer lab. These lessons showed similar instructional patterns. The students spent large amounts of time in independent research except the short introduction and closure provided by the teacher. Though all the groups and students showed different progress in their work, generally they started by using computational tools for analysis and then, finally, *PowerPoint.* The students kept searching information on the web while working on data analysis. The teacher's role at this stage was limited to be a helper and technical supporter, giving useful guidance and direction to anyone in need of help.

This lesson was not the exception. The learning goal of this lesson was that students understand how to organize, analyze, evaluate, make inferences and predict trends from data. In the beginning of the lesson, the teacher provided a short direction to the students about what they needed to do. Then, all the students moved to the computer lab located in a different building. In the lab, the students worked independently for data analysis under minimal supervision for the most of the lesson period.

I. Lesson 9 – Preparing a final presentation. Like other lessons conducted in the computer lab, the students worked individually on data analysis and interpretation under minimal supervision, after short directions before moving to the computer lab. In this lesson, more students seemed to finish working with *Image J* and starting to use *PowerPoint* for final presentation. Sometimes, several students got together in groups to discuss ideas and formats for final presentations. Individual students were in charge of different parts of the presentation depending on their assigned roles in the group. The "leader" was responsible for introductory materials as well as research questions and hypothesis. The "plant-supporter" was expected to provide background information on *Arabidopsis*. The "protocol person" was supposed to present the experimental procedure, while the "technology person" was responsible for technology procedures. Therefore all members of the group needed to collaborate and constantly communicate to make an organized final presentation. At the end of the lesson, the teacher gave a short closure to remind students to save their work and log off on the computer.

J. Lesson 10 – A final presentation. Once the students finished working with *PowerPoint,* they had a chance to practice their oral presentations in the classroom. The teacher revealed that most of the students had not had a chance to present in public. Therefore, the practice session was indispensable for students to learn appropriate norms for presenting and communicating in public. Then on the last day of the 10-week period, the students finally presented their project results in front of other classmates and some guests, including the school principal and counselor. Through this process, the students learned how to communicate their scientific arguments and make valid conclusions. The lesson began with the teacher’s short introduction. Then, she added directions for final presentation (e.g., the order of presentation, tips for presenter). Each group presented their slides following the similar format. Every student in the group introduced themselves first, then presented their assigned part. Each presentation took about 10 minutes. At the end of every presentation, there was a short question and answer session for other classmates and visitors. The students seemed very serious on this day maybe due to the existence of visitors or the feeling that they had actually accomplished a scientific research project. Student presentations were video-taped and evaluated by the teacher to be used as post-tests as well as the scores for storyboard and content tests.

The SPA-map Analysis

The SPA-maps for these 10 lessons are shown in Appendix E. Each strand of scientific practices was cross-compared in the inquiry sequence and then compared to other strands. First, strand 1, which represents students’ understanding of scientific explanation, showed high levels of practices in the beginning of the sequence (Lessons 1, 2, and 3), where students were working with researchable questions and experimental conditions. At this time, the teacher provided the students with background information on the plant project considering students’ prior knowledge. Lesson 6 also showed high-level strand 1 practices as the teacher wanted to directly communicate with the students to check their progress and understanding right before transitioning into the stage where the students conduct independent research. Lesson 10, where the students communicate their findings, also showed high-level strand 1 practices. When compared to other strands, the level of strand 1 was higher than strand 3 and 4 practices, especially in the beginning of the sequence where the teacher delivered direct instructions to teach students scientific concepts.

Overall, the levels of strand 2 practices, which represent students' generating scientific evidence, were very high compared to other strands. However, the context in which students were involved was quite different according to the stages. In the first half of the unit, the students participated in strand 2 practices mostly in a form of guided research under teacher supervision and direct instruction. However, in the latter part of the unit, the students could actively participate in strand 2 practices through independent project works.

Strand 3, which represents student's reflection on scientific knowledge, showed no particular pattern when compared across the 10 lessons. When compared to other strands, the level of strand 3 was very low except for Lessons 1, 6, and 10. In these lessons, the students had a chance to discuss on the nature of science and reflect on their own experiments.

Higher strand 4 practices, which represent students' productive participation in science, were shown in the latter part of the unit, in which students worked in the computer lab for data analysis and presentation in groups. The level of strand 4 practices was low, compared to strands 1 and 2. Though the students were continuously involved in group discussions and activities, most were teacher-guided or occurred only for a limited portion of the lesson period. However, in the last three lessons, the students mostly worked independently to analyze and present their data. Table 4.4 shows the patterns in levels of scientific practices for 10 lessons.

Table 4.4

Cross-comparison of 10 Lessons by the Level of Scientific Practices across All Four Strands

Scientific practice	Lesson									
	1	2	3	4	5	6	7	8	9	10
Strand 1	◉[1]	◉	◉	⊙	⊙	◉	○	⊙	⊙	◉
Strand 2	⊙	◉	◉	◉	⊙	⊙	◉	◉	◉	◉
Strand 3	⊙	○	○	○	○	⊙	○	○	○	⊙
Strand 4	○	⊙	⊙	○	○	○	○	◉	◉	◉

Note. [1]◉ = High; ⊙ = Medium; ○ = Low.

The M-SCOPS Analysis

The M-SCOPS profiles for 10 lessons were shown in Appendix F. To make the comparison across the lessons possible, each lesson composed of multiple segments with different levels transformed to one representative level of instructional scaffolding for the entire lesson. To obtain this number, multiple levels within a lesson were averaged according to the number of segments and length of time allocated for each segment. Once the numbers were obtained, they were compared relatively to categorize the lessons into high, medium, and low levels of instructional scaffolding (See Table 4.5).

Table 4.5

Levels of Student-centered Instructional Scaffolding across 10 Lessons

	Lesson									
	1	2	3	4	5	6	7	8	9	10
Average No.	1.42	1.72	2.59	2.16	2.11	2.18	1.67	4.46	4.37	1.3
Representative level[1]	○	○	⊙	⊙	⊙	⊙	○	●	●	○

Note. [1] Higher level represents more student-centered instructional strategies. [2]● = High; ⊙ = Medium; ○ = Low.

Overall, the level of student-centered instructional scaffolding showed an increase throughout the inquiry sequence except for Lessons 7 and 10. In the beginning, the teacher checked students’ prior knowledge and taught new scientific concepts which became students’ background knowledge for the project (Lessons 1 and 2). In the middle of the sequence, lectures and whole-group discussion alternated with student experiments in turns (Lessons 3 through 6). Finally, the students began to independently work on the project without any teacher guidance (Lessons 8 and 9). To make this transition possible, the teacher used Lesson 7 to review each group’s experimental progress and introduce new analysis tool the students might need, necessarily presenting more teacher-directed instructional strategy. In Lesson 10, the students presented their findings in front of others. As the class was conducted in presentation format, the level of instructional scaffolding was very low. However, the lesson was primarily directed by the students who presented in turns with minimal facilitation by the teacher.

Using the same system, the levels of representational scaffolding for symbols, pictures and objects were calculated. Only “acted on” aspects of representations were considered in the analysis, as the focus of analysis was on students' active participation. Table 4.6 shows the flow of levels in representational scaffolding across the 10 lessons.

Table 4.6

Levels of Representational Scaffolding for Symbols, Pictures and Objects across the 10 lessons

Acted on representation		Lesson									
		1	2	3	4	5	6	7	8	9	10
Symbols	No.	2.85	1.91	4.24	3.44	2.24	2.30	3.14	4.46	4.37	4.50
	Level	○[1]	○	◉	⊙	○	○	⊙	◉	◉	◉
Pictures	No.	1.94	0.37	0	0.48	0.71	1	0.63	3.46	3.37	0.64
	Level	◉	○	○	○	⊙	⊙	⊙	◉	◉	⊙
Objects	No.	1.71	0.30	2.26	2.9	1.00	1.2	0.24	3.46	3.37	0
	Level	⊙	○	◉	◉	⊙	⊙	○	◉	◉	○
Overall	Sum	6.50	2.59	6.50	6.82	3.95	4.50	0.90	11.38	11.11	5.14
	Level	⊙	○	⊙	⊙	○	⊙	○	◉	◉	⊙

Note. [1]◉ = High; ⊙ = Medium; ○ = Low.

Among the 10 lessons, four lessons (i.e., Lesson 3, 8, 9, and 10) showed high level of representational scaffolding for symbols where the students worked on high-order thinking such as designing experiments, comparing different systems, inferring from the data and presenting argumentations. Regarding pictures, three lessons showed high levels of representational scaffoldings when the students used diagrams to study cells (Lesson 1) and worked with movies and pictures to analyze data (Lessons 8 and 9).

The overall levels of representational scaffolding for objects were higher than pictures. The students worked on high levels of representational scaffolding through camera and plants (Lessons 3 and 4) in the beginning part while they worked on computers in the later part of the sequence (Lessons 8 and 9).

The Integration through Hexagon Profiles

Hexagon profiles show the patterns of scaffolding with four strands of scientific practices. Figure 4.5 shows hexagon profiles for 10 lessons. In Lesson 1, where the teacher gave a direct instruction (i.e., low-level instructional scaffolding), the students received a high level of scientific knowledge (i.e., high-level strand 1 practices). However, there were little collaborative activities among students (i.e., low-level strand 4 practices). In continuation from Lesson 1, Lesson 2 also presented low-level instructional scaffolding that accompanied high-level strand 1 practices.

As the students began to work on designing experiments in Lesson 3, levels of both instructional and representational scaffolding increased to a medium level, and the students could participate in high-level strand 1 and 2 practices. In Lesson 4, the students worked actively to set up experiments using project materials such as plants and cameras (i.e., medium-level representational scaffolding). As a result, the students could participate in high-level strand 2 practices.

In Lessons 5 and 6, the students were involved in two different types of instruction. The students received direct instructions on scientific concepts while they keep collecting data on a regular basis. In Lesson 5, however, no particular scaffolding or scientific practices showed high levels. According to Puntambekar et al. (2003), a teacher’s way of organizing different types of activities is a key for effective science teaching. The teacher might try to integrate different types of activities in Lesson 5 without allowing students to realize meaningful relationships between instruction and experiments. Lesson 6 showed a similar pattern with Lesson 5 but with overall increase in scaffolding and practices.

Lesson 7 was a transitional day when the students finished data collection and planned for future steps in the project. Lesosn 7 showed highest strand 2 practices with all low scaffolding and practices. High-level strand 2 practices without significant representational scaffodling implies that students were not actually involved in working on content but mostly received the information on how to work on content.

The students began to work on data analysis in Lessons 8 and 9. The lessons presented high levels of scaffolding as the students worked independently using computational tools. The students participated in high levels of strand 2 and 4 practices as they actively discussed with peers for data analysis. Instead of inflow of new knowledge, the students worked with previously obtained knowledge (i.e., medium-level strand 1 practices). The students showed no explicit discussion on the nature of science or changes in their view that caused low-level strand 3 practices.

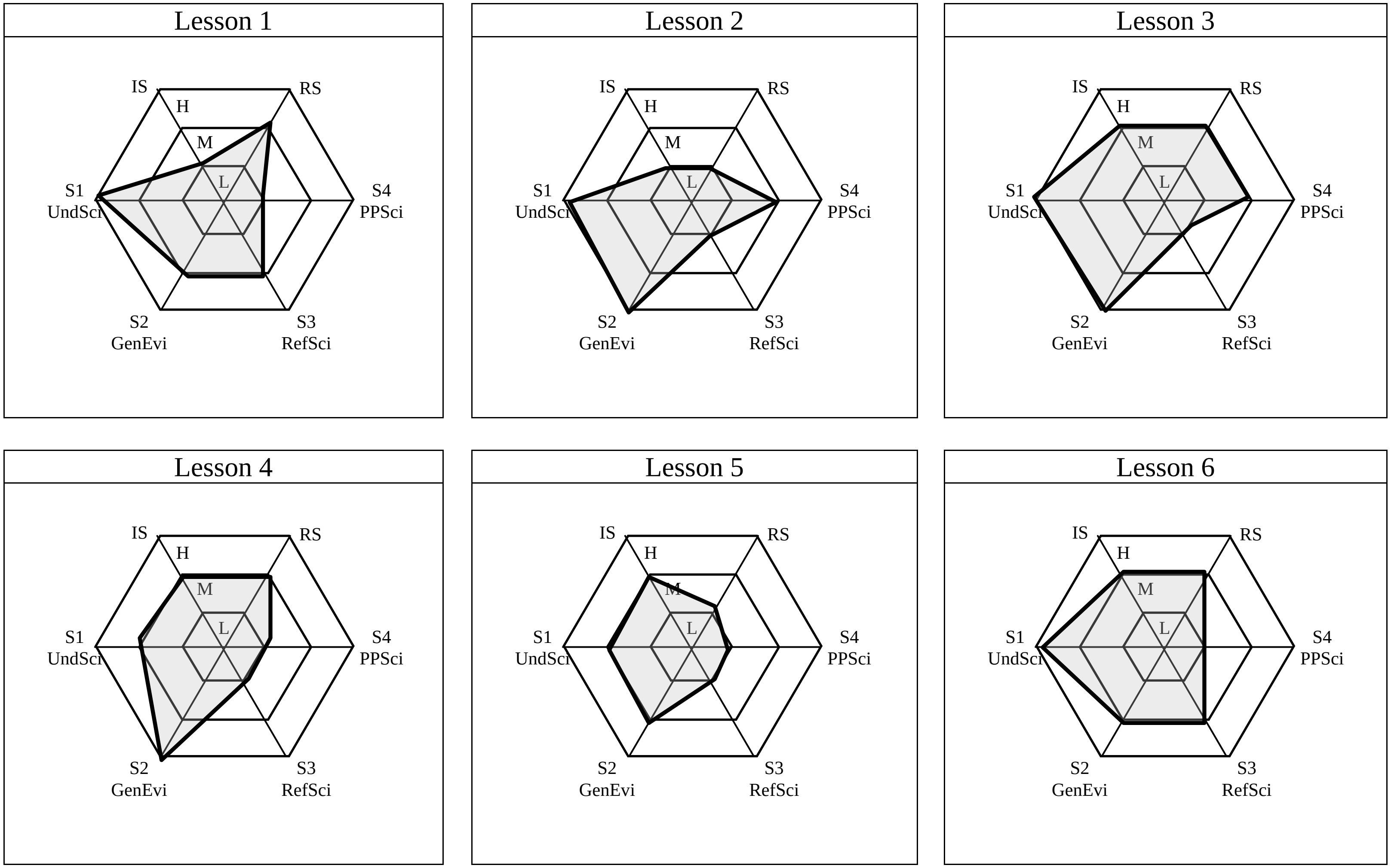


Figure 4.5. The hexagon profiles of 10 lessons. (IS: Instructional Scaffolding, RS: Representational Scaffolding, S1: Understanding Scientific Explanations, S2: Generating Scientific Evidence, S3: Reflecting on Scientific Knowledge, S4: Participating Productively in Science).

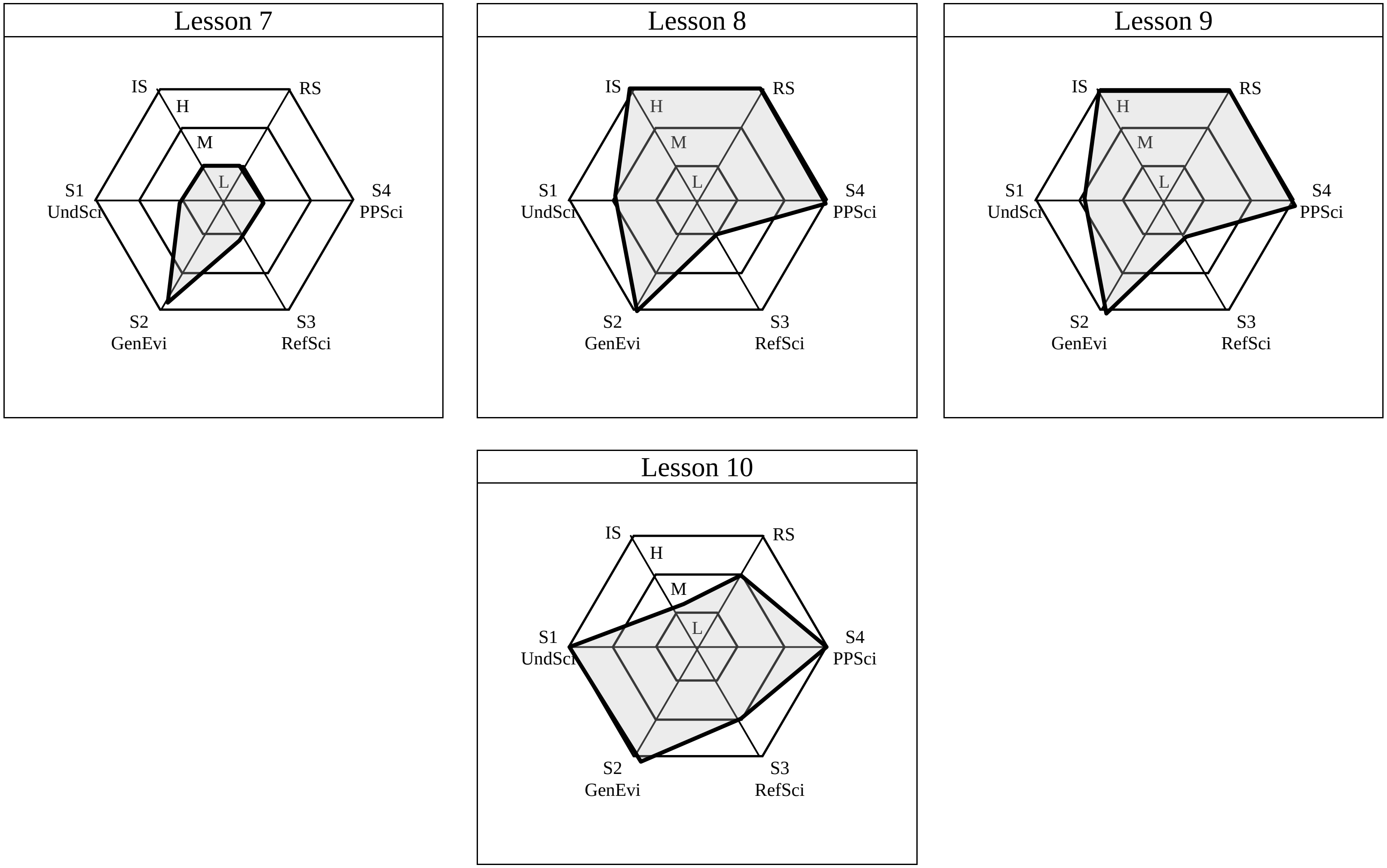


Figure 4.5. Continued.

In Lesson 10, as a consequential task, the students presented findings obtained from accumulated knowledge (i.e., high-level strand 1 practices) and completed experiments (i.e., high-level strand 2 practices). The students also discussed limitations and implication of their studies (i.e., medium-level strand 3 practices) and they presented in groups (i.e., high-level strand 4 practices). The students used a PowerPoint as a presentation tool. However the level of representational scaffolding was not so high, as the tool was mainly used for visualization only. The level of instructional scaffolding was also low as the most students were attending other groups' presentations.

Discussion

This study describes the dynamics of classroom enactment of inquiry in terms of teacher-provided scaffolding and students' engagement in scientific practices and. The findings revealed the kinds of scientific practices in which students participated, the levels of instructional and representational scaffolding in which student engaged, and patterns of interaction between practices and scaffolding during the entire inquiry sequence.

Levels of Scientific Practices

Completed SPA-maps revealed the types and interrelationships of scientific practices students had participated in each lesson. When cross-compared, accumulated maps showed the patterns of scientific practices over the whole inquiry sequence.

First, both strand 1 and 2 scientific practices occupy a large portion in the maps during the whole inquiry sequence. In some lessons, however, strand 2 showed a disconnect from strand 1 (e.g. high-level strand 1 with low-level strand 2). Ideally, strands 1 and 2 would occur together to enhance students' gains in scientific knowledge (NRC, 2007). Just as direct instruction without students' opportunities to "do" science can lead to students' development of inert knowledge, hands-on experience without much consideration for scientific knowledge would not effectively advance students' scientific proficiency.

Second, NRC (2007) stated that strand 3 practices, reflecting on scientific knowledge, is a less robust but emerging and compelling element of scientific practice. In this study, as expected, strand 3 showed the lowest occurrences in the SPA-maps regarding both the number of related concepts and the number of cross-links with other strands.

Finally, Michaels, Shouse, and Schweingruber (2008) pointed that strand 4, students' productive participation in science, is the least focused area of scientific practices and is often completely overlooked. In this particular inquiry unit, the teacher designed the unit with peer collaboration as one of her top priorities. Therefore, the students showed steady and increased development of scientific proficiency in strand 4.

Levels of Instructional and Representational Scaffolding

Among the diverse types of scaffolding that are available (Hmelo-Silver et al., 2007; Quintana et al., 2004), this study focused on levels of student-centered instructional and representational scaffolding. To be engaged in authentic inquiry, independent student research is indispensable. Lessons 8 and 9 showed highest levels of student-centeredness in students' engagement with complex forms of representation materials that involved the use of movies, pictures, and computer software along with articulation and reflection.

Teacher-directed instruction (i.e., Lessons 1 and 2) followed by teacher-guided student research (i.e., Lessons 3 through 7) made it possible for students to be equipped with sufficient knowledge and skills needed to conduct independent research (i.e., Lessons 8 and 9). As Hemlo-Silver et al. (2007) stated, even in inquiry modes of teaching, teacher-directed instruction is essential as it scaffolds student understanding. The problem is how to balance direct guidance with more open types of inquiry activities.

Association between Levels of Scientific Practices and Scaffolding

The hexagon profiles present all the elements discussed above – levels of scientific practices and scaffolding – in one dimension. I assumed that high levels of scaffolding provided in inquiry lessons would promote students' engagement in scientific practices by helping their cognitive processes. As both scaffolding and scientific practices are complex constructs involving so many different factors, it was hard to pinpoint a direct causal relationship between them. Besides, NRC (2007) pointed out that it may be difficult to separate the effect of scaffolding from the promoted practices, in that a practice itself can often work as an intervention. However, the introduction of the concept of cognitive load in analysis revealed some meaningful associations between practices and scaffolding.

A. Cognitive load and instructional scaffolding. Reeves (1996) argued that the cognitive load of a student-centered lesson is higher than the cognitive load of lessons in which teachers direct students' learning. When students direct their own learning, they are necessarily involved in complex cognitive processes such as decision-making, research design and meta-cognitive reflection. To logically explain the variability of instructional scaffolding observed in the inquiry sequence, I used the concept of cognitive complexity in analyzing inquiry lessons. In this study, I assumed that cognitive load of each lesson refers to the levels of high emphasis on the four strands of scientific practices. In this context, we would predict that an effective teacher would balance instruction in ways higher levels of cognitive load would yield lower levels of student-directed instructional scaffolding. To investigate if the teacher in this study adjusted her instructional scaffolding during the inquiry sequence to balance out the students' engagement in complex cognitive processes with scientific practices, I performed a simple analysis. Scores for cognitive load for each lesson were obtained based on a following equation: Cognitive load score = (No. of high level strands x 10) + (No. of medium level strands x 5) + (No. of low level strands). It is assumed that the students experience more complex cognitive process with higher-level scientific practices. To distribute the scores, the number of high level strands was weighted with 10 points, while the medium and low level strands were weighted with 5 and 1 point, respectively (See Table 4.7).

Table 4.7

Calculation of Cognitive Load Scores for 10 Lessons from the Inquiry Sequence with Their Levels of Instructional Scaffolding (IS)

Lesson	Level of IS	Level of scientific practices				Cognitive load score	Cognitive load level
		S1	S2	S3	S4		
1	L	H	M	M	L	21	M
2	L	H	H	L	M	26	H
3	M	H	H	L	M	26	H
4	M	M	H	L	L	17	M
5	M	M	M	L	L	12	L
6	M	H	M	M	L	21	M
7	L	L	H	L	L	13	L
8	H	M	H	L	H	26	H
9	H	M	H	L	H	26	H
10	L	H	H	M	H	35	H

Note. IS = Instructional scaffolding; S1 = Strand 1 scientific practice; S2 = Strand 2 scientific practices; S3 = Strand 3 scientific practices; S4 = Strand 4 scientific practices.

When the level of cognitive load was compared to the level of instructional scaffolding for each lesson, the analysis revealed the following correspondences (See Table 4.8). First, when the cognitive load was high, the instructional scaffolding was lower or equal to the level of cognitive load regardless of the stage in the inquiry sequence. Also, in case of the lessons with medium-level cognitive load, the instructional scaffolding was lower in one lesson and equal to the cognitive load rank in two lessons. In lessons with cognitive loads that were low, the instructional scaffolding was higher or equal to the cognitive load level.

Table 4.8

The Rank of Cognitive Load Level for 10 Lessons as Compared to the Level of Instructional Scaffolding (IS)

Cognitive load rank	Lesson	Level of IS	Rank to IS
H	2	L	>
	3	M	>
	8	H	=
	9	H	=
	10	L	>
M	1	L	>
	4	M	=
	6	M	=
L	5	M	<
	7	L	=

Note. IS = Instructional scaffolding.

Overall, instructional scaffolding levels appear to follow a logically consistent pattern to balance the cognitive load of the lessons. Lessons with medium and high cognitive loads were balanced with lower or equal levels of instructional scaffolding while lessons with low cognitive loads yielded equal or higher-level instructional scaffolding. That is, in most cases, the level of the cognitive load of the lesson predicted opposite or equal levels of instructional scaffolding. Therefore, the finding revealed that the teacher in this study did indeed adjust the instructional scaffolding of the lessons to balance the overall cognitive load of lesson emphasis and student-centeredness.

B. Cognitive load and representational scaffolding. In a similar fashion, I analyzed the lessons in terms of their cognitive load (i.e., levels of emphasis on the four strands of scientific practices) in association with their level of representational scaffolding. Representational scaffolding, as measured by the use of multiple representations to scaffold complex information, is usually placed in inquiry lessons to lower the cognitive loads imposed on students (Quintana et al., 2004). Therefore, one could assume that high cognitive loads level in the lesson would yield also high levels of representational scaffolding. That is, we could expect that an effective teacher would scaffold her instruction so that higher levels of cognitive load would follow with higher levels of representational scaffolding. In this way, scaffolding can “counteract” cognitive load of students by presenting more representations for their processes of difficult tasks. To investigate if the teacher in this study adjusted the representational scaffolding during the inquiry sequence following students engagement in scientific practices, the levels of cognitive load and representational scaffolding were compared (See Table 4.9).

Table 4.9

Calculation of Cognitive Load Scores for 10 Lessons from the Inquiry Sequence with Their Levels of Representational Scaffolding (RS)

Lesson	Level of RS	Level of scientific practices				Cognitive load score	Cognitive load level
		S1	S2	S3	S4		
1	M	H	M	M	L	21	M
2	L	H	H	L	M	26	H
3	M	H	H	L	M	26	H
4	M	M	H	L	L	17	M
5	L	M	M	L	L	12	L
6	M	H	M	M	L	21	M
7	L	L	H	L	L	13	L
8	H	M	H	L	H	26	H
9	H	M	H	L	H	26	H
10	M	H	H	M	H	35	H

Note. RS = Representational scaffolding; S1 = Strand 1 scientific practice; S2 = Strand 2 scientific practices; S3 = Strand 3 scientific practices; S4 = Strand 4 scientific practices.

The comparison between the level of cognitive loads and representational scaffolding revealed the following points (see Table 4.10). First, in lessons with high cognitive loads, levels of representational scaffolding were lower or equal in every case. In case of lessons with medium and low-level cognitive loads, the levels of representational scaffolding were equal to the cognitive load levels.

Table 4.10

The Rank of Cognitive Load Level for 10 Lessons as Compared to the Level of Representational Scaffolding (RS)

Cognitive load rank	Lesson	Level of RS	Rank to RS
H	2	L	>
	3	M	>
	8	H	=
	9	H	=
	10	M	>
M	1	M	=
	4	M	=
	6	M	=
L	5	L	=
	7	L	=

Note. RS = Representational scaffolding.

Except the lessons with high-level cognitive loads, the level of cognitive loads and representational scaffolding were equal in the inquiry sequence, indicating that some counteraction of cognitive load occurred with the adjustment in the level of representational scaffolding. However, in lessons with high-level cognitive loads, the levels of representational scaffolding were equal or lower, indicating a conflict with overall expectation.

Overall, representational scaffolding levels appear to follow a consistent pattern except a few lessons (i.e., Lessons 2, 3, and 10) by balancing the cognitive loads with equal levels of representational scaffolding. In addition to this exploratory analysis, more investigations are warranted to investigate the interactions of instructional scaffolding, representational scaffolding, and overall cognitive load of the lessons planned during the inquiry sequence. As such, this finding produces an implication for further investigation.

Implication

Researchers argue that teachers often have incomplete conceptions of inquiry that lead them to adopt only a part of inquiry or implement it in inconsistent ways (Kang, Orgill, & Crippen, 2008; Wallace & Kang, 2004; Yerrick, Parke, & Nugent, 1997). These incomplete conceptions may originate from a misunderstanding that inquiry is a mere teaching strategy, when inquiry is actually a goal to achieve through the teaching process (Johnston, 2008).

The NRC (2007) defined the learning goal of science education as students being able to develop scientific proficiency, which can be achieved only through the balanced incorporation of all four types of scientific practices. As shown in the analysis of the 10-week inquiry sequence, no lesson showed high levels of all scientific practices at the same time. However, within a prolonged inquiry sequence, the progression of inquiry was shown to move towards to an emphasis on all four strands of scientific practices. Considering inquiry as a teaching goal, teachers need to continuously reflect on and modify their teaching to optimize learning environments as their way of organizing and presenting activities can significantly impact student learning (Puntambekar et al., 2007).

Currently, no other study has incorporated the NRC (2007)’s conceptualization of scientific proficiency into an evaluation system for inquiry lessons. A primary purpose of this study was to characterize what inquiry lessons look like in naturalistic classroom environments in terms of students’ engagement in scientific practices. As the process of achieving proficiency in science involves all four strands, it is important to design learning environments that address diverse scientific practices. By characterizing inquiry lessons with a focus on scientific practices, this study may help teachers design and reflect on their lessons aligned with the goals of science education and their knowledge of pedagogy.

Analyzing inquiry lessons from the perspective of scientific practices may also provide researchers with a holistic view to elucidate complex relationships that exist between classroom activity and science information in a prolonged sequence of lessons. In addition, the knowledge gained by this study may reinforce the need for coordinated support for teachers. The NRC (2007) revealed that current teacher preparation and training courses do not reflect the strands of scientific proficiency but mainly focus only on strands 1 and 2. To achieve science proficiency, a coherent system among research, standards, teaching, and professional development is required (NRC, 2007).

CHAPTER V

CONCLUSIONS

Conclusions

This dissertation employs a methodology developed to analyze inquiry lessons in terms of students' engagement in scientific practices and teacher-provided scaffolding. The methodology integrates two instruments, the Scientific Practices Analysis (SPA)-map and the Mathematics and Science Classroom Observation Profile System (M-SCOPS) to provide a more complete understanding of inquiry in a naturalistic context of the classroom environment. With the integration of data obtained from both instruments, hexagon profiles were created to visually present patterns of multiple elements (i.e., diverse types of scaffolding and scientific practices) within and across the lessons. When applied to one science teacher's inquiry implementation, the analysis from this methodology revealed three points.

First, the levels of scaffolding embedded in each lesson were diverse depending on the emphasis of the lesson and the stage in the unit. When the teacher designed the unit, she expected her students to be engaged in an open inquiry. However, based on Bonnstetter (1998)'s categorization, the overall level of the inquiry shown in the unit was close to the form of "guided inquiry" in a way that the teacher provided a big guiding question and materials for student research. When analyzing from the perspective of individual lessons, the instructional strategies adopted in each lesson varied from teacher-directed instruction to students' independent research, according to the stages in the inquiry unit.

In the follow-up interview, the teacher mentioned how hard it was for her to keep balance between teacher direction and student autonomy. To guide students to independently manage their own projects and actively communicate with the peers in a form of "open-inquiry" in the latter part of the unit, she spent more time than originally planned on direct instruction (both for content and process skills) in the beginning of the unit. Considering the multi-faceted nature of inquiry, having diverse forms of lessons in one unit is somewhat expected. However, the more important thing is whether the teacher and students were aware of the connections between the different lessons. Puntambekar, Stylianou, and Goldstein (2007) pointed out that teachers' ways of organizing and presenting activities in a unit is important for inquiry. When considering inquiry as a progression where multiple elements were interacting together over a prolonged sequence, how to organize and connect each lesson in a convergent theme is another important factor that teachers need to consider when designing lessons.

Second, Hmelo-Silver, Duncan and Chinn (2007) argued that scaffolding is one of the key factors that impact student achievement in inquiry-based lessons. I expected high levels of scaffolding would improve students' levels of participation in scientific practices. However, the findings from this study revealed that high-level scaffolding was not necessarily associated with high-level scientific practices. For example, high levels of scientific practices was associated lower or equal levels of instructional scaffolding to "balance" students' cognitive loads. Similarly, the level of representational scaffolding had associations with scientific practices in a way to “counteract” the complexity of presented content.

Scaffolding in terms of the use of representational materials is considered to be essential in inquiry-based lessons in order to support students’ deep understanding of scientific concepts. However, as argued by Schneider et al. (2005), how to create instruction using those materials is an even more critical concern. The findings imply that teachers need to focus on providing scaffolding in alignment with learning goals that are strands of scientific practices. Both scaffolding and scientific practices are complex constructs involving multiple sub-concepts. Therefore, to reveal entangled relationships between teacher-provided scaffolding and students’ scientific practices, further studies focusing on particular associations between a particular type of scaffolding with a specific strand of scientific practices will be needed.

Third, inquiry implementation requires teachers to change their beliefs. Minstrell and van Zee (2000) argued that some teachers view inquiry as a simple teaching strategy that involves hands-on activities. However, this concept of inquiry may frustrate teachers when inquiry does not show immediate outcomes. Actually, conducting inquiry requires significant time, effort, and most of all, changes in their core beliefs (Wallace & Kang, 2004). Teacher reflection is considered as a means to enhance teacher knowledge and beliefs, therefore leading to improved practices (Hoffman-Kipp, Artiles, & Lopez-Torres, 2003). I conducted a series of follow-up interviews with the teacher to make the reflection process explicit. The following section presents the reflections of the teacher and me as an instructor and as a researcher, respectively.

Reflections

On reflection of the course for completing the dissertation, I realized that inquiry was not only the subject of the study but also the process, in which the teacher and I were involved. As mentioned above, the teacher needed to go through the process of implementation, revision, and reflection while the researcher experienced the similar explorative process of development, revision, and reflection.

The Teacher's Process of Inquiry

With so much teaching experience and participation in diverse professional development programs, the teacher was surely eligible to be considered as a veteran teacher. However, in one of the interviews, the teacher mentioned that the implementation introduced in this study was her first trial in explicit "inquiry teaching." In this sense, the teacher who had participated in this study can be considered not only an experienced instructor but also an inquiry learner.

Crawford (2000) argued that teachers need to perform versatile roles in inquiry lessons where highly scaffolded learning occurs. Being a learner oneself is one of the critical roles imposed on teachers as identified by Crawford. The teacher in this study also went through the process of learning new concepts, new technology and new styles of teaching as her students showed curiosity and excitement for a new kind of project. Also, because of this noviceship, the teacher could willingly go back to the instructional plan and revise it whenever needed. In the process of the implementation, the teacher faced multiple challenges including the lack of technology support, conflict with standardized tests, and difficulties in classroom management. However, the teacher managed to revise the implementation to better support student learning. As a result of this reflective and adaptive curriculum, the enacted inquiry unit presented a much different form from the teacher’s original instructional plan regarding the period, content, and the use of technology. In a follow up interview, the teacher stated that these unexpected changes provided her with meaningful implications for future plans for inquiry teaching.

The Researcher’s Process of Inquiry

As a researcher, I also went through the process of “inquiring into inquiry teaching” (Minstrell & van Zee, 2000) by exploring the teacher’s inquiry unit and figuring out possible ways to present what I found. For this purpose, I used multiple data sources including video-taped lessons, transcripts, M-SCOPS profiles, scientific practices rubrics, SPA-maps, lesson plans, teacher interviews, student artifacts and assessment data. Following Yin (1994)’s guidelines, all these data were converged to understand the overall case, rather than treating each data source as separate and independent set (Figure 5.1).

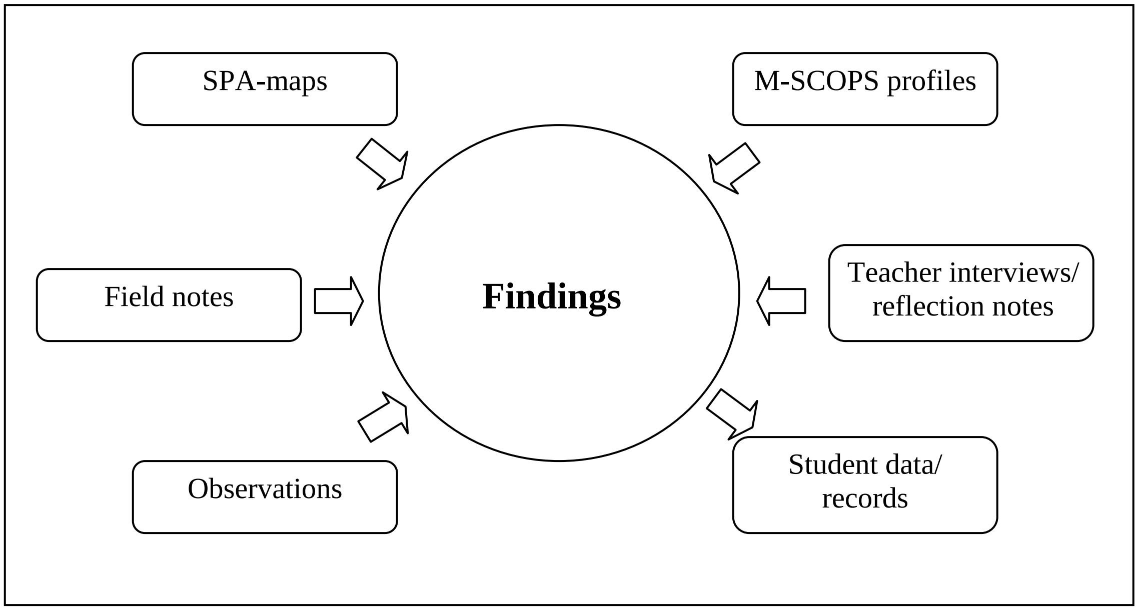


Figure 5.1. Convergence of evidence from multiple sources (adapted from Yin, 1994, p. 93).

By treating multiple data in a relational point, I could easily control the grain size of the data. Depending on the perspective of analysis, I could cluster or divide the data set (i.e., overall scientific practices vs. each strand of scientific practices). Also, because the analysis was conducted not by a linear format but in a reiterative format, I could conveniently revisit the data and refine my interpretation. In this way, even raw data could be easily retrieved for independent inspection, which resulted in improving the reliability of the qualitative analysis process (Baxter & Jack, 2008).

Overall, the curiosity I had for one teacher’s inquiry-based lessons led me to develop the methodology through numerous revisions, allowed me to explore the classroom dynamics and finally, to connect these findings with my prior knowledge which elicited more research questions.

Limitations

Several limitations were associated with this study. First, the study focused on exploring one teacher’s classroom in a particular context. Therefore the findings from this case would not be able to be generalized over the other cases in different educational settings. To address this issue, the study was conducted for a prolonged period using multiple data sources to provide more depth, in addition to the accumulated body of previous research. Also, due to the qualitative aspects of the SPA-map and M-SCOPS, the analysis may involve the researcher’s personal beliefs and judgments. To increase the reliability of the process, the results were shared with other educational researchers and the teacher as a process of member-check.

Recommendations

At the time that this teacher was observed, she was not aware of the distinctions of scientific proficiency brought about by the National Research Council (NRC) in 2007. Overall, findings imply that an experienced science teacher who “teaches by inquiry” without this knowledge will create a learning environment that addresses some, but not all, of the scientific proficiencies in her inquiry-based lessons. When designing instruction, teachers need to have clear understanding of these strands of scientific practices as if they focus on subject matters to promote students’ scientific proficiency.

The methodology introduced in this dissertation needs to be applied with more diverse modes of teaching such as modified version of inquiry instruction. The application of the methodology in different contexts across the subjects, students and locations will more clearly reveal how teachers need to design scaffolding and what kinds of impact inquiry can make on students’ achievement in scientific proficiency. Also, beyond confirming students’ engagement in scientific practices, assessment system for student performance regarding their level of scientific proficiency needs to be developed.

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APPENDIX A

A RUBRIC FOR THE SPA-MAP

A Rubric for the Strands of Scientific Practices Class _______ Recorder ______________

	Description	Check	Practice
Strand 1 **Understanding scientific explanations**	Students learn scientific facts, concepts, principles, laws, theories, and models.		
	Students connect their prior knowledge with new scientific knowledge listed above.		
	Students use scientific knowledge listed above to explain natural phenomena.		
	Students use scientific knowledge listed above to predict natural phenomena.		

	Description	Check	Practice
Strand 2 **Generating scientific evidence**	Students ask research questions.		
	Students formulate hypotheses.		
	Students use skills to build and refine models and explanations.		
	Students design experiments (e.g. Students develop measures to test their hypotheses).		
	Students conduct investigations (e.g. Students observe and record data).		
	Students analyze their own or others' data.		
	Students evaluate their own or others' data (e.g. Students recognize whether they have sufficient evidence to draw a conclusion. Students determine what kind of additional data they need.)		
	Students learn or use the conceptual and computational tools to evaluate knowledge claims.		
	Students construct and defend arguments using data.		
	Students interpret their own or others' data.		
	Students use results from data analysis to refine arguments, models and theories.		
	Students visually represent what they learned and know.		

	Description	Check	Practice
Strand 3 Reflecting on scientific knowledge	Students recognize that predictions or explanations can be revised based on new data.		
	Students discuss alternative perspectives.		
	Students learn the history of scientific ideas.		
	Students learn models of the nature and how they can be used to construct scientific knowledge.		
	Students engaged in metaconceptual thinking or activities.		
	Students discuss how their current ideas have changed from past ideas.		
	Students employ analogies and metaphors		
	Students discuss the implications of their study.		
	Students discuss the limitations of their study.		
	Students discuss future investigations.		

	Description	Check	Practice
Strand 4 Participating productively in science	Students work in a small group to discuss their ideas or conduct research.		
	Students discuss their ideas in a whole group discussion led by a teacher.		
	Students argue about their ideas in groups to persuade peers.		
	Students recognize that understanding science requires constant effort.		
	Students take different parts in science investigation to benefit their peers.		
	Students show willingness to participate in science.		
	Students understand the appropriate norms for presenting scientific arguments and evidence (e.g. preparing for presentation).		

Note. In many cases, same activity can involve more than two different strands. Teachers' directions for students to be involved in these activities can also be considered as valid evidences for strands.

APPENDIX B

INSTRUCTIONAL SCAFFOLDING STRATEGIES (STUESSY, 2002)

R&D[1]	P&I[2]	Description	Examples
5	1	Individual students are directed to listen as the teacher or another student talks to entire group; students are directed to read or do seat work; assimilation and/or accommodation occur passively with little or no interaction	Direct instruction models, including those where the teacher asks rhetorical questions requiring yes-no or one-word answers; lecture, silent reading, independent practice, seat work
4	2	Individual students respond orally or in writing to questions asked by the teacher, in the whole group; responses are shared	Teacher-led recitation; question and answer; discussion led and directed by the teacher
3	3	Students in pairs or small groups work together under the teacher's supervision – with discussion; all groups do basically the same task	Student discussion in groups; may include task completion, verification laboratories, cooperative learning models
2	4	Groups and/or individual students work on different tasks; while all are participating, tasks may be very varied; but they are coordinated, as when one group presents and others ask questions or evaluate results; loosely supervised by teacher with teacher intervention	Individuals or groups present information while the rest of the class responds; intervals of work are often interrupted by the teacher to coordinate activities or encourage sharing
1	5	Students in pairs or small groups discuss, design, and/or formulate their own plans for working in class on a specified task; minimal supervision for longer periods of time; little coordination by the teacher	Open-ended laboratory or project work, invited by the teacher but definitely where students are less restricted
0	6	Individuals or groups carry out their own work independently; minimal supervision	Individualized laboratory or project work

Note. [1]R&D refers to Reception and Direction. [2]P&I refers to Performance and Initiative.

APPENDIX C

COMPLEXITY LEVELS OF REPRESENTATIONAL SCAFFOLDING

(STUESSY, 2002)

Action	Level	Receiving	Acting
Attend	1	External or superficial features, attributes, directions to perform a level 1 action	Listen to, attend to, observe, watch, read, view
Replicate	2	Pictures, models, examples, identifications, descriptions, explanations, clarifications, calculations, duplications, measurements, reproductions, demonstrations, algorithms, level 2 directions	Recall, remember, list, tell, label, collect, examine, manipulate, name, tabulate, identify, give examples, describe, explain, clarify, calculate, document
Rearrange	3	Comparisons, groupings, sequences, patterns, rearrangements, balancing, classifications, disassembled parts of a whole; processes of putting parts of a whole together, level 3 directions	Compare, group, put in order, rearrange, identify a pattern, paraphrase, balance, classify, identify parts of a whole, assemble parts to make a whole, disassemble parts of a whole
Transform	4	Different representations of the same system; arrangements of complex parts into a whole system, transformations, changes, level 4 directions	Represent symbolically or pictorially, experiment, interpret, contrast, apply, modify, make choices, distinguish, differentiate, transform, change, arrange complex parts into a system
Connect	5	Alternative points of view, connections, relationships, justifications, inferences, predictions, plans, hypotheses, analogies, systems, models, solutions to complex problems, level 5 directions	Connect, associate, extend, illustrate, explain relationships in a system, use and/or connect representations to develop explanations, explain different points of view, infer, predict, plan, generate hypotheses, use analogies, analyze, generate solutions to complex problems already conceived, rank with justification
Generate	6	Analyses, evaluations, summaries, conclusions, abstract models and representations, problem scenarios, level 6 directions	Justify, defend, support one's own point of view, develop or test one's own hypotheses or conceptual models, define relationships in new systems, generalize, recommend, evaluate, assess, conclude, design, generate a problem, solve a problem of one's own generation

APPENDIX D

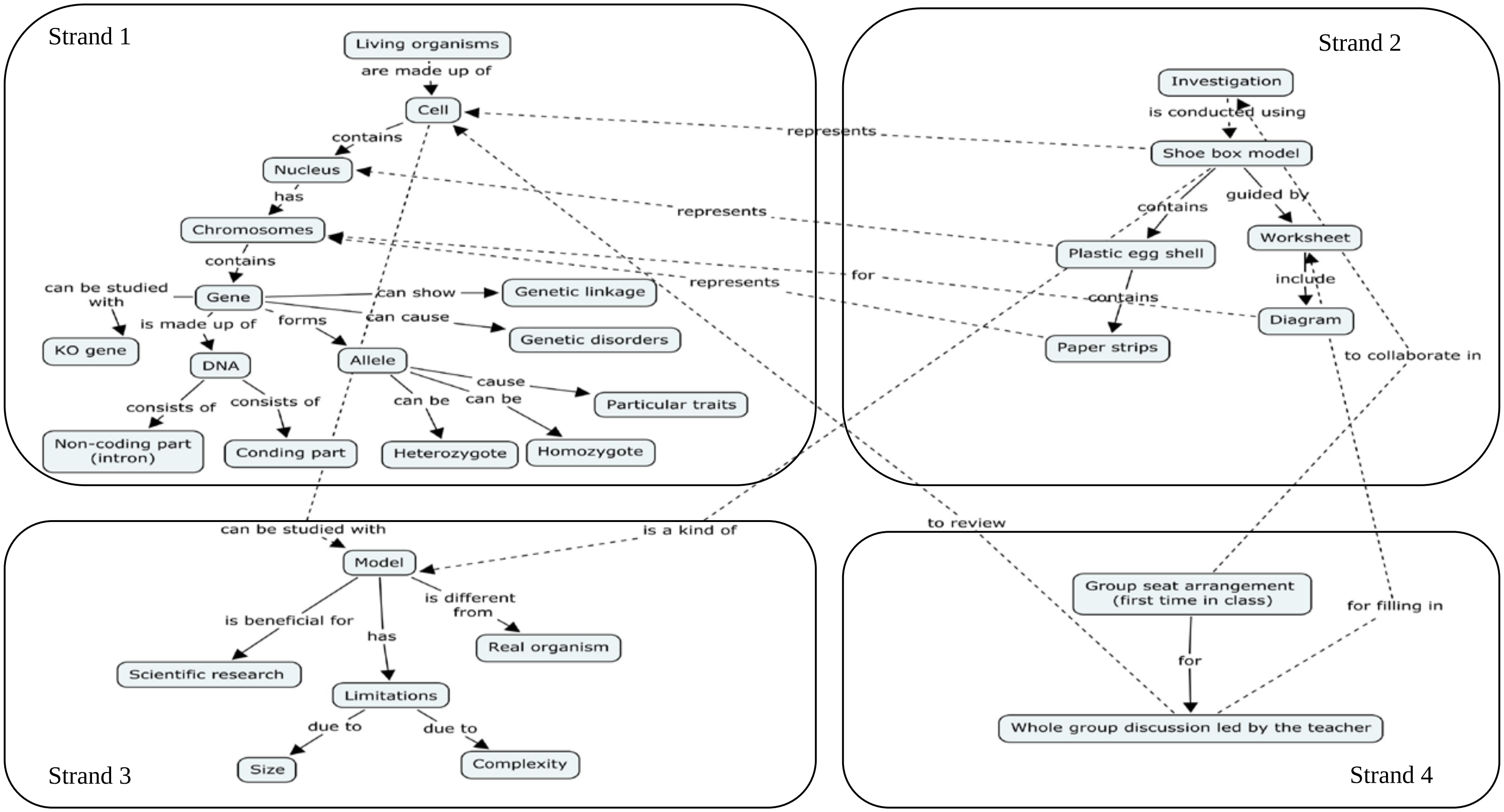
THE CALENDAR FOR THE INQUIRY UNIT

Week	Mon	Tue	Wed	Thu	Fri
1	2/19 Teacher preparation for plant project	2/20 Teacher preparation for plant project	2/21* - Lesson 1 Introduction of genetic concepts & model activity	2/22* - Lesson 2 Assignment of project groups & Introduction for *Arabidopsis*	2/23 Brainstorming ideas for experiment
2	2/26* - Lesson 3 Designing experiment	2/27 Benchmark lesson on the use of camera for data collection	2/28 Review of genetic concepts & preparation of materials for experiment	3/1 Final check on experimental conditions with teacher demonstration	3/2* - Lesson 4 Setting up time-lapse movie & quiz as a summative assessment
3	3/5* - Lesson 5 A review for quiz & instruction on genetic concepts	3/6 Continued instruction on genetic concepts	3/7 Continued instruction on genetic concepts	3/8 Fly cross activity I	3/9 Fly cross activity II
Spring break	3/12 Spring break (with continued time-lapse movie)	3/13 Spring break	3/14 Spring break	3/15 Spring break	3/16 Spring break
4	3/19* - Lesson 6 Discussion on each groups' progress	3/20 Removal of camera & final still photos	3/21 Discussion on future steps of plant project	3/22 Teacher-absent UIL	3/23 Watching movie about plants (e.g., eyewitness)
5	3/26* - Lesson 7 Instruction on *Image J* as an analysis tool	3/27 Continued data collection	3/28 Continued data collection	3/29 Teacher-absent NSTA conference	3/30 Teacher-absent NSTA conference
6	4/2 Brainstorming ideas for data analysis	4/3 Benchmark lesson on the use of *PowerPoint* for presenting data	4/4 Continued instruction on final presentation	4/5 Demonstration for power point & dividing parts within a group	4/6 Construction of a DNA structure
7	4/9 Introduction of *Excel* as an analysis tool	4/10 Benchmark lesson on data analysis	4/11 Benchmark lesson on data analysis	4/12* - Lesson 8 Working in a computer lab for data analysis	4/13 Computer lab
8	4/16 Computer lab	4/17 Computer lab	4/18* - Lesson 9 Working on final presentation in a computer lab	4/19 Computer lab	4/20 Computer lab
9	4/23 Computer lab	4/24 Computer lab	4/25 Computer lab	4/26 Computer lab	4/27 Computer lab
10	4/30 A final check on students' presentation files	5/1 Practice session for final presentation	5/2* - Lesson 10 Final presentation	5/3	5/4

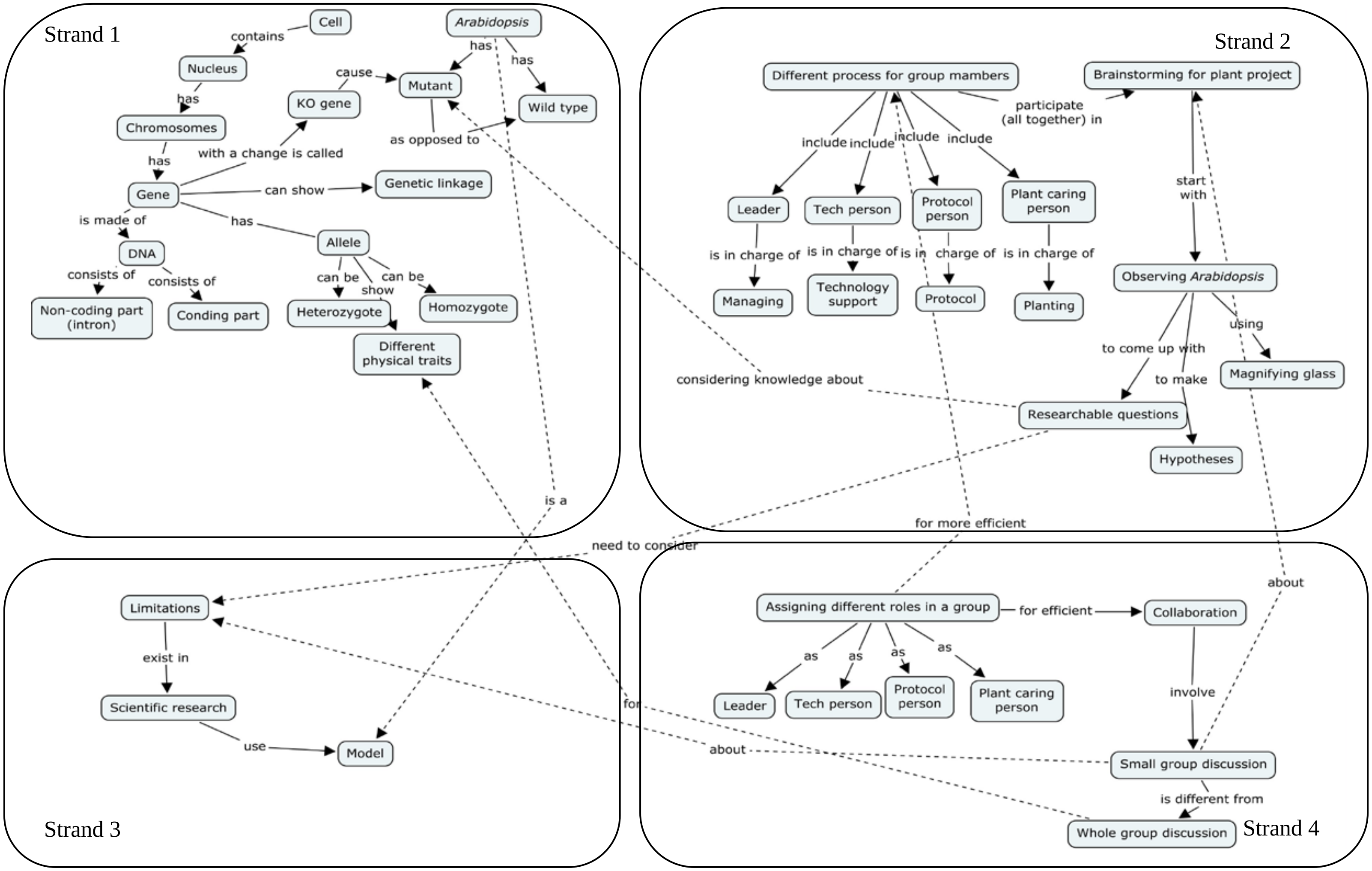
Note. *Marked lessons primarily represent the stages of inquiry and they were analyzed in-depth to present the inquiry sequence.

APPENDIX E

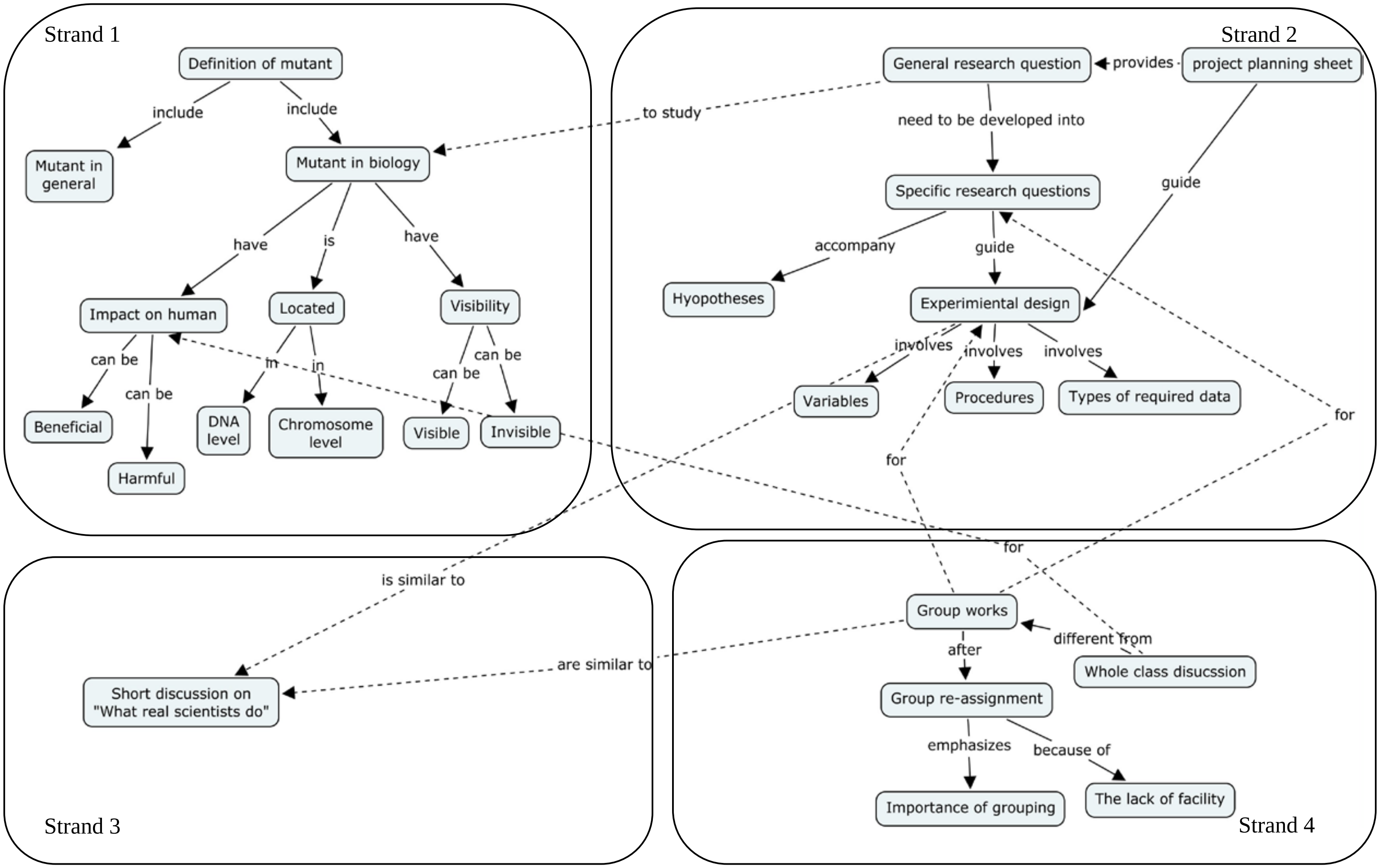
SPA-MAPS FOR 10 LESSONS FROM THE INQUIRY SEQUENCE



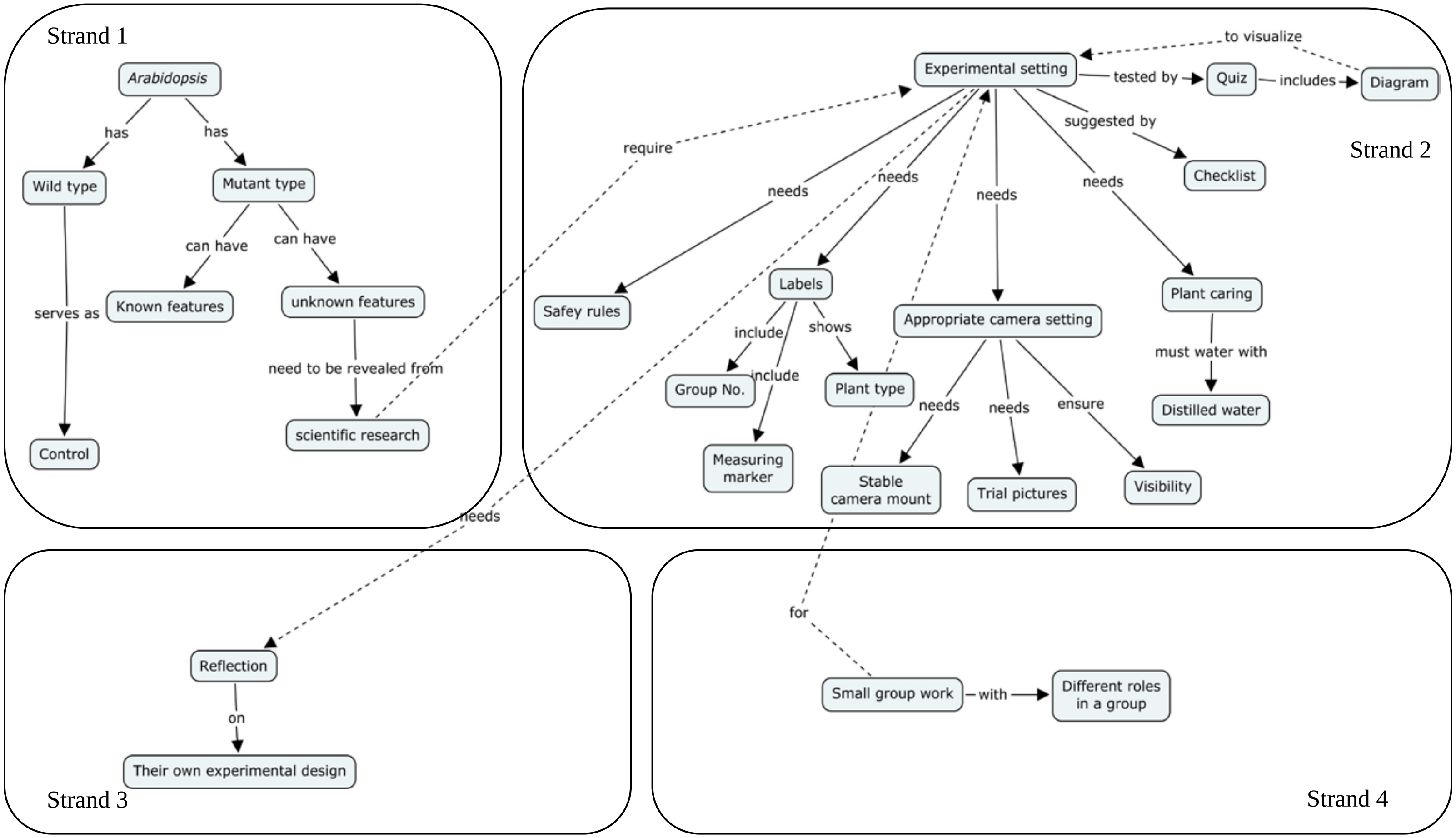
(a) The SPA-map of Lesson 1



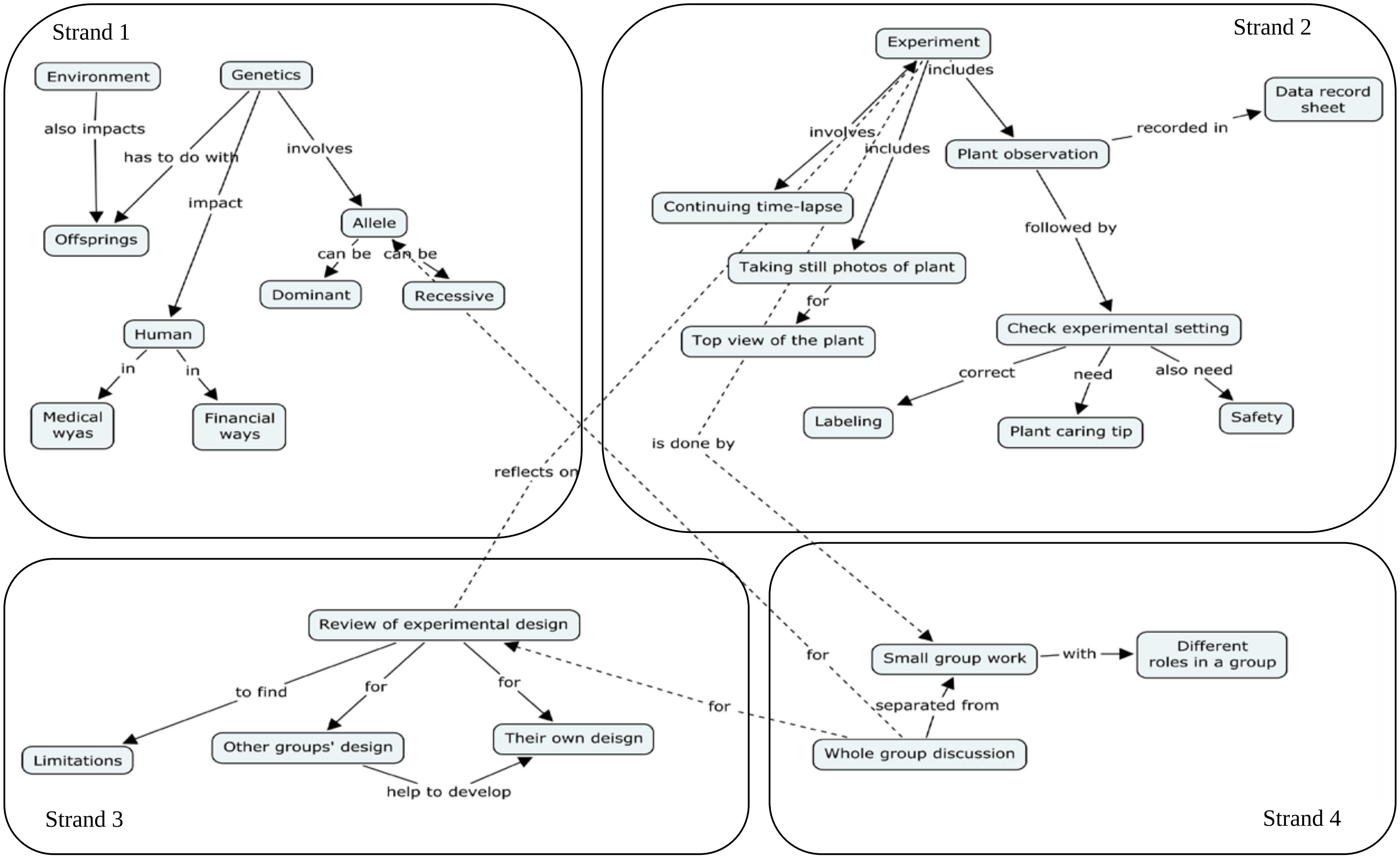
(b) The SPA-map of Lesson 2



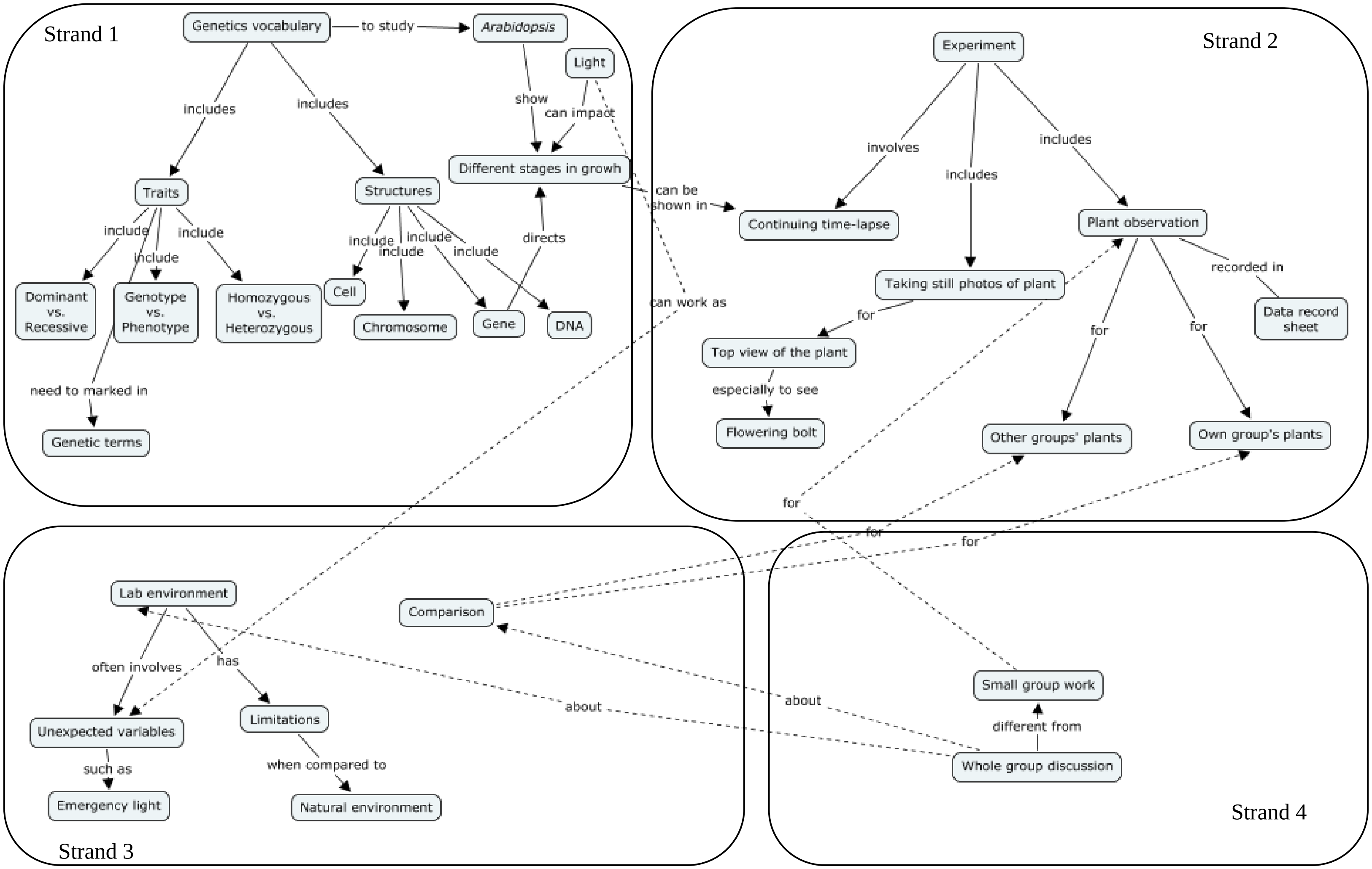
(c) The SPA-map of Lesson 3



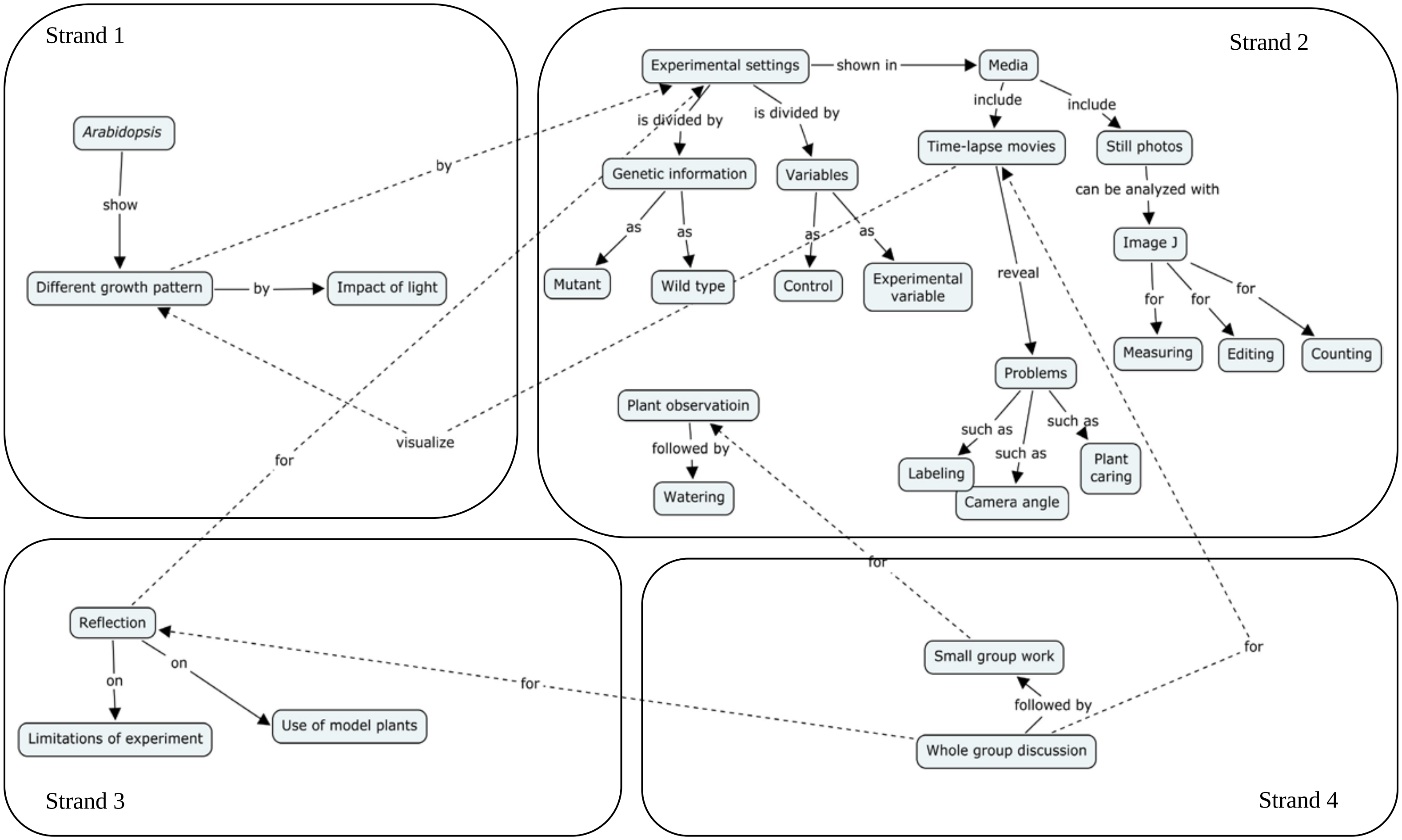
(d) The SPA-map of Lesson 4



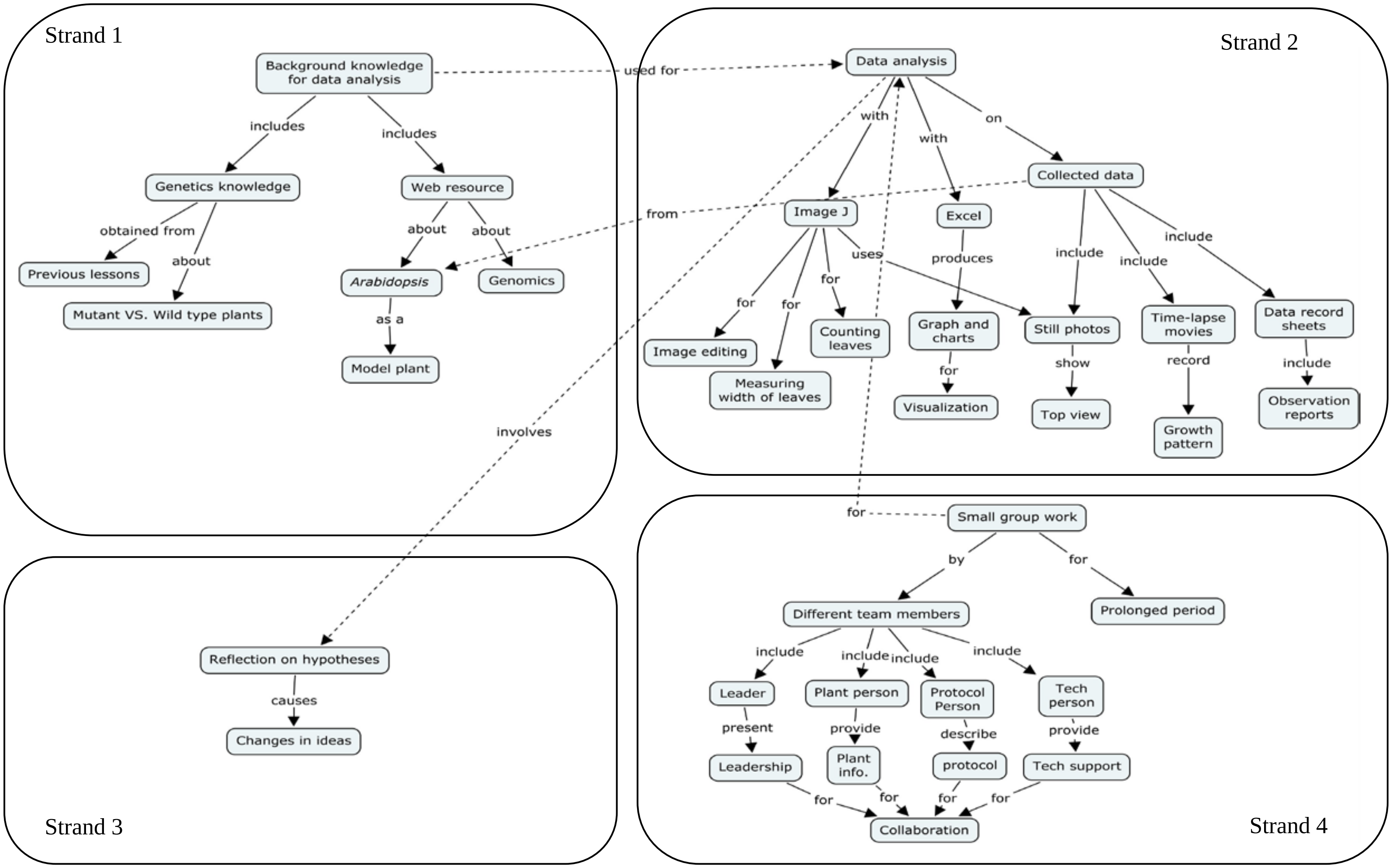
(e) The SPA-map of Lesson 5



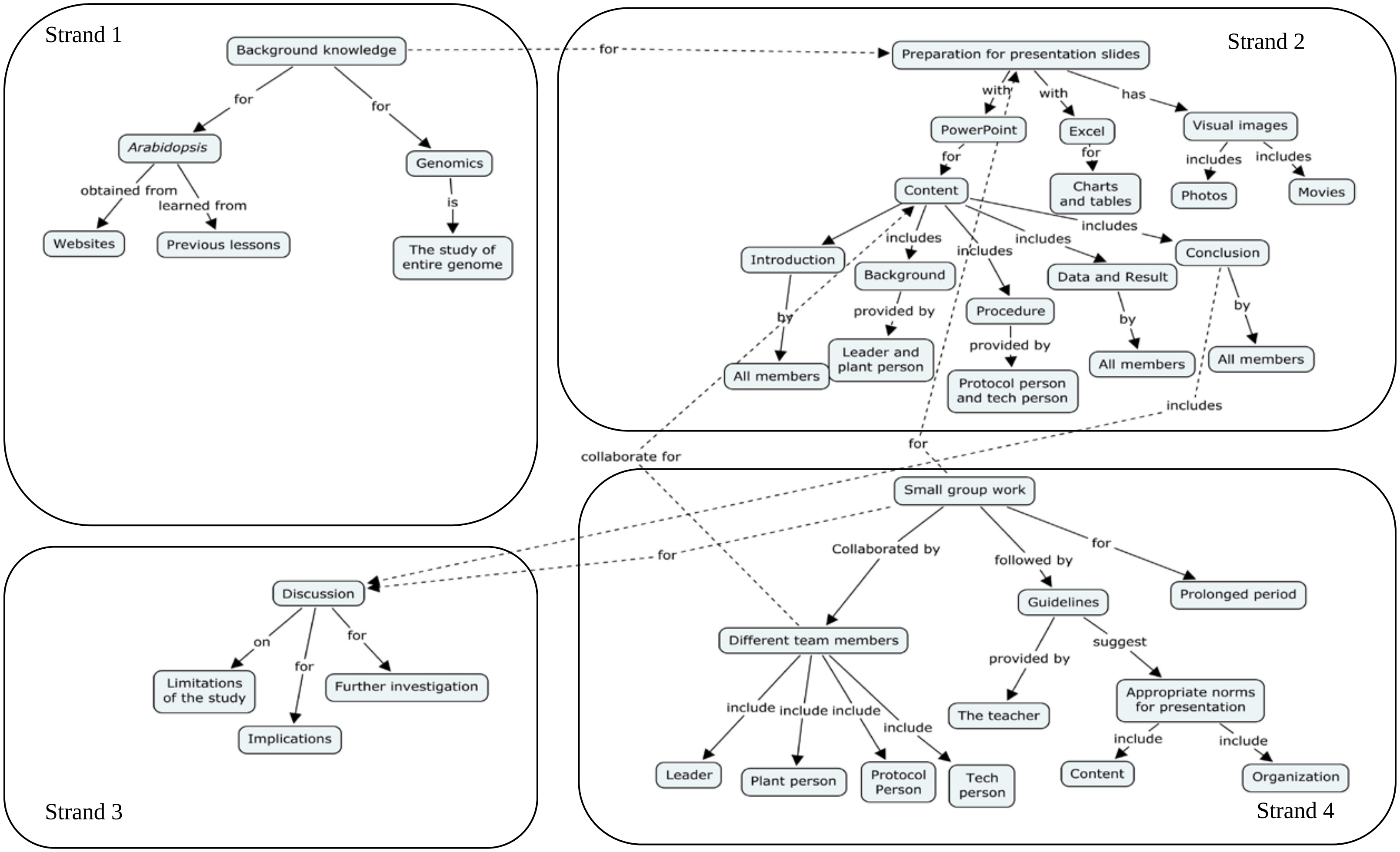
(f) The SPA-map of Lesson 6



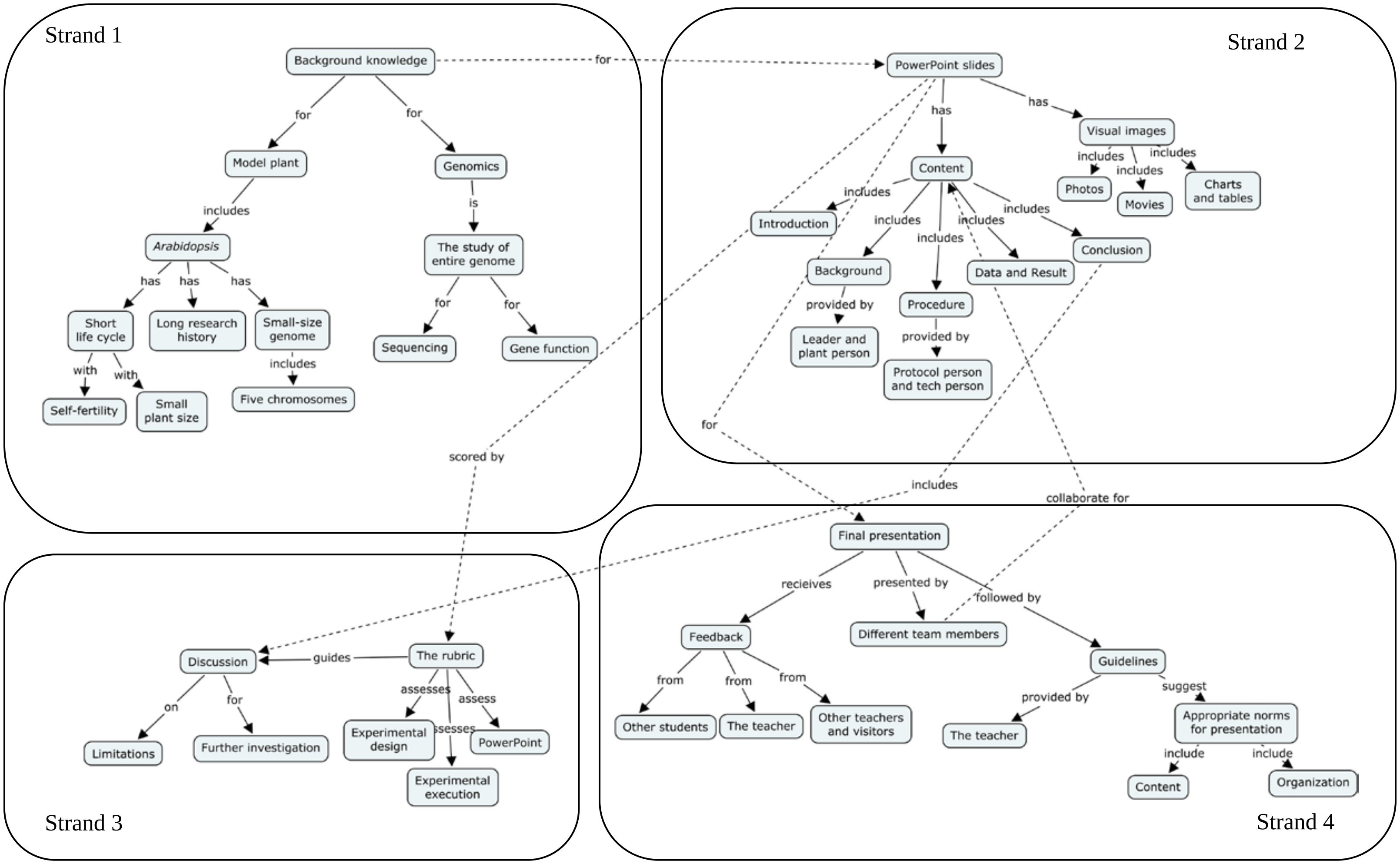
(g) The SPA-map of Lesson 7



(h) The SPA-map of Lesson 8



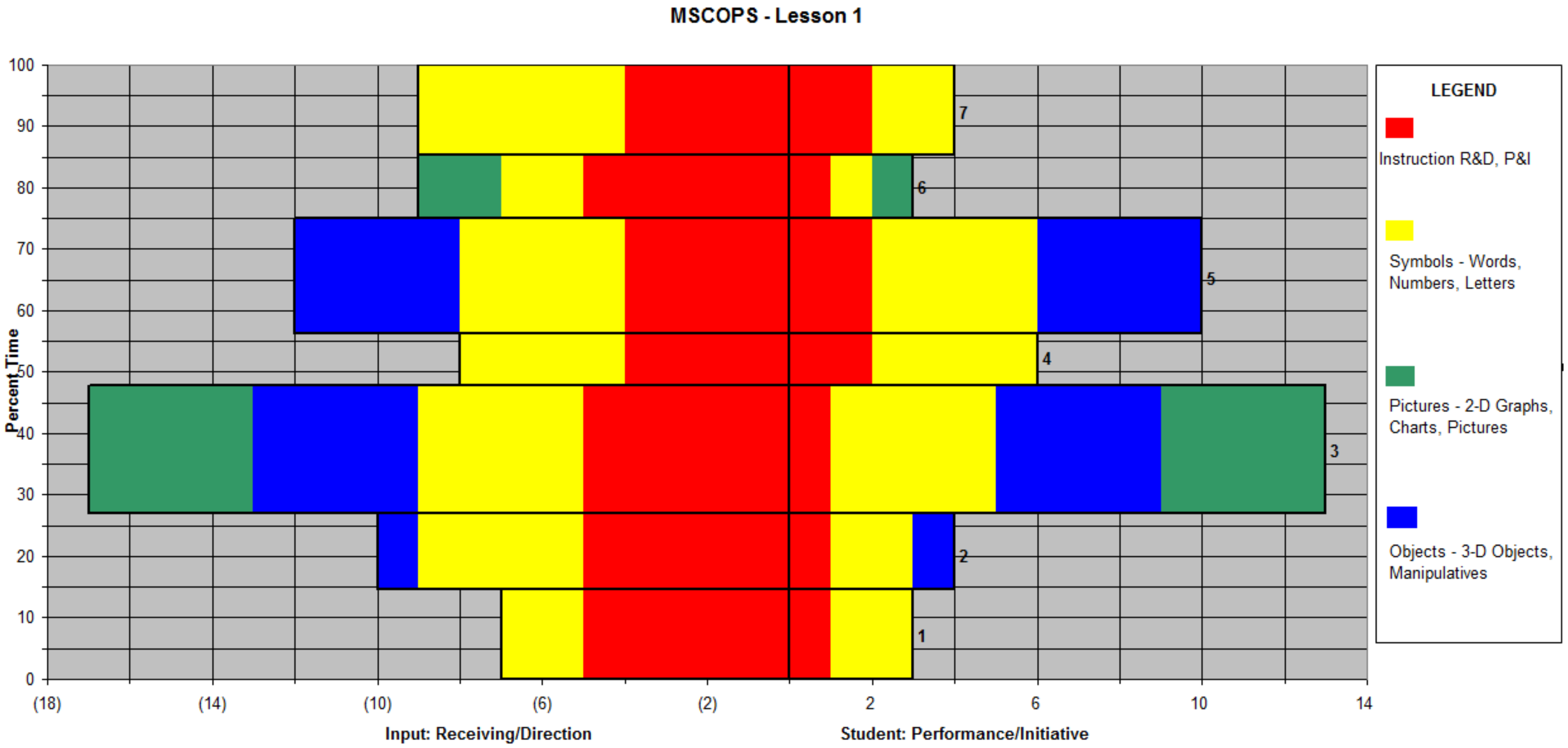
(i) The SPA-map of Lesson 9



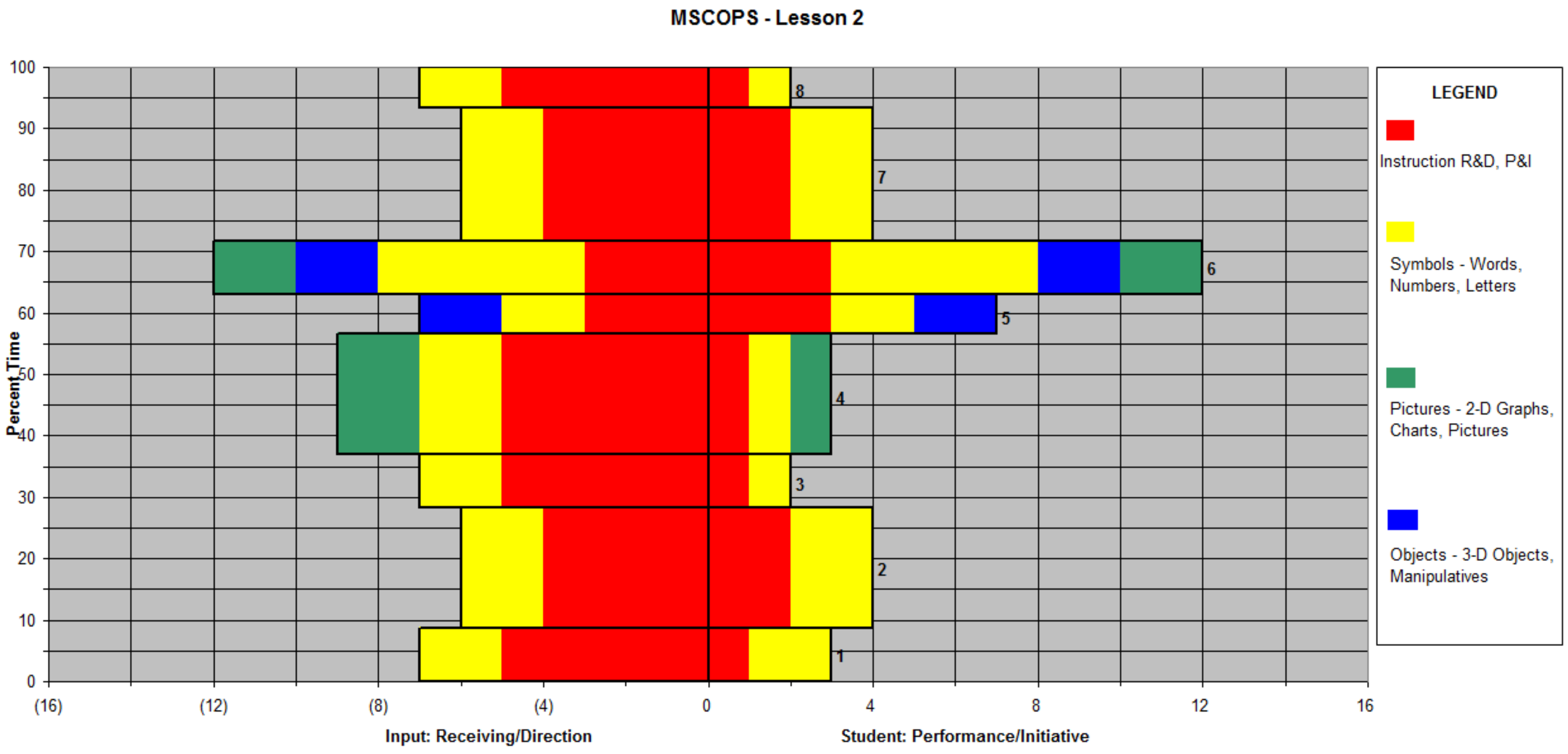
(j) The SPA-map of Lesson 10

APPENDIX F

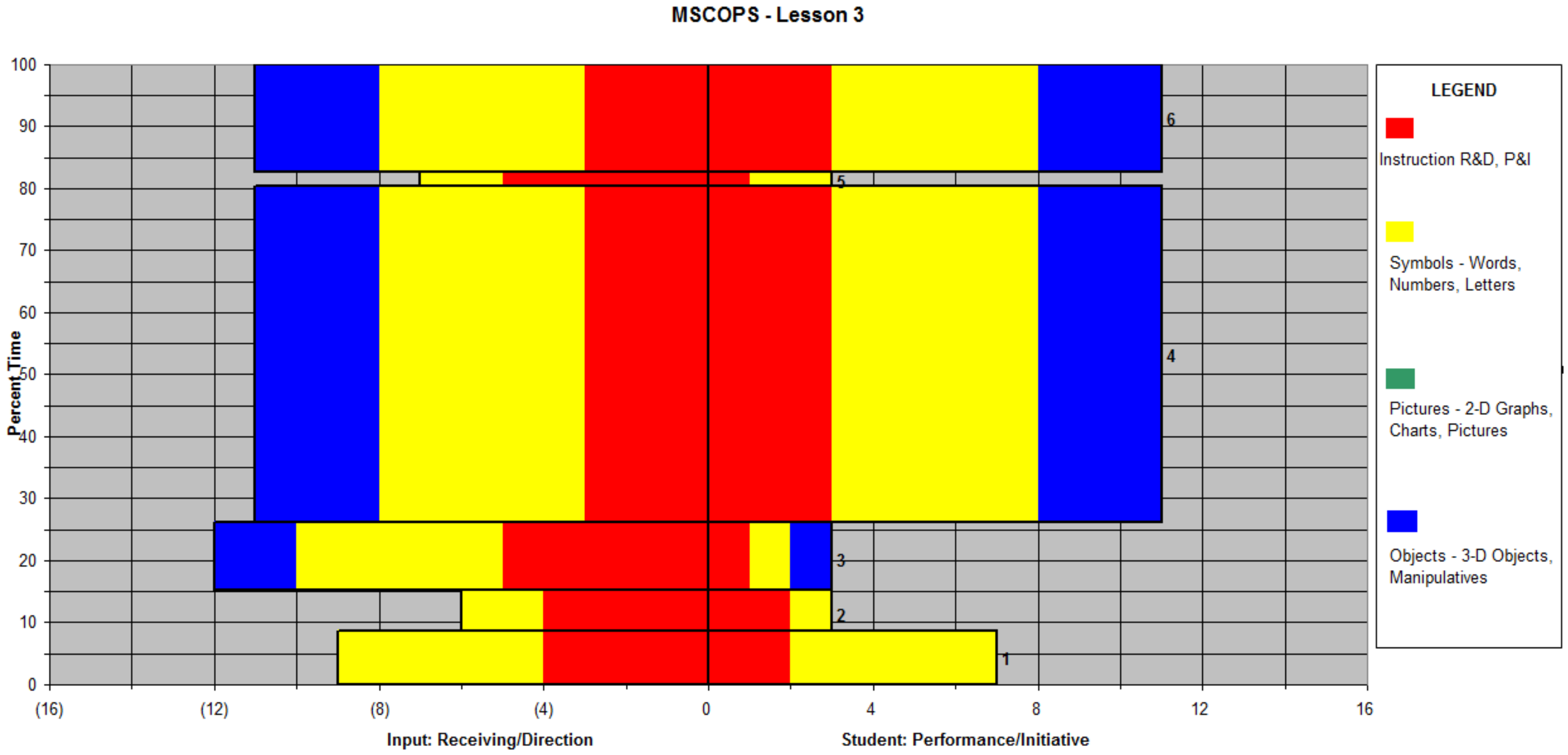
M-SCOPS PROFILES FOR 10 LESSONS FROM THE INQUIRY SEQUENCE



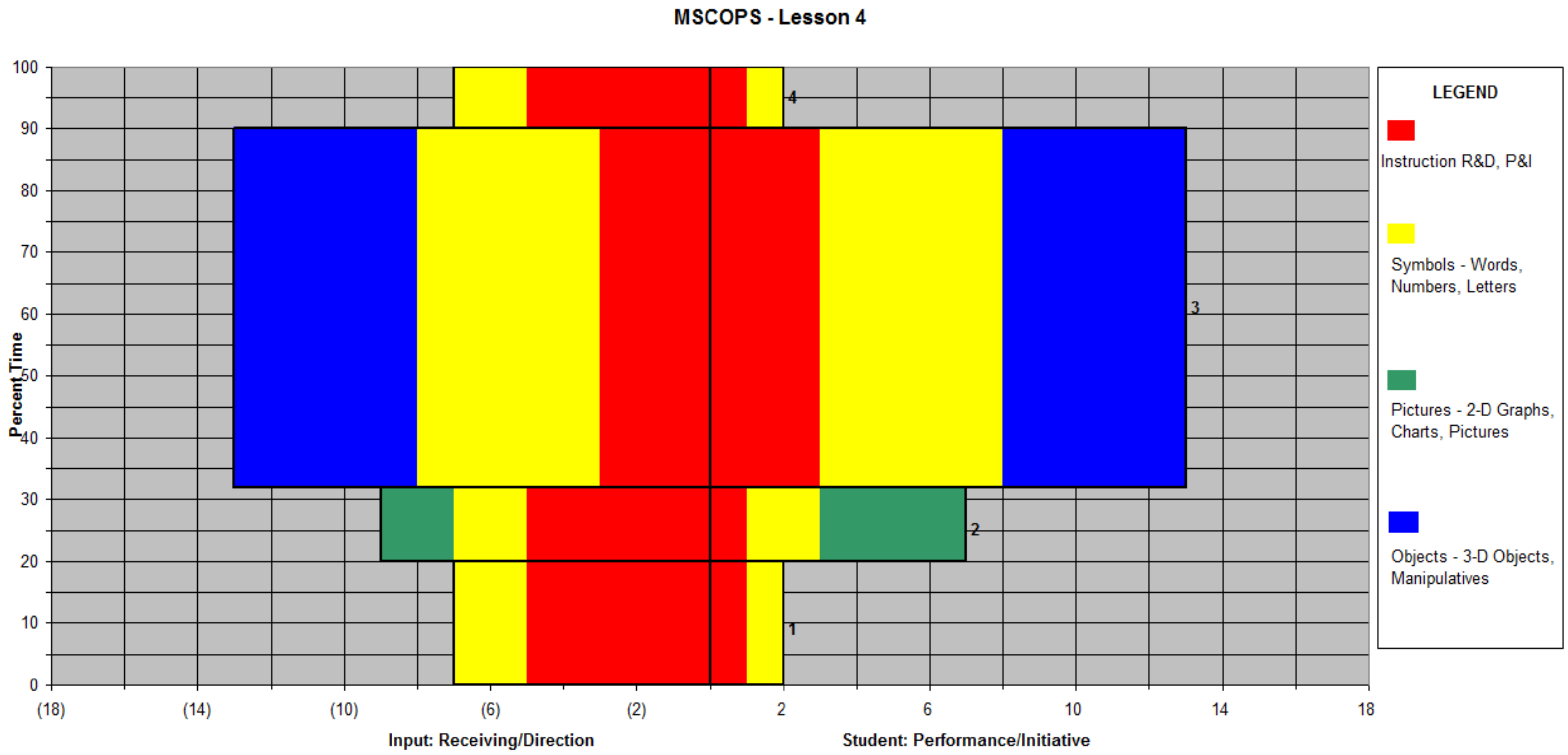
(a) The M-SCOPS profile of Lesson 1



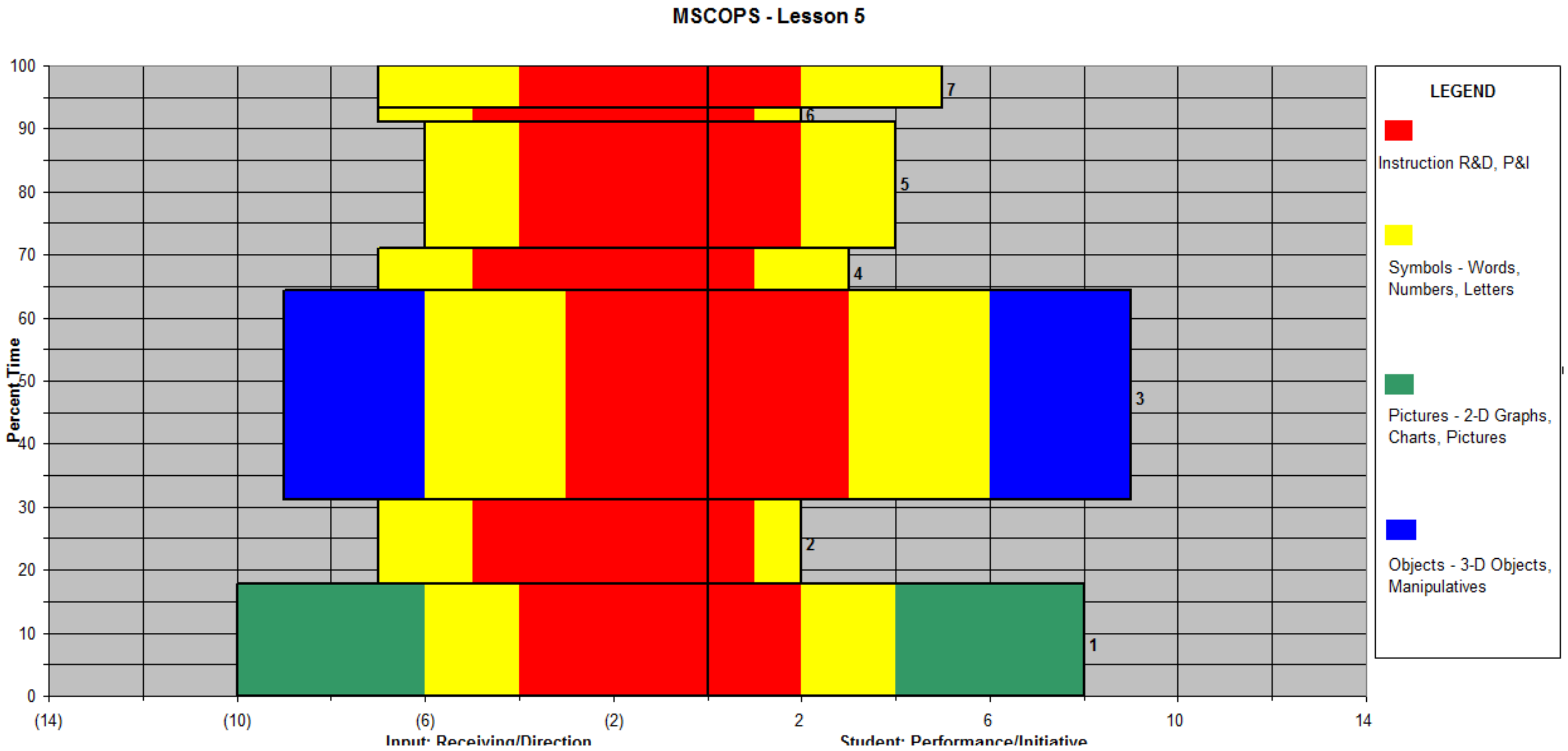
(b) The M-SCOPS profile of Lesson 2



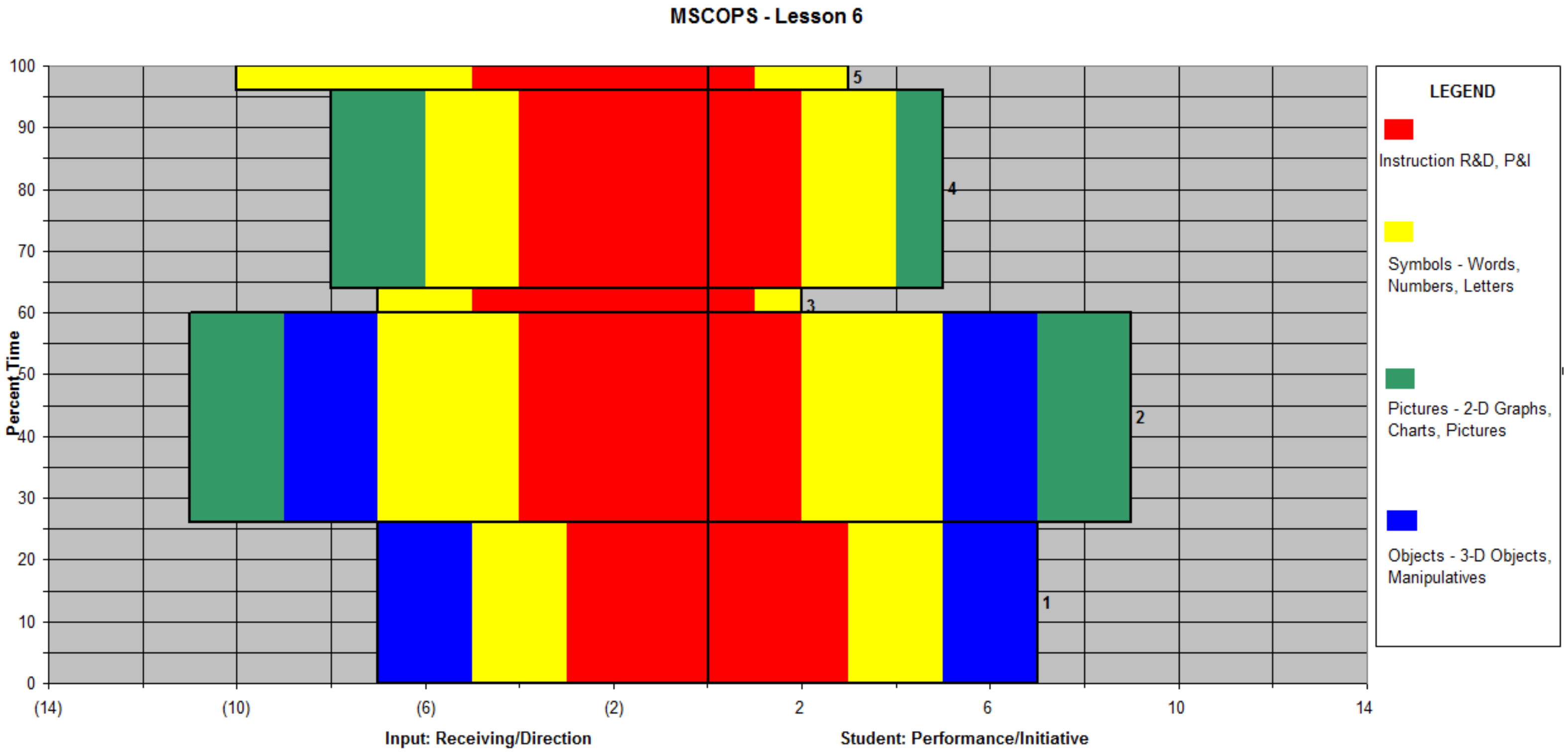
(c) The M-SCOPS profile of Lesson 3



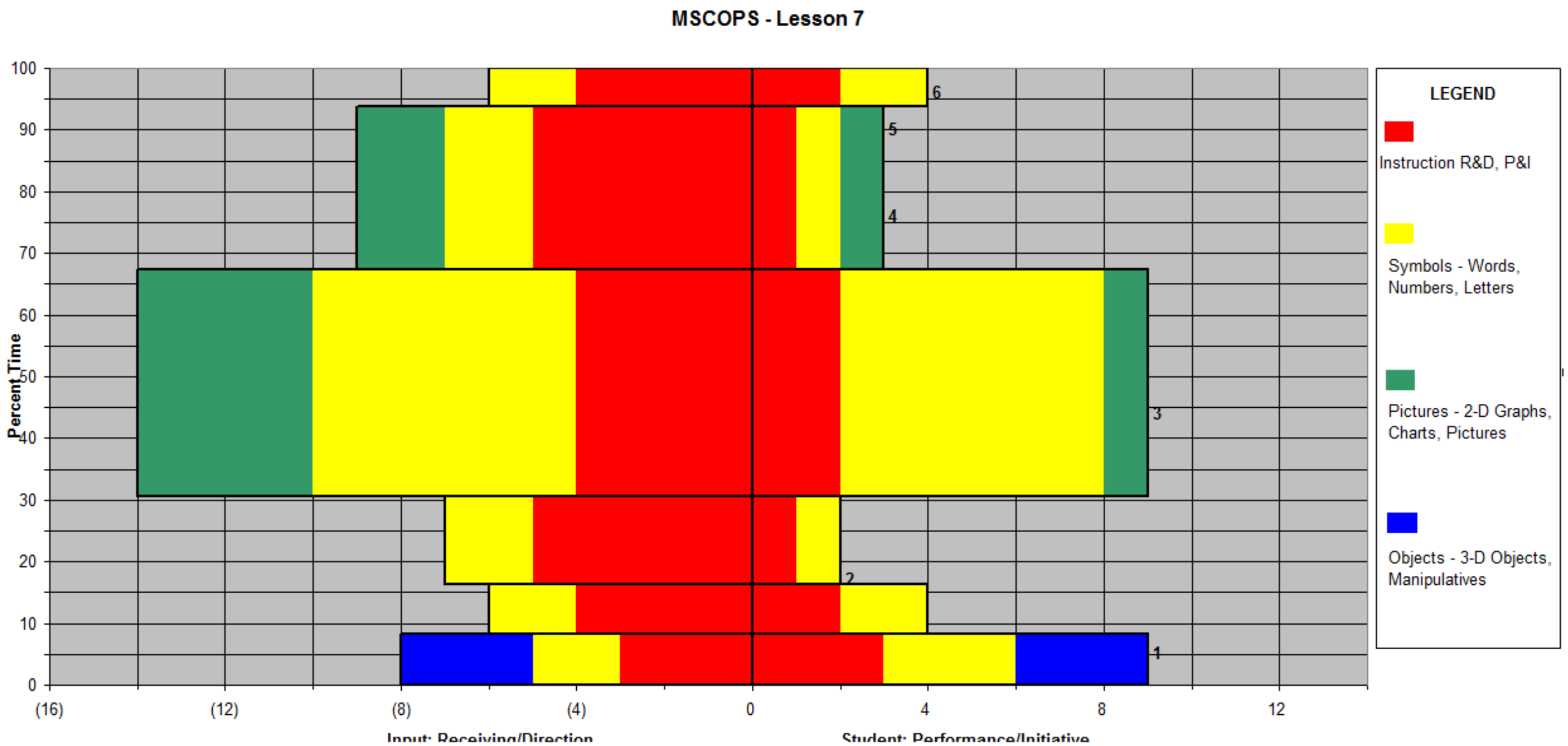
(d) The M-SCOPS profile of Lesson 4



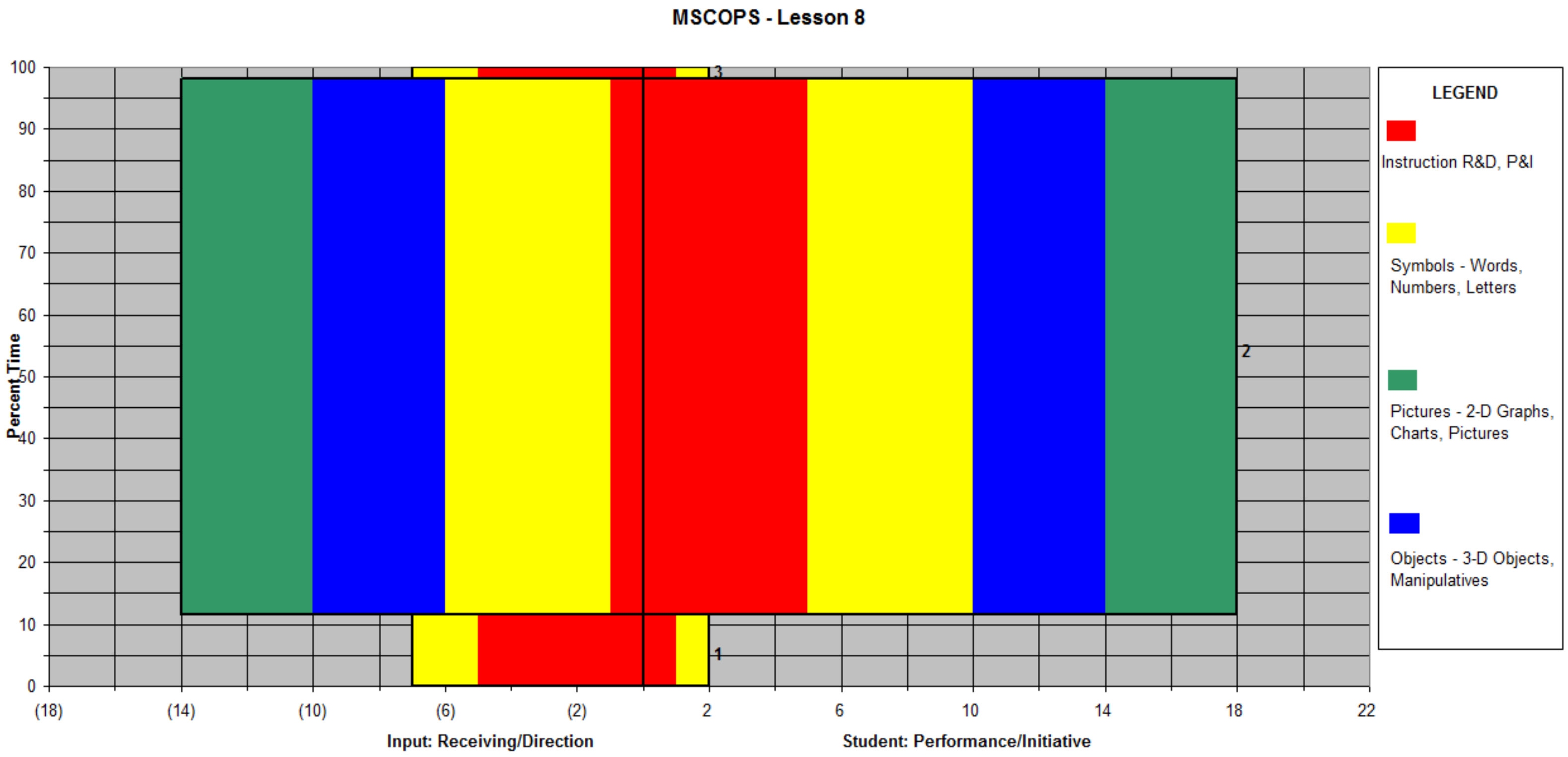
(e) The M-SCOPS profile of Lesson 5



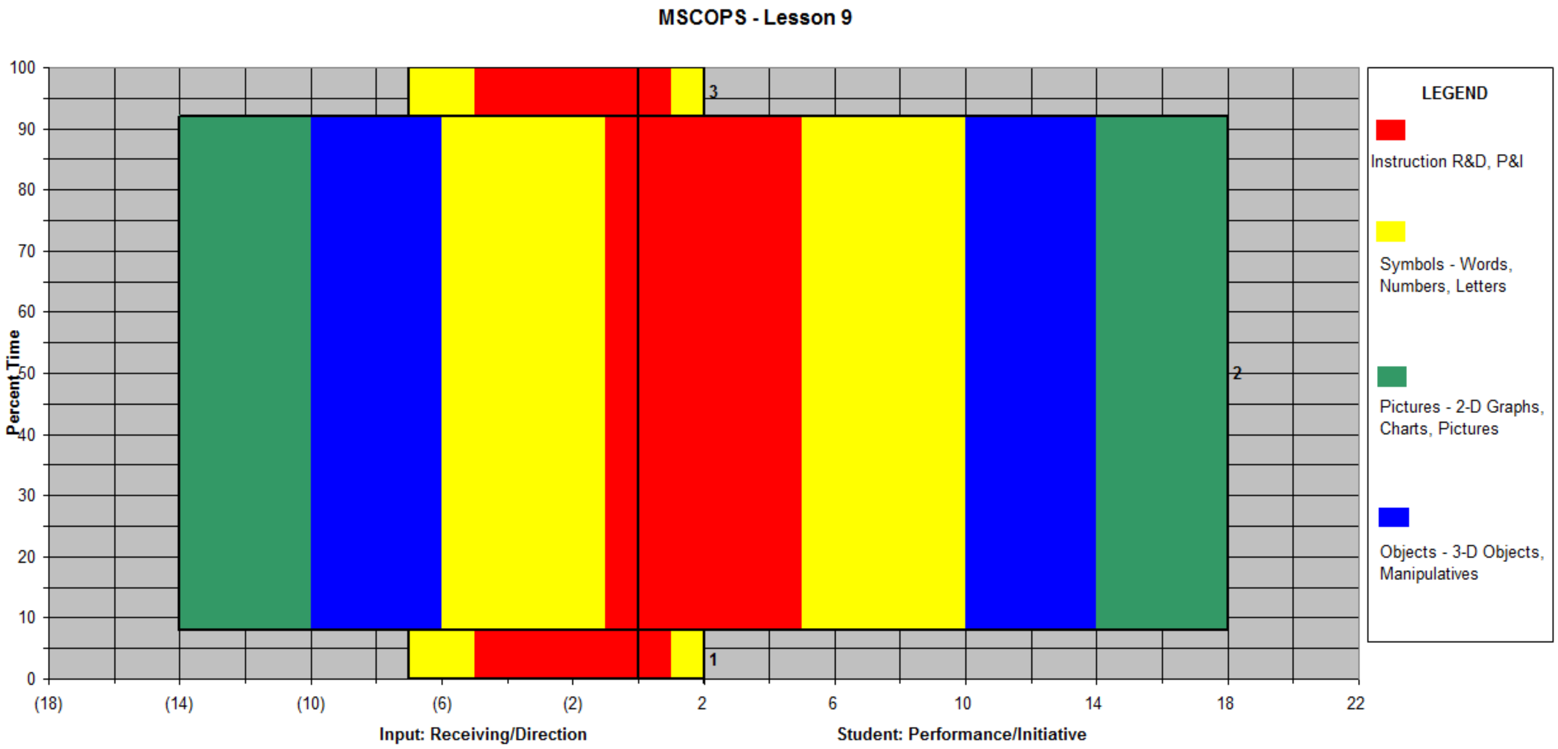
(f) The M-SCOPS profile of Lesson 6



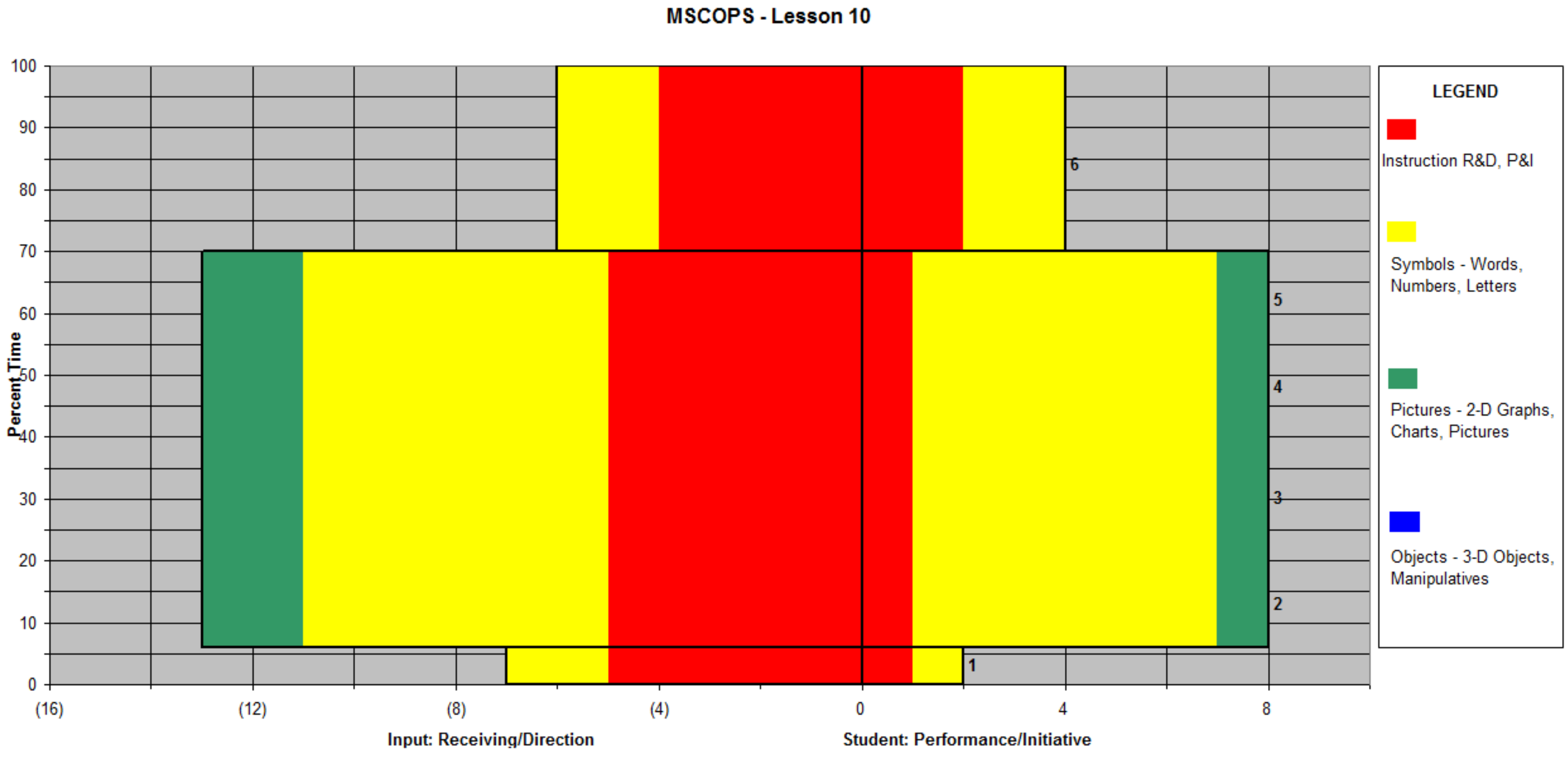
(g) The M-SCOPS profile of Lesson 7



(h) The M-SCOPS profile of Lesson 8



(i) The M-SCOPS profile of Lesson 9



(j) The M-SCOPS profile of Lesson 10

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Yoo, D., & Mehmet, A. (2010). *Understanding the relationship between professional development and job satisfaction in Texas high schools: A mixed method study*. Paper presented at the annual meeting of the American Educational Research Association. Denver, CO

Stuessy, C. L., Bozeman, D., Hollas, T., Spikes, S., Richardson, R., Vasquez, C., Yoo, D., Ivey, T. (2010). *Predicting science achievement and science teacher retention in Texas high schools with school- and teacher-level variables*. Paper presented at the annual meeting of the National Association of Research in Science Teaching. Philadelphia, PA

Yoo, D., & Stuessy, C. L. (2008). *Education graduate students' orientations toward research*. Paper presented at the 20th Annual Meeting of the Ethnographic and Qualitative Research Conference, Columbus, OH

Yoo, D., & Stuessy, C. L. (2007) *Analyzing one science teacher's inquiry-based instruction using M-SCOPS*. Paper presented at the annual meeting of the Southwest Association for Science Teacher Education, Dallas, TX