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Pathways of Professional Learning for Elementary Science Teachers Using Computer Learning Environments

by

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B.B.A. (University of Texas at Austin) 1992
M.A. (University of California, Berkeley) 2001

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ABSTRACT

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Doctor of Philosophy in Education

University of California, Berkeley

Professors Marcia C. Linn and Paul Ammon, Co-chairs

This dissertation reports on a three year study designed to investigate the trajectories of two urban elementary school teachers—a novice and an experienced teacher—learning to teach a science curriculum unit using an inquiry approach supported by the *Web-based Inquiry Science Environment (WISE).* This research investigated teachers' development in knowledge and practice. Through analyses of video records of classroom instruction and professional development meetings, repeated interviews, and student assessments, I have produced case studies of teachers' journeys as they implement the technological inquiry-based instructional model.

This study captures the interplay between the teachers' pedagogical content knowledge, enacted practice, and insights into students' thinking about complex science ideas. I trace the factors that encouraged and supported the teachers' development, in addition to the kinds of struggles they faced and overcame. I discuss the social supports I provided for the teachers, including scaffolding them in reflecting on their practice, assisting them with curriculum customizations, and supporting their learning such as

arranging online interactions with scientists. I analyze spontaneous activities such as teachers' own reflections.

The results suggest that the novice and experienced teacher's classroom practices became more inquiry oriented across time. For both teachers, use of technology accompanied an increase in science dialogue with small groups in years two and three. The novice teacher began asking inquiry questions in her second year of classroom experience, after a great deal of professional support. Both teachers improved in their pedagogical content knowledge from years one through three as a result of the varied professional development supports. The results suggest that teachers' improvement in instructional strategies and pedagogical content knowledge accompanied students' improvement in understanding of the science content.

To my husband, with love

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CHAPTER 1

TOWARD AN UNDERSTANDING OF PATHWAYS TO PROFESSIONAL LEARNING

Introduction

> *In a world filled with the products of scientific inquiry, scientific literacy has become a necessity for everyone. Everyone needs to use scientific information to make choices that arise every day. Everyone needs to be able to engage intelligently in public discourse and debate about important issues that involve science and technology. And everyone deserves to share in the excitement and personal fulfillment that can come from understanding and learning about the natural world* (NRC, 1996, pp. 1-2).

To foster student inquiry, it is important to understand the practices that promote inquiry and how teachers learn how to teach for science inquiry. In this dissertation, I show the benefit of understanding the experiences and struggles practicing teachers face across time. I discuss the trajectories teachers follow as they learn to implement scientific inquiry. These studies can help the science professional development community create more systematic initiatives for supporting teachers' professional growth. These learning trajectories can shed light on how teachers make sense of new practices and how their pedagogical conceptions evolve across time.

This dissertation reports on two case studies of elementary school teachers[1]—a novice called Alice and an experienced teacher called Lee—learning to teach a science curriculum unit using an inquiry approach supported by the Web-based Inquiry Science

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[1] The names of the schools and their participants, teachers and students, have been changed to preserve anonymity.

Environment (WISE) over three years. WISE[1] is an online science learning environment (http://wise.berkeley.edu) for students in grades 4-12. My research entailed investigating the teachers' development in both practice and knowledge. In order to achieve my objectives, I pursued the following sub-questions: (a) What was the interplay over time between teachers' practices and their pedagogical content knowledge as they implemented a technology-based curriculum? (b) How did more effective practices emerge as a result of using technology, and what were they? (c) What encouraged or supported the teachers' development? In this study, I define *trajectories* as paths that teachers take when implementing the inquiry science curriculum. The construct pedagogical content knowledge was introduced by Shulman (1986a, 1986b, & 1987). He defines pedagogical content knowledge as: (a) teachers' knowledge of ways of representing or formulating particular content to make it understandable to students to promote student learning, and (b) teachers' knowledge of students' ideas, including students' conceptions and preconceptions about the content area, as well as what makes specific content difficult or easy for students to understand. In my study, I am interested in how novice and experienced teachers improve their practices as their pedagogical content knowledge develops across three years through the use of the WISE plant curriculum. This includes understanding how teachers monitor students' progress and what remedies they put in place to help promote learning.

Case studies such as the ones presented in this research provide unique insights into the possible pathways to professional learning. The knowledge gained from this research will enable the professional development community in science education to create more systematic initiatives for supporting teachers as they learn inquiry teaching.

The National Science Education Standards (1996) call for teachers to: (a) implement inquiry instruction, (b) encourage their students to use scientific evidence to support claims, (c) allow students to conduct investigations over extended periods of time, and (d) invite students to collaborate and communicate science explanations. In the standards, learning science is viewed as an active process. At the same time, the Standards contend that learning science is more than just utilizing process skills such as conducting observations and experiments; it is also engaging in inquiry. Scientific inquiry is defined by the National Science Education Standards as *"diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world"* (NRC, 1996, p. 23). More specifically, inquiry activities may involve students critiquing existing sources of information about science topics, constructing explanations, asking questions, making predictions, and utilizing tools to gather, analyze and interpret data. Research shows that learning is enhanced when students engage in inquiry—having opportunities to explore scientific phenomena in-depth and receiving frequent feedback from teachers and peers (Bransford, Brown, & Cocking, 1999; Linn & Clark, 2003; Linn & Hsi, 2000). When students are engaged in inquiry, they have opportunities to make connections/linkages among preexisting and new understandings, including having adequate time to reconcile confusing ideas about scientific phenomena.

Using an inquiry approach to science teaching promotes deep understanding in students, but it is complex and demanding for teachers. Moreover, as Ball (2000) points

out, inquiry teaching is particularly challenging for many elementary teachers of mathematics or science, because it requires them to integrate and utilize deep understandings of the content and pedagogy. Many elementary school teachers do not have strong backgrounds in science content or technology or in inquiry-oriented instruction (e.g., Alberts, 2000; Becker, Ravitz, & Wong, 1999; Pedersen & Yerrick, 2000; Smith & Neale, 1989). Inquiry teaching in a technology-based learning environment is complex and demanding for teachers because it requires:
(a) understanding of the discipline or content well enough to allow students to ask ill-defined questions, (b) use of new representations of science content such as graphs,
(c) new logistical practices such as managing small groups of students, and
(d) understanding of technological and network related issues (Fishman, Marx, Best, & Tal, 2003; Ladewski, Krajcik, & Harvey, 1994; Li, 2002; Marx, Blumenfeld, Krajcik, Blunk, Crawford, Kelly, & Meyer, 1994; Slotta, 2004). This study reports on two elementary teachers' development in meeting these challenges and on the factors that encouraged and supported their development. My research is informed by an instructional model of professional development that is built upon the *Scaffolded Knowledge Integration* framework or *SKI* (Linn, 1995; Linn & Hsi, 2000). This model called *Inquiry Science Teaching* (discussed later in the chapter) identifies dimensions along which teachers grow as professionals and helps clarify the factors that contribute to the emergence of improved instructional decision making.

Role of Researcher

In this dissertation, I compare how an experienced and novice teacher adapted WISE into their classroom practice across time (Ragin, 1987). In the early phases of this research, I formed a partnership that initially included an experienced fifth grade teacher (one of the two case teachers in this study), science educational researchers, scientists, and technology specialists. After the first year, I expanded the partnership to include five additional elementary teachers at two different school sites, including the novice teacher in this study. Two of the five teachers did not remain in the study because their classrooms did not have the technology necessary to access WISE. A third teacher moved to another city so she was unable to continue her participation in the study. A fourth teacher had similar experience to the initial teacher-partner but participated for a shorter time. I selected two teachers who participated consistently and contrasted in expertise.

This longitudinal case study traces the development of both the novice and the experienced teacher (the initial teacher-partner) across a three year time span. I collected the following types of data: (a) interviews, (b) direct observations of classroom instruction and professional development meetings (using videotape and audiotape), and (c) teachers' written reflections.

In this study, I was a participant in addition to being an observer. As in all participant-observation research, my methodology had to balance the objectivity as an observer with the need to be accepted in the classroom and in professional meetings, and to participate in a way that ensured that I understood the participants' experience in depth[2]. I provided social supports for the teachers which included:

- Scaffolding them in reflecting on their practices and knowledge
- Assisting them with curriculum customizations
- Participating in class discourse during the novice teacher's first year of teaching WISE by her request
- Assisting the teachers with putting other scaffolds in place to support their learning such as interactions with scientists

- Providing technical support—i.e., training the teachers to use the authoring environment and curriculum software in WISE
- Providing technology support—i.e., assisted the teachers in writing a successful grant proposal that provided more networked computers in their classrooms

To identify trajectories of change in the teachers' practices and knowledge, I traced what factors contributed to their professional development, factors including the above social support. For this reason, I collected data using both video and audiotape for later analysis, to ensure that my participation did not compromise my analysis of the teachers' trajectories. The videos served as backup documentation of my participation. As an observer, I already knew something about the culture of teaching. I had experience teaching at the elementary level, training in social science in the field of education, and a background in the development of the WISE software.

Later in this chapter, I discuss what is known in the science education research literature about how teachers develop over time with regards to their instructional decisions and pedagogical conceptions. In chapter 3, I discuss the research design and methods used in this study. Chapter 4 discusses the context in which the teachers implemented the Web-based Inquiry Science Environment. In chapters 5 and 6, I discuss how the teachers learn to teach inquiry science over the three year span. Chapter 7 compares and contrasts the novice and experienced teacher's development in both knowledge and practice over the course of the three year time span.

Theoretical Background

It is a complex undertaking to investigate how novice and experienced teachers learn to teach inquiry science within a technology-based curriculum across time, while at the same time capturing the interplay between professional development, teachers' practices and pedagogical content knowledge. A necessary step is the development of a theoretical framework to support this research agenda. I have adopted Scaffolded Knowledge Integration framework—SKI to view teachers' development (Linn, 1995; Linn, Eylon, & Davis, 2004). In this framework, learners are viewed as adding ideas to their repertoire of models and reorganizing their knowledge. Teachers have unique ideas, and need opportunities to add and sort out new/preexisting knowledge. This perspective takes on a sociocognitive frame, thus positing that learning is influenced by both individual construction of knowledge and social supports such as collaborative learning situations between students and teachers/peers or scientists.

SKI Tenets as Applied to Classroom Practice

The SKI framework features four tenets to promote knowledge integration for learners (i.e., both students and teachers): (a) making thinking visible for learners, (b) providing social supports to learners, (c) making science accessible for learners, and (d) promoting autonomy for lifelong science learning.

The first tenet of the Scaffolded Knowledge Integration framework emphasizes that teachers can help make students' scientific thinking visible through eliciting their science ideas and encouraging them to explicitly connect new and prior ideas, and to use technological supports such as various representations (e.g., graphs, models, illustrations). Research by the Cognition and Technology Group at Vanderbilt (2002) shows that when practices make students' thinking visible, teachers can attend to students' conceptualizations of the content, including their preconceptions and non-normative ideas. Curricular activities in WISE ask students to make predictions, draw inferences, and construct generalizations, which in turn also helps to make their scientific thinking visible (Champagne, Klopfer, & Gunstone, 1982). These practices help students by supporting their knowledge integration. Also, presenting teachers with opportunities to add ideas to their repertoire and sort out preexisting and new ideas can help them to make their own thinking visible. This study takes into account how elementary teachers come to make students' scientific thinking visible through the use of technology over time.

The second tenet of the SKI framework emphasizes that providing students with social supports in a science classroom can promote knowledge integration. As a number of researchers have pointed out, collaborative learning situations such as discussions and debates can provide students with opportunities to offer explanations, interpretations, and resolutions supported by a peer, the instructor, or a scientist (e.g., Brown & Palincsar, 1989; Tharp & Gallimore, 1988). These sorts of interactions can also help make students' scientific thinking more visible, as pointed out by Linn and Hsi (2000). This dissertation study takes into account student collaboration, teacher-student interactions and my role in the teachers' development, specifically the social supports that I provided.

The third tenet of the Scaffolded Knowledge Integration framework is that science becomes accessible to all students when instruction affords them the opportunity to connect science class information with real world experiences. Traditionally elementary science instruction has relied on the presentation of content (Roth, 1989), and science learning has been accessed in terms of acquisition of isolated ideas. When students learn isolated ideas, they quickly forget them, rather than linking and connecting scientific concepts to personally relevant problems (Ammon & Black, 1998; Linn, diSessa, Pea, & Songer, 1994). This activity studied here makes science accessible for learners by including relevant content and connections to prior ideas.

The fourth tenet of the SKI framework is to promote autonomy for lifelong science learning. To prepare students to integrate the ideas they learn in science and revisit them once they have completed a science course, WISE software (i.e., online curricular units) supports questioning, analyzing, and reflecting (Linn, Clark, & Slotta, 2003). Students are asked to identify weaknesses in arguments and question the validity of the scientific information presented.

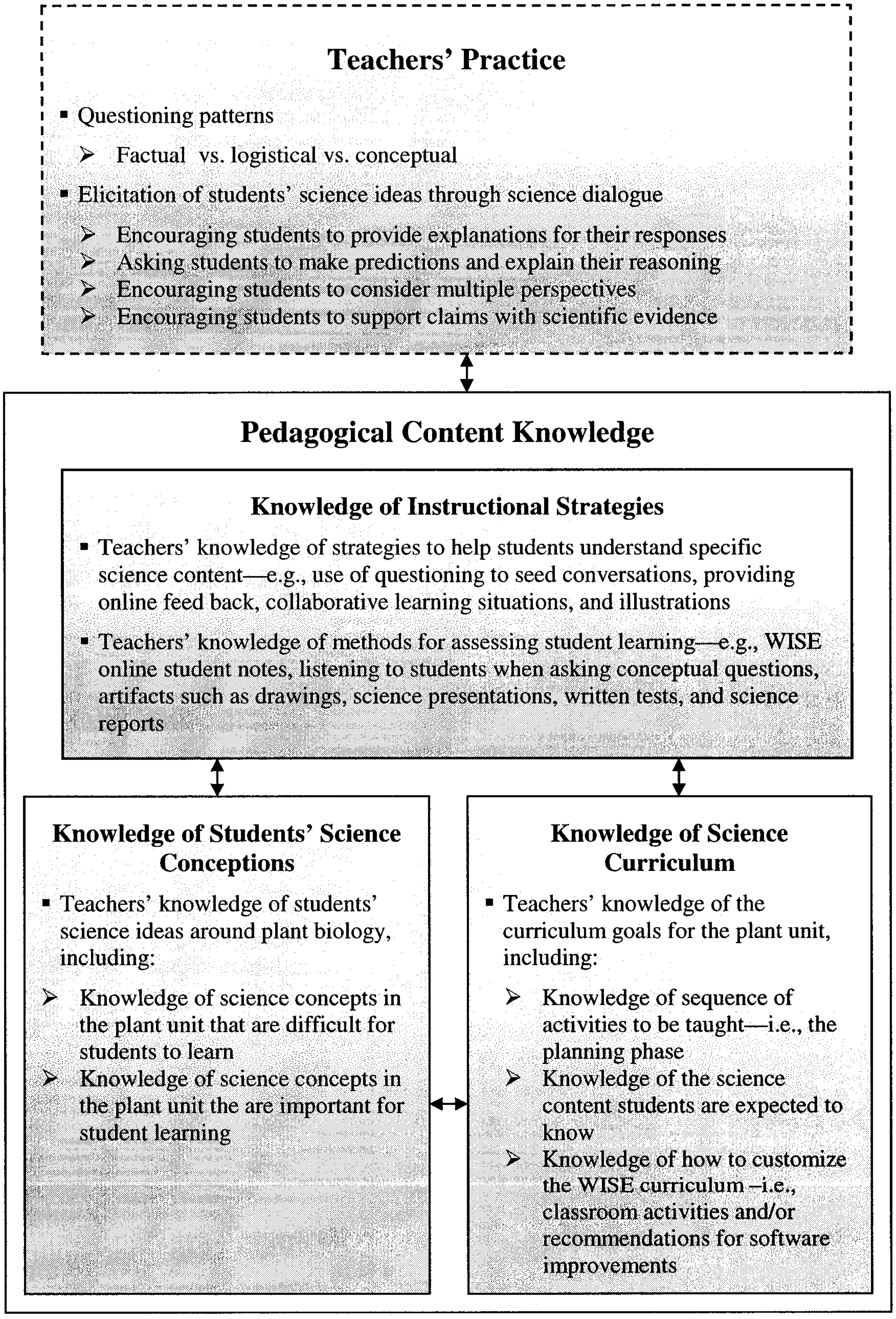
SKI Tenets as Applied to Teacher Learning

As Davis (2004) points out, the knowledge integration perspective has primarily been used to analyze students' cognition in the domain of science, but is applicable to all learners. In the knowledge integration framework, learners are viewed as adding ideas to their repertoire of models and reorganizing their knowledge. Students and teachers sort out their ideas as a result of following the four SKI tenets—reflecting, comparing ideas to those of others, making their ideas visible, and testing ideas in their classrooms (Linn & Hsi, 2000). Instructors can help students build on their existing knowledge by connecting with their prior existing knowledge and then "*incrementing it*" (Leinhardt, 1992).

Thus one may conclude that using the four tenets of SKI, the student-teacher relationship will result in learning by both teacher and student, and create an environment for effective teaching and learning science.

Effective teaching requires what Shulman called pedagogical content knowledge. He identifies two components of pedagogical content knowledge: First—the ways teachers represent or formulate content to make it understandable to students to promote student learning and teachers' knowledge of students' ideas (i.e., students' conceptions and preconceptions about the content area), second—knowledge of what makes specific content difficult or easy for students to learn (Shulman, 1986a, 1986b, & 1987). SKI tenets take advantage of pedagogical content knowledge of how learners acquire, organize/sort, and make sense of information (Linn & Hsi, 2000). SKI helps teachers see how to respond to the new and preexisting ideas learners have in their repertoire and helps them to organize their understandings of scientific phenomena, including attending to what ideas are promoted. Pedagogical content knowledge identifies knowledge teachers can use to teach subject matter in a given field (not specific to science) to students. Combining these perspectives suggests that providing teachers with opportunities to add new ideas to their own repertoire, sort out ideas as a result of reflection, and integrate ideas can enable them to develop in pedagogical content knowledge.

In this dissertation, I build upon the work of Grossman (1990), Linn and Hsi (2000), Magnusson, Krajcik, and Borko (1999), and Sherin (2002) in terms of conceptualizing pedagogical content knowledge. As shown in Figure 1.1, I conceptualize pedagogical content knowledge for science teaching as consisting of three components: (a) knowledge of instructional strategies for science, (b) knowledge of students' science conceptions, and (c) knowledge of the science curriculum. Following the SKI framework in the Inquiry Science Teaching Model in Figure 1.1, I focus on *Teachers' Practice*. To study how teachers' practice makes thinking visible, I study: (a) questioning patterns and (b) elicitation of students' science ideas through science dialogues. I chose these categories because they emerged from the data themselves and because they mesh with the SKI framework.



Teachers' Practice

- Questioning patterns
    - Factual vs. logistical vs. conceptual
- Elicitation of students' science ideas through science dialogue
    - Encouraging students to provide explanations for their responses
    - Asking students to make predictions and explain their reasoning
    - Encouraging students to consider multiple perspectives
    - Encouraging students to support claims with scientific evidence

Pedagogical Content Knowledge

Knowledge of Instructional Strategies

- Teachers' knowledge of strategies to help students understand specific science content—e.g., use of questioning to seed conversations, providing online feed back, collaborative learning situations, and illustrations
- Teachers' knowledge of methods for assessing student learning—e.g., WISE online student notes, listening to students when asking conceptual questions, artifacts such as drawings, science presentations, written tests, and science reports

Knowledge of Students' Science Conceptions

- Teachers' knowledge of students' science ideas around plant biology, including:
    - Knowledge of science concepts in the plant unit that are difficult for students to learn
    - Knowledge of science concepts in the plant unit the are important for student learning

Knowledge of Science Curriculum

- Teachers' knowledge of the curriculum goals for the plant unit, including:
    - Knowledge of sequence of activities to be taught—i.e., the planning phase
    - Knowledge of the science content students are expected to know
    - Knowledge of how to customize the WISE curriculum –i.e., classroom activities and/or recommendations for software improvements

Figure 1.1. Inquiry Science Teaching Model for Looking at Teacher Development.

Trajectories of Teaching

In this section, I discuss what is known about how teachers develop over time with regards to their instructional decisions and pedagogical conceptions in the area of science (e.g., Akerson & Abd-El-Khalick, 2003; Davis, 2004; Loughran, Mulhall, & Berry, 2003). I include associated literature in mathematics. I justify inclusion of studies of mathematics teachers' teaching because mathematics and science are similar in that both are used to answer fundamental questions and find solutions to pragmatic problems (Loucks-Horsley, Hewson, Love, & Stiles, 1998; Schoenfeld, 1992). Finally, I consider studies in language arts as well as and research studies independent of a subject-matter domain that look at teacher development (i.e., Grossman, Valencia, Evans, Thompson, Martin, & Place, 2000; Levin & Ammon, 1996). I justify inclusion of these studies because they are grounded in theory, and provide evidence as to how teachers develop in their understandings across time.

Development in Science and Mathematics

Studying how teachers develop in both their understandings and practice over time is highly complex. As previously discussed, to frame my work I adopt a knowledge integration perspective on teacher development (Linn, 1995; Linn, Eylon, & Davis, 2004).

Davis (2004) illustrates the utility of research on teacher learning guided by Linn's Scaffolded Knowledge Integration framework. Davis's study focuses on the development of pre-service teachers' content knowledge and pedagogical content knowledge across time, thus looking at the integration of the two. Her work focuses on how pre-service teachers add scientific ideas to their repertoire, distinguish between ideas, link ideas, and reconciled ideas. Davis (2004) followed several prospective teachers in an elementary science methods course for a semester, although, to date, she has reported primarily on one participant. Davis traced the teachers' development in subject matter knowledge and pedagogical content knowledge around the following topics: (a) *role of light in vision,* (b) *physics and biology of vision,* and (c) *reflection and absorption of light.*

The research findings indicated that, at the onset of the study, the teacher demonstrated a robust understanding of the topic *role of light in vision*. She linked ideas to scientifically normative principles, including real world experiences. In a second interview (time frame not indicated), the pre-service teacher continued to demonstrate an integrated understanding of the topic *role of light in vision*. In contrast, at the onset of the study, the teacher demonstrated a less integrated understanding of the topic *physics and biology of vision*, including alternative conceptions. For example, the teacher had difficulty linking scientific ideas and distinguishing between ideas. When discussing how to teach the topic *physics and biology of vision*, the pre-service teacher primarily focused on pedagogy rather than the science content. It was not until the end of the second interview that the teacher began to focus on how teach the science (referring to the topic *physics and biology of vision*). Lastly, at the beginning of the study, the teacher held both normative and non-normative ideas with respect to the topic *reflection and absorption of light*. At the same time, the she had well developed pedagogical content knowledge. Over the course of the semester, the teacher reconciled most of her contradictory ideas (referring to the topic *reflection and absorption of light*). As a result of Davis's scaffolding, the prospective teacher was able to add ideas to her repertoire and make links between the ideas. Moreover, the second interview revealed that as a result of the teacher's inability to distinguish between light and heat, she did not see the value in teaching this distinction to her students. Studies that investigate the relationship between content knowledge (i.e., pedagogical content knowledge) and practice can shed light on how teachers learn during the implementation of instructional activities (e.g., Sherin, 2002). Davis (2004) shows how the teacher added new ideas to her repertoire, linked ideas, and made more distinctions among science ideas across time.

This dissertation draws on the contribution of Davis's research which furthers our understanding on changes in teachers' repertoire of ideas across time. While at the same time, I incorporate into the analysis the interplay between knowledge (i.e., pedagogical content knowledge) and practice, and trace the factors that encouraged or supported teachers' development over time.

Theoretical perspectives in mathematics. The work of several math education researchers focus on the process by which teachers learn and the applicable changes in math teachers' practices at the elementary and middle school level. I review two studies in particular that target my areas of concern, Wood, Cobb, and Yackel (1991) and Smith (2000). Both studies draw on Piaget's constructivist theory, focusing on the notion that cognitive conflict can promote learning as well as the view that learners are active constructors of their own learning (e.g., Piaget, 1970; 1980). Their framework also draws on a social interaction epistemology (e.g., Blumer, 1969). Similarly, Linn and Hsi's (2000) model of learning posits that learning is influenced by both individual construction of knowledge and social supports. Thus, the cognitive dilemma perspective argues that reconciling conflicting ideas in one's repertoire can promote understanding.

However, *KI* argues that learners have a repertoire of ideas and illustrate how learners can reinterpret contradictions as contextualized examples (Linn & Hsi, 2000).

Wood, Cobb, and Yackel's (1991) initial intention was to focus on student learning in a second grade classroom, however they found during the initial implementation of the study that the classroom provided learning opportunities for the teacher as well. As a result, their 1991 paper focused most of its attention on the teacher's learning and teacher's beliefs about student learning from a cognitive conflict perspective, which included conflicts the teacher faced when her established ways of practice conflict with her new pedagogy. Thus, their model of teacher learning parallels their model of student learning (Cobb, Yackel, & Wood, 1993).

In Wood, Cobb, and Yackel's research, findings revealed that the teacher faced several tensions over the course of the year. The first tension the teacher struggled with was allowing students the opportunity to express their own mathematical ideas. The teacher's prior teaching experience entailed teaching students mathematical procedures step by step from a teacher's manual. Oftentimes students completed their work individually, with little emphasis on small group interactions and whole class discussions. A second tension existed between steering students toward the correct answers or allowing them to sort out their incorrect answers. By the end of the year, the teacher had taken on a more facilitative role, recognizing that students had unique ways of solving mathematical problems. She also took on the task of understanding students' reasoning for particular mathematical responses (i.e., errors). The teacher began posing "how" questions (e.g., "how can we figure this out?") that allowed students to explain their rationale as well as figure out incorrect answers for themselves during the course of discussions as opposed to telling them the solution or leading them directly to the correct answer. The teacher participated in weekly staff development sessions over the course of the year. During the staff development sessions, the teacher reflected on prior classroom experiences and planned upcoming mathematics lessons with the researchers. The second grade teacher reconciled her contradictory ideas through: (a) ongoing participation in the staff development meetings, (b) and ongoing interactions with her second grade students. This new approach resonates with the SKI framework because it emphasizes adding ideas and sort out a repertoire of ideas.

The focus of Smith's (2000) research study is to further the understanding of the role of conflict in teacher learning. Smith identified particular dilemmas that a practicing middle school science teacher encountered when implementing a math curriculum aligned with the mathematics reform initiatives. Smith provided insight into the teacher's learning process by tracing how particular dilemmas originated, how the dilemmas were resolved, and what factors contributed to the resolution process. Smith extends Wood, Cobb, and Yackel's work by looking at teaching dilemmas within a middle school context as opposed to elementary school.

Smith found that at the beginning of the year, the instructor posed mostly mathematical questions that led to the desired answers. Responses, in unison, were encouraged in answering the teacher-directed questions. The teacher wanted all students to feel a sense of success. As a result, she presented students with less demanding tasks, which consisted of little challenge. In addition, the teacher allocated minimal instructional time for independent and collaborative thinking. At the first staff development session, the teacher was challenged by other colleagues and university resource partners to rethink the aforementioned ideas as the group viewed particular video segments of the teacher's practice which occurred during the first observation cycle. The staff development session appeared to be a triggering event for the teacher, because she began to question whether or not she was structuring lessons too much, etc., which was documented in her journal entries. By the middle of the school year the teacher began to engage the students in considering alternatives, encouraging them to present multiple solutions to a problem. The students were also allowed to question each other for clarification purposes. However, during the second staff development session, it became apparent that the teacher began resorting back to a few of her prior ways of teaching during the later part of the second observation cycle. For example, the teacher was cognizant of the fact that she asked too many leading questions and students knew the answers in advance. Toward the end of the school year, the teacher again began to allow students to tackle more challenging mathematical problems. Much instructional time was allocated toward individualized thinking and small group interactions.

Implications from the Wood, Cobb, & Yackel (1991) study and the Smith (2000) study. Both studies provide evidence of mathematics teachers adapting new instructional practices as well as pedagogical beliefs. For example, both teachers' backgrounds entailed using a traditional approach to teach mathematics. Initially, they struggled with implementing instruction strategies that allowed consideration of alternative solutions. The teachers faced the dilemma of steering students toward the correct answers or allowing individual constructions even if the answers were incorrect. In both studies, the teachers' pedagogical beliefs about how students learned changed by the end of school year. For example, in Smith (2000), the teacher realized that students were not understanding the material or even trying to understand the material at times because her questioning methods were too choppy and directive. She admitted at the end of the year that she struggled with change at times during the year, because change was not always an easy process. As a result, at times the teacher became scared and questioned her own ability as a teacher, thus reverting back to direct instruction when the fear became too overwhelming. The ongoing staff development sessions along with the teacher's personal reflections of her teaching during the meetings (i.e., reflections by the teacher after staff development sessions) served as catalysts for how the teacher resolved the aforementioned conflicts. The study conducted by Wood et al. (1991) discussed particular changes in the teacher's pedagogical conceptions and practices, but was not able to connect these changes to specific experiments. Both studies did a thorough job discussing the possible trajectories of practicing teachers.

I adopt a knowledge integration perspective to view teacher development because the cognitive dilemma perspective depends on direct contradiction and may not take into account the full repertoire of teacher ideas. Like my approach, the cognitive dilemma approach follows specific knowledge processes across time, and provides insights on the relationship between teachers' practices and their pedagogical conceptions. Davis's (2004) research showed development in teachers' content knowledge as they had opportunities to reconcile incompatible scientific principles—i.e., non-normative and normative scientific ideas about light. While at the same time, her work, which is based on a knowledge integration perspective, showed respect for the repertoire of ideas and illustrated how teachers added scientifically normative ideas to their repertoire, linked ideas, and made distinctions among ideas over time. In my study, I investigate what factors contributed to elementary teachers' development in practice and knowledge (specifically pedagogical content knowledge) using the knowledge integration perspective.

Looking at Teachers' Trajectories in Language Arts and within a Non-Subject Matter Domain

To supplement what is known about teacher development in science and mathematics, I reviewed work of several researchers who look at teacher development in the domain of language arts, as well as independently of a subject-matter domain. Below, I consider the work of Grossman et al. (2000) who documents how preservice teachers' conceptions and practices of teaching language arts develop over time, and continue to evolve three years after the completion of the preservice program. Additionally, I review the work of Levin and Ammon (1996) who investigated the evolution of teachers' thinking about pedagogy and cognitive development.

Grossman et al.'s research builds on a sociocultural framework (e.g., Cole, 1996; Grossman et al., 1999). In particular, they focus on activity theory. The underlining assumption behind this perspective is that learners acquire knowledge through participating in particular social contexts. Sociocultural theory also posits that learners' practices develop as a result of their participation in social contexts, in addition to their thinking processes (Grossman et al., 2000). Additionally, Grossman et al.'s work considers the role of tools (i.e., pedagogical) in mediating teachers' understandings and practices of teaching writing (Wertsch & Kanner, 1992). Likewise, the SKI Framework argues that social interactions in classrooms as well as online discussion forums can promote knowledge integration (Linn & Hsi, 2000). A difference between these two theoretical perspectives is that knowledge integration also emphasizes the repertoire of ideas that an individual uses in the social and cultural context.

Grossman et al.*'s* (2000) study focuses on how beginning teachers learn to teach writing over time. They followed 10 beginning teachers into their first three years of full-time teaching, starting in the last year of the teachers' preservice program. This included both elementary and secondary level teachers. In the 2000 study, Grossman et al. report on three of the teacher-case studies.

Findings indicated that the teachers continued to develop in their understanding and practice during the first three years of their full-time teaching experience, drawing on pedagogical ideas introduced during the preservice program. Due to contextual factors in the first year of full-time teaching, two of the three case studies implemented curriculum pedagogy that was contrary to their epistemological beliefs. For example, they believed that students should have ownership of the writing process but did not implement this. In year 2, these teachers modified their practice in the direction of their beliefs which included drawing on pedagogical tools (i.e., practical tools and conceptual tools) introduced in their preservice program. Examples of practical tools were journal writings and writers' workshop, and examples of conceptual tools were concepts of instructional scaffolding and the writing process. Although my study focuses on practicing teachers as opposed to beginning teachers, similar to Grossman et al., I will investigate how teachers develop in their practice and understanding of teaching inquiry science across a three year time period. The lesson learned from this study is that the knowledge and techniques acquired by teachers during a preservice program may not surface until they have successfully completed a year of full-time teaching.

Levin and Ammon's (1996) Study. Levin and Ammon's (1996) research draws on Piaget's constructivist theory; the authors argue that individuals of whatever age attain understanding of the world around them through analysis of their own actions, not merely by memorization or imitation. Thus, the way an individual constructs his or her knowledge involves self-regulation. This perspective and the knowledge integration perspective are both similar and different on several dimensions. For example, both perspectives take the view that learners assimilate new knowledge into their repertoire of ideas, thus not beginning with an empty slate. In other words, individuals construct their own knowledge as they interact with the physical and social world. Drawing on Piaget's work, Levin and Ammon (1996) view development of knowledge in terms of a sequence of stages. Linn and Hsi (2000) extend the work of Piaget by positing that learners develop robust understandings by reconciling a repertoire of ideas that is not tied to stages. Learners are therefore encouraged to build on their repertoire of ideas—i.e., adding new ideas and organizing the ideas in their knowledge structures rather than being viewed as constrained by their stage of development.

Levin and Ammon's research focuses on the development of pre-service teachers' pedagogical conceptions (a teacher's thinking about behavior, development, learning, and teaching) over time. Their work focuses on changes in the knowledge systems as well as the behaviors in teachers. This research study traced a preservice teacher's pedagogical conceptions at the beginning of a two-year credential program, at the end of the pre-service program, and then during his third and sixth year of full-time teaching as a fifth grade teacher (referred to as Time 1, 2, 3, and 4). Levin and Ammon analyzed the teacher's pedagogical perceptions pertaining to teaching, learning, development and behavior using Ammon and Hutcheson's (1989) model of teachers' thinking. This model proposes five qualitative levels of development in teacher's pedagogical thinking. The four dimensions are: *(a) level one—naïve empiricism, (b) level two—everyday behaviorism, (c) level three—global constructivism, (d) level four—differentiated constructivism, and (e) level 5—integrated constructivism* (p. 21). Their study does not look at a teacher's development as part of a particular domain.

Levin and Ammon traced how the teacher developed in his repertoire of ideas across time. Results indicated that the preservice teacher developed in his pedagogical conceptions between the pre-service years and graduation, as well as during his third and sixth year of full-time teaching. For example at the onset of the preservice program (Time 1), the teacher's conceptions about learning and teaching were at a level two and his conceptions about development and behavior were at a level three. To further illustrate, the teacher viewed learning as doing an activity when entering the credential program and viewed learning as more exploratory at the time of graduation. Levin and Ammon also illustrate how the teacher's thinking about teaching and behavior increased to heightened levels by his third year of full-time teaching. Thus, in the teacher's sixth year of teaching, he perceived learning as being able to solve problems while at the same time considered how other internal/external factors such learning styles and environment interacted with the learning process. Moreover, the teacher continued to develop in his pedagogical conceptions across time as a result of having the opportunity to: (a) read and reflect on ideas in educational related books (i.e., fiction books) and compare those ideas to his own teaching, and (b) mentor student teachers in the credential program.

Adopting the Knowledge Integration Perspective

In conclusion, adopting the knowledge integration perspective to view teacher development takes into account the full repertoire of teacher ideas (Linn et al., 2004). Davis's (2004) research furthers our understanding on changes in teachers' repertoire of ideas across time. Moreover, her work showed respect for the repertoire of ideas and illustrated how teachers added ideas to their repertoire, linked ideas, and made distinctions among ideas over time. While at the same time, in this dissertation, I incorporate into the analysis the interplay between knowledge and practice, and trace the factors that encouraged and supported the teachers' development over time.

Review of Methods for looking at Teachers' Development

As discussed at the onset of the chapter, this dissertation reports on two case studies of elementary school teachers learning to teach a science curriculum unit using an inquiry approach supported by the Web-based Inquiry Science Environment (WISE) over three years. My research entailed investigating the teachers' development in both practice and knowledge.

I use data triangulation which entails gathering information at different times, from different people in multiple settings, and methodological triangulation which includes using multiple methods (e.g., interviews, direct observations) to provide evidence of teacher learning. The main purpose of data and methodological triangulation is to ensure that assertions are not made haphazardly, but verifiably. I anchor the analysis of practice around Linn's Scaffolded Knowledge Integration framework.

Similar to Davis (2004), in order to trace changes in each category of pedagogical content knowledge (see Figure 1.1 for detail), I looked for evidence of knowledge integration activities for teachers proposed by Linn and Hsi (2000), which include adding new ideas to their repertoire, sorting ideas, reconciling ideas that appear contradictory, and integrating preexisting and new ideas.

Organization of the Dissertation

I organize the remainder of this dissertation in six chapters. In chapter 2, I discuss the WISE curriculum design process for the *Plants in Space* project and provide an overview of the WISE plant curriculum materials.

In chapter 3, I discuss the research design and methods used in this study. I use a qualitative case study research design. I trace two teachers' (a novice and an experienced teacher) development with respect to their instructional decisions and the relations between knowledge and practice as they implement the WISE plant curriculum over a three year time period.

In chapter 4, I provide background on the context in which the two teachers implemented the plant project (i.e., the curriculum coverage). I also examine these teachers' students' progress across the three year time frame, which entailed analyzing their students' in-class-work (WISE online notes). In many respects, the student results validate the teacher performance observations and contribute to an integrated view of the trajectories.

In chapters 5 and 6, I discuss how the teachers learn to teach inquiry science in a technology-based environment over the course of three years. This involves discussing changes in the teachers' practices and understandings, including examining what factors encouraged or supported the teachers' development. Chapter 5 concludes with a discussion of what constitutes a trajectory, which is informed by data analysis.

In chapter 7, I look at how the novice teacher is similar and different from the experienced teacher.

In chapter 8 (the final chapter), I discuss my conclusions and implications for research.

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[1] WISE is supported by the National Science Foundation. The website was developed at the University of California at Berkeley seven years ago.

[2] I draw on the following participant-observation methodology: e.g., Emerson, Fritz, & Shaw, 1995.

CHAPTER 2

WISE AND THE PARTNERSHIP DESIGN PROCESS FOR THE *PLANTS IN SPACE* CURRICULUM

Introduction

In this chapter, I discuss the WISE curriculum design process for the *Plants in Space* project and provide an overview of the WISE plant curriculum materials. In brief, the WISE plant curriculum asks students to determine the specific conditions for plant growth. Teachers guide their students to reasonable hypotheses concerning plant development and growth. The curriculum and teaching practices in WISE were designed using the Scaffolded Knowledge Integration framework to support inquiry learning (Linn & Slotta, 2000). WISE helps students connect scientific concepts to pre-existing knowledge as well as build on their initial understandings (Ammon & Black, 1998; Bransford, Brown, & Cocking, 1999; Lampert, 2001; Linn & Hsi, 2000; Palincsar & Brown, 1984; White & Frederiksen, 2000).

The WISE environment offers research-tested activities for students (Linn, Clark, & Slotta, 2003). WISE projects integrate the Internet and feature software tools (i.e., an inquiry map, note-taking and data analysis tools, and electronic discussions); activities are combined in curriculum design patterns that enable students to pursue a line of inquiry (Linn et al., 2003). WISE features support students' knowledge integration by (Linn & Slotta, 2000): (a) modeling inquiry with navigations systems, (b) supporting peer-interactions through online discussions and debates, (c) prompting predictions and explanations, and (d) providing models and explanations with varied representations to make their scientific thinking visible. For example, *Plants in Space*, the WISE software makes students' thinking visible by scaffolding their activity as they make predictions, draw inferences, compare plant growth, collect data, graph results, and analyze findings.

Not only does WISE enhance student learning of scientific content, WISE also supports teachers by providing them with the capability to respond electronically to students' online work and by giving detailed accounts of student learning (Slotta, 2004). WISE projects enable teachers to interact with students about science concepts. Teachers contribute to students' knowledge integration process by asking students to reflect on scientific evidence in the projects, make links between scientific ideas, explain their reasoning, and provide evidence to support claims.

Partnership Design Process

The WISE *Plants in Space* curriculum unit was designed by a multidisciplinary partnership of individuals that jointly created and tested the curriculum materials (Linn, Shear, Bell, & Slotta, 1999). This partnership included teachers in urban schools, a professor of Integrative Biology at the University of Texas at Austin, a scientist at NASA Kennedy Space Center, science education researchers, and technology specialists. A Web-based discussion forum was used to develop and design the *Plants in Space* curriculum, in addition to face to face meetings.

Creating an environment of mutual respect is essential to the success of a partnership. We designed activities to ensure that the partners supported each other's professional development and built on each others' ideas. Each member, whether an educational researcher, a teacher or a scientist, came to the community with a unique set of pedagogical commitments, and collaborated to design the goals for *Plants in Space*. For example, several researchers and a scientist suggested having the students design a hydroponic garden in the classroom to simulate a space environment. They further suggested including nutrition, specifically fertilizer, as a factor in plant growth. Another scientist-partner was concerned that hydroponic gardening could confuse students and advocated an ecological perspective, commenting, "*Scientifically, we are rather ignorant about the symbiotic aspects of soil, organisms, and plants, and eventually the health of animals. But, as ecologists we know that there is a lot of important work needed to be learned about these underground aspects of a living community.*" Eventually, the group decided to limit attention to plant nutrition in favor of photosynthesis.

In another example, the community members contemplated whether to develop a debate or critique unit as a prelude to a design unit on light conditions and plant growth. Two partners (Scientist Katherine and Teacher Lee), considered this choice:

> **Teacher Lee:** *Based on my experience, I think the unit should allow students to debate their ideas. At this age students have a natural tendency to argue. I have found that mediated debate gives them the opportunity to air their views in a socially accepted manner and to take risks.*
>
> **Scientist Katherine:...***Do you think students would be interested in debating what light conditions would promote faster growth in plants? For example, present them two different lighting conditions and have them make a prediction as to which one would grow faster. Then present them with evidence pages and a hands on activity.*
>
> **Teacher Lee:** *I'm not sure that a debate would serve the purpose of preparing students for the design unit. The more I think about it, perhaps more of an inquiry based lesson would be more appropriate. Student prior knowledge needs to be established. What do students know about plants? What do students know about space? /gravity? /the importance of oxygen? What do students know about phototropism? What are their thoughts on the importance of having plants in space? What do they want to learn about these things?*
>
> **Scientist Katherine:** *After investigating further, I keep coming up with the following dilemma; a debate can only focus on one*

factor of the effects of light on plant growth, whereas a critique could cover multiple factors. Because we will want to incorporate multiple factors of light and plant growth in the design unit, a critique format may be better suited to our needs. Specific factors to be investigated could include; wavelength, intensity, direction of light and time exposure…For a critique project, the cognitive goal would be to investigate light, plant growth and the relationship between the two.

Teacher Lee: *I think I now have a better idea of how a critique format would look…I think what you have described is going in the right direction.*

Through many meetings and electronic discussions, the group reached a consensus. We decided to develop a curriculum that consisted of two WISE software projects, *What Makes Plants Grow?* and *How do Earth and Space Plants Grow?* The curriculum design team was challenged to make science relevant to the different cultural contexts at schools. Many children did not have a garden at home. For that reason, we included a hands-on activity in the curriculum that allows students to design a plant growth chamber for an imaginary space flight mission.

The electronic discussions were professional development for Teacher Lee because it supported his pedagogical content knowledge development (see chapter 5 for more detail). For example, as a result of Lee's participation in this design process for the plant curriculum and his experience with the tensions between a debate or a critique project, he was able to sort out these conflicting ideas over time through his participation in the online discussion forum with the WISE scientists.

WISE *Plants in Space* Curriculum

Background on WISE

The Web-based Inquiry Science Environment (WISE) is a free, online science-learning environment for students in grades 4-12. Supported by a National Science Foundation grant to Dr. Marcia C. Linn, WISE has developed and tested over 30 projects in the last seven years to qualify for the WISE Project Library. Similar to *Plants in Space*, other WISE projects were created by multidisciplinary partnerships.

To implement a WISE project, teachers need to have computers and an Internet connection. The WISE support team recommends Power Macintoshes, running Mac OS 8.0 or later, or Pentium PC's, running Windows 95 or later. Each computer must have an Internet browser such as Netscape Navigator 4.08 or higher or Microsoft Internet Explorer 4.5 or higher. Online resources including lesson plans, assessments, and relevant science standards assist new users in preparing to run a WISE project.

When teachers register to use WISE (http://wise.berkeley.edu), they gain access to over 30 inquiry science projects such as *Plants in Space* created by partnerships on topics relevant to standards for each grade level. The project library provides information to help teachers select a project appropriate to their curriculum. For example, students can study plants, water quality, heat and temperature, rain forest interactions, life on Mars, and light. WISE suggest that teachers pair up students to conduct investigations in class and via the Web. Once a project is selected, students and teachers conduct an investigation in class, and via the Web, communicate directly with scientists or other students to share their experiences, and use evidence to reach conclusions.

Plant Curriculum Activities

Using *Plants in* Space, students increase their understanding of plant growth and development by critiquing Internet evidence, conducting classroom experiments, and discussing ideas (Williams & Linn, 2002). The overarching goal of the curriculum unit is for fifth-graders to determine which crop (earth plants or AstroPlants—a type of Wisconsin Fast Plant ™) is best suited for accompanying NASA scientists on an imaginary space flight mission. This question is answered through scientific investigations online and also growing real plants in the classroom for comparison. For example, fifth-graders utilize the World Wide Web to investigate factors needed to sustain plant life on earth and in space, and compare different conditions for growing plants. They grow earth plants and Wisconsin Fast Plants under varied light conditions to simulate growth in space. The goal here is for students to develop an understanding of why light is important to plants and how it is an integral part of the internal production of food (i.e., glucose or sugar), regardless of the context in which plants are grown. Students make links between scientific ideas such as the color changes of plants' leaves, the reduction in the amount of chlorophyll, and plants' inability to perform photosynthesis.

Additionally, *Plants in Space* affords students the opportunity to connect science class ideas to personally relevant problems and prior knowledge through conducting the plant observations and online investigations. Students are also presented with opportunities to revise their initial conceptions—i.e., non-normative ideas such as light is food for plants and light is used to keep plants warm (discussed in chapter 4).

The WISE *Plants in Space* curriculum unit meets fifth-grade content and inquiry standards—connecting to the Benchmarks for Science Literacy, National Science

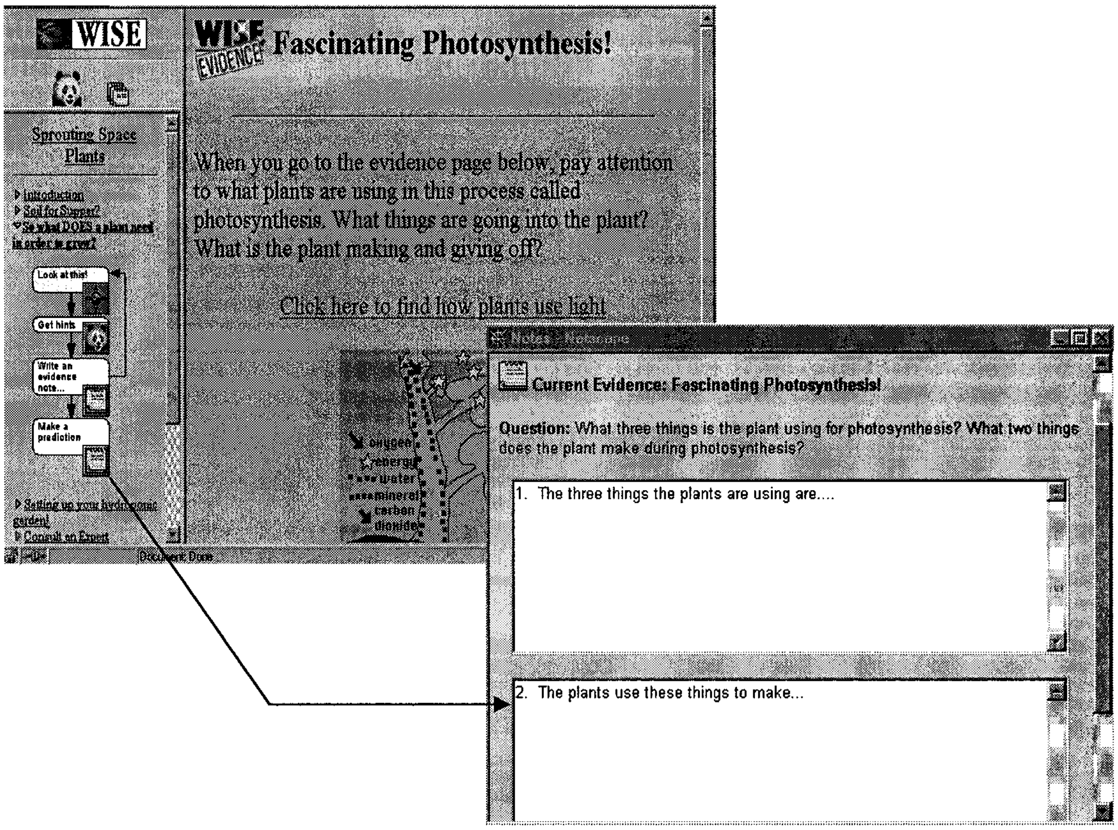
Education Standards and the Science Framework for California Public Schools—while also promoting technology and language literacy (American Association for the Advancement of Science, 1993; California Department of Education, 2003; National Research Council, 1996). For example, the National Science Education Standards emphasize that all students in grades five through eight should develop *abilities necessary to do scientific inquiry* and *understandings about scientific inquiry* (NRC, 1996, p. 143). The plant unit aligns with the National Science Education Content Standard C—Life Science: Populations and Ecosystems. The curriculum is broken down into a total of six key science topics: (a) *light/photosynthesis*, (b) *hydroponics*, (c) *conditions in space*, (d) *nutrients*, (e) *comparing plants life cycles*, and (f) *graphing data*. *Light/photosynthesis* is the core science topic, while the other five topics revolve around it (more detail is provided in chapter 4).

Figure 2.1 below describes how the WISE *Plants in Space* curriculum can be taught over a six week period. The curriculum unit involves both classroom investigation and Internet activities. Although the curriculum lesson plans (Appendix A) suggest a time frame for each activity, teachers can choose whether to allocate more or less time to a given activity. WISE gives teachers the flexibility to customize curricular units to their classroom needs. In chapter 4, I discuss how the two teachers in my study made particular customizations to the plant curriculum unit such as designing repeated classroom activities on the core science topic *Light/photosynthesis* to further assess their students' understanding of this topic. Below I provide an overview of the *Plants in Space* curriculum activities, and Appendix A contains additional detail.

Identify factors affecting plant growth	Pairs of students make online predictions about what plants need to live and discuss this with classmates. Using the Internet, students explore sustaining plant life on Earth and in space. Students take online evidence notes, participate in small group and whole group electronic discussions, and seek electronic guidance when needed.
Discuss plant needs with peers or scientists	Students discuss plant needs with peers or scientist partners in online discussions. They assess the challenges of growing plants in space and other extreme situations such as a desert environment (optional).
Grow plants under varied conditions	Students compare a hydroponic and soil garden, contrasting three different durations of light per day (0, 12, and 24 hours) with two types of plants (radishes and AstroPlants—a type of Wisconsin Fast Plant ^{tm}).
Record and interpret data	Students compare plants by observing the height and stage in the life cycle. They record features such as height, number of leaves, number of flowers, etc. They learn that radishes grow taller and go through their life cycle slower than AstroPlants; they observe that 24 hours of light results in optimal plant growth.
Analyze results	Students pool their data and discuss plant life cycles and plant height. They consider which features are best for growing plants in space.

Figure 2. 1. Summary of the *Plants in Space* Project Activities.

Identifying factors affecting plant growth (the first two weeks). The project—*What makes plants grow?* begins with pairs of students making online predictions about what plants might need in order to live. Students defend their predictions to classmates. Using the Internet, students then critique Web-based evidence about the role of light, water and nutrients in sustaining plant life on earth. Figure 2.2 below shows an example of a WISE evidence page. For example, students investigate the role of light in the photosynthesis process for plants. This entails taking online evidence notes, participating in small group and whole group class discussions, and seeking electronic guidance when needed.



Fascinating Photosynthesis!

When you go to the evidence page below, pay attention to what plants are using in this process called photosynthesis. What things are going into the plant? What is the plant making and giving off?

Click here to find how plants use light

Current Evidence: Fascinating Photosynthesis!

Question: What three things is the plant using for photosynthesis? What two things does the plant make during photosynthesis?

1. The three things the plants are using are....

2. The plants use these things to make...

Figure 2.2. Internet Evidence Page and Note from the What Makes Plants Grow Project in WISE.

Discuss plant needs with peers or scientists (intermittently over the six weeks). Through the investigation, students can utilize the discussion forum to discuss the progress of their plant studies with collaborating scientists or their peers. Brown and Campione's (1996) research on *Fostering Communities of Learners* emphasizes the importance of linking teachers and students to a broader community. They point out that, "*Extending the learning community beyond the classroom walls to form virtual communities across time and space not only enriches the knowledge base available to students but also exposes them to models of reasoning and reflection about the learning process"* (Brown & Campione, 1996, p. 300). Online communities can also support teachers' content knowledge development. Figure 2.3 below shows an example of an online conversation between fifth-grade students and scientists. WISE provide teachers with the capability to create the topic of discussion. This particular WISE activity is optional for teachers.

Online discussion question:

Can plants where you live grow in the desert? Why or Why not?"

Shelly/Mia: "We don't think plants that live in our environment can grow in the desert. We know that most plants living around us need water almost every day. Therefore, most plants around us can't live in the desert because the desert does not get enough rain. What other plants besides a cactus can grow in the desert?"

Scientist D: "I've seen some scrubby trees growing in the desert, up on the rocky hillsides. I wonder, what would allow some plants to grow in the desert and not others?"

Thomas/Michael: "Some plants can grow in the desert because they have water inside of them."

Shelly/Mia: "We think we know the answer to your question. We think that some plants are used to hot air and some are used to more cold air than hot air."

Erika/Mary: "Some plants CAN grow in the desert such as grass. The reason we think that grass can grow in the desert is because grass makes its own moisture. That means that it can survive in the desert and won't become dehydrated."

Scientist T: Most plants that live in temperate climates (like most of the U.S. where they have four "normal" seasons) cannot tolerate long periods without water. Desert plants (cactus is only one type) can tolerate long dry periods because of a number of adaptations. Many have a thick, waxy skin to prevent drying out and can store water for long periods. Plants have small pores that they can open or close to breathe called stomates and many desert plants keep their stomates closed during the day and only breathe in carbon-dioxide at night when it is cooler and not so dry. Others have very deep root systems to find any water that is available. Many of them can flower and produce seed in a very short period of time to take advantage of short wet seasons. So they have adapted over many years to their particular environment. Other examples of desert plants are sages, rice grass, horsebrush, pickleweed, and juniper. These are all small brush or bush-like plants that have adapted to dry climates."

Figure 2.3. Excerpts from Online Discussions between Fifth-Grade Students and Scientists.[1]

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[1] The names have been changed to preserve anonymity.

Critique evidence about conditions in space (four weeks). During the second phase of the project, students conduct online investigations of conditions on the NASA space shuttle (i.e., the amount of space in a shuttle, the type of lighting source used on NASA shuttles, and so on). They answer how these conditions restrict which plants are more feasible to grow in a space shuttle environment based on the plants' life cycles. Students also take online notes as they discuss scientific conditions about the life cycles of plants. These activities were chosen because the curriculum design team wanted students to understand that there are benefits associated with both earth plants and AstroPlants. If the goal is to conduct research at various stages of a plant's life cycle during a short space flight mission, then the AstroPlant (an AstroPlant can go from seed to seed in 30 days) would be the better option in comparison to the radish plant (referred to as earth plants). If the goal is to have fresh vegetables on the space shuttle, then radishes would be the better option. However, AstroPlants could be used for this purpose also, if scientists grow more of them since they are extremely small plants. Since space is limited on a shuttle, the height and width of a plant matters a great deal.

Growing plants under varied conditions (concurrent with critique of evidence about conditions in space, three weeks). Students design experiments, record data, interpret findings, and analyze results. They set up hydroponic gardens under three different lighting conditions (0, 12, and 24 hours—see Figure 2.4 for an example of a hydroponic garden). Students grow two types of plants: earth plants (radishes) and AstroPlants (a type of Wisconsin Fast Plant ™). Each pair of students plants the two types of plants in a 12-hour lighting environment. One-half of the pairs of students plant the two types of plants in a 24-hours lighting environment, and the other half plant the two types of plants in a no-light environment. All students are informed that they will be growing both Fast Plants and earth plants. They are assigned variables for the two types of plants. For example, the Fast Plant seeds are labeled as the "A" plants and the radish seeds are labeled as the "B" plants. The overarching goal for the WISE plant unit is for fifth-graders to determine which crop (earth plants or AstroPlants) is best suited for accompanying NASA scientists on an imaginary space flight mission. Students observe plant growth and development daily. They record quantitative results for height, number of leaves, and number of flowers. They also record qualitative differences in appearance. Extension activities (refer to Appendix A for detail) are suggested to teachers to further extend students' knowledge.

Figure 2.4. A Hydroponic Garden that Students built.

In conclusion, participating in a project such as *Plants in Space* helps students learn how to plan research, record data, reflect on their results, and extrapolate from them (Williams & Linn, 2003). The WISE interface provides a navigation system that scaffolds the scientific process. Students are guided to gather evidence, record observations, and reflect on their work. Teachers can review students' notes online. In chapter 4, I provide background on the context in which the two teachers in my dissertation study implement the plant project (i.e., the curriculum coverage, the teachers' customizations to the instruction). I also examine the students' progress across the three year time frame, by analyzing their in-class-work (WISE online notes).

CHAPTER 3

RESEARCH DESIGN AND METHOD

Research Strategy

As discussed in chapter 1, the overarching question for this dissertation is:

> *What are the trajectories of elementary school teachers learning to teach a science curriculum unit using an inquiry approach in a Web-based Inquiry Science Environment?*

To answer, I focus on the following sub-questions: (a) What is the interplay between teachers' practice and their pedagogical content knowledge as they implement a technology-based curriculum? (b) How did more effective practices emerge as a result of using technology, and what were they? (c) What supported the teachers' development? To address this organizing question and its related sub-questions, I utilized a mixed methods case study research design. To capture trajectories of change in elementary teachers' practices and pedagogical content knowledge across time, I collected three types of data: (a) open-ended interviews, (b) direct observations (fieldnotes supplemented with videotape and audiotape), and (c) teachers' written reflections. These data were gathered at the two case studies' school sites over a period of three years.

School Contexts

This three-year study of two fifth grade teachers, Lee and Alice, was conducted at two elementary schools located in a West Coast Metropolitan area. Each school is located in a different school district. Lee teaches at Madison Elementary School, and Alice teaches at Parker Elementary School.

Madison School enrolls 206 students. The school serves an urban population. The ethnicity for the student body is 95.1% African American, 1.5% Pacific Islander,1% Caucasian, 1% Hispanic, 0.5% Filipino, and 1% Other. Students are socio-economically diverse, in that some are from two parent working families in the neighborhood, and others are bused or driven in. A number of students at Madison live in foster families. More than 46% of the student body receive free or reduced meals. There are no special assistance programs in operation at Madison School, except special education for fourteen students out of the 206.

Parker School enrolls 443 students. The school serves an urban population, including ethnically and socio-economically diverse students. The ethnicity for the student body is 26% Hispanic, 23% Asian, 20% Filipino, 17% Caucasian, 8.9% African American, and 1% Native American. Approximately 29% of all students at Parker School are enrolled in the Economic Impact Aid (EIA) program for limited-English proficiency students. Free or reduced meals are provided for students who qualify.

Teachers

Teacher-participant Lee. Lee is an experienced African American teacher excited about teaching inquiry science with a technology-based learning environment. He is experienced with computer technology, inquiry, and science. Prior to implementing the WISE project—*Plants in Space*, Lee had 11 years of classroom teaching experience with a multiple subject credential and a Master's in Educational Technology and Instructional Design. Several years prior to his involvement with WISE, Lee received a Silicon Valley PC Day II technology grant (i.e., six PCs that were connected to the Internet) for his fifth grade classroom, but faced the dilemma of not knowing what to do with a networked environment. WISE enabled him to integrate the World Wide Web into the core content area of science in a meaningful way.

Lee was a co-developer of the WISE *Plants in Space* curriculum and participated in the re-design process. He taught the plant curriculum unit during all three years and, although Lee teaches multiple subjects (i.e., social studies, reading, language arts, and mathematics), he allocates a substantial amount of time daily to the teaching and learning of science. Each year Lee had students collaborate in pairs as they conducted online WISE investigations and hands-on science experiments. He rotated groups of students through the classroom computers in years one, two and three. In year 2, I assisted Lee's school in writing a successful grant proposal for a Hewlett-Packard K-12 Silicon Valley Technology Grant. This grant provided the teacher with more networked computers in his classroom.

Lee participated in several professional development workshops at both the university and the school site over the course of the three years, all of which were coordinated by me (refer to Table 3.1 for details). Lee also became a mentor to other teachers who were not a part of the study during the WISE teacher workshops. The topics of the meetings included: (a) discussions around core science content in the WISE plant curriculum and student science ideas (i.e., students' initial conceptions and science content ideas in general), (b) teacher reflections on prior experiences running WISE in the classroom, (c) customization of the *Plants in Space* curriculum unit, and (d) lesson planning.

Teacher-participant Alice. Alice is a white teacher very motivated to implement an inquiry classroom. She is a novice teacher with limited experience with technology, inquiry, and science. Prior to implementing the WISE plant curriculum, Alice had two and a half years of classroom teaching experience with a multiple subject credential. She indicated early on that she had little science content knowledge in general, but was willing to learn with her students. WISE offered her the first real opportunity to integrate technology into her classroom practice in a meaningful way.

Alice taught the WISE plant curriculum during each year to her fifth grade students along with reading, language arts, mathematics and social studies. Similar to Lee, Alice allocated a substantial amount of time weekly in all three years to the teaching and learning of science. Each year she had students collaborate in pairs as they conducted online WISE investigations and in-class experiments. In year one, Alice took her students to the computer lab because she only had a few computers in her classroom. In year two, she decided to rotate groups of students through the classroom computers rather than use the laboratory, since her school had been awarded the Hewlett-Packard K-12 Silicon Valley Technology Grant. The granted provided Alice with more networked computers in her classroom. In year three, Alice continued to rotate groups of students through the classroom computers, but occasionally took the students to the school laboratory as well.

Alice participated in several professional development meetings at the school site in years one, two and three, all of which were coordinated by me (refer to Table 3.2 for details). Two other fifth grade teachers participated in the meetings. The topics of the meetings ranged from lesson planning, discussions around core science content in the WISE plant curriculum, and students' science ideas, to students' initial conceptions/science content ideas in general.

Research Approach and Data Sources

This qualitative case study traces the teachers' development with respect to their instructional decisions and the relations between knowledge and practice as they implemented the WISE plant curriculum over a three year time period. Using case studies as a research design is particularly useful in exploring the *processes* and *dynamics* of practice (Merriam, 1988). This type of research design enabled me to investigate individual teachers in a systematic way for an extensive period of time.

Merriam (1988) and Denzin (1978) propose several strategies for enhancing the internal validity of research findings in case studies. The strategies I draw on include: triangulation of multiple data sources, long term observations at the research site, and peer examination (i.e., other researchers reviewing findings as they emerged). My multiple sources include direct observations, interviews, and the teachers' written reflections to gather information from an individual over the 3-year time frame (see Tables 3.1 and 3.2 below). Observations of phenomena provide detailed descriptions of individuals' activities, actions, and behaviors (Patton, 2002). Interviews allow for open-ended questioning and probing, thereby enabling me to gain insight into teachers' experiences, knowledge, and perceptions (Weiss, 1994). Materials such as teachers' written reflections provide records of what they think regarding their teaching and student learning in the context of their classrooms.

To increase the internal validity of my assertions about teacher change, at different points in time, the participants were asked to comment on observations and findings—a method Merriam calls 'member checks.' This also entailed soliciting the participants' own attributions for the factors that led to the changes I observed in their instructional practices and pedagogical conceptions. To further enhance the validity of the research findings, other researchers were asked to comment on findings as they emerged.

The teachers were observed and videotaped teaching the plant curriculum once to three times a week for approximately three months in years one, two and year three. Videotaped recordings of the teachers' and students' interactions at different points in time, in both whole and small group settings, were used to identify patterns of change for triangulation purposes.

Prior to implementing the WISE project in year one, an extensive interview was conducted with Alice and Lee which focused on their background with technology and science, and their pedagogical beliefs (refer to Tables 3.1 and 3.2). Alice participated in five interviews during year two and four interviews in year three, including before and after implementing the WISE plant curriculum unit. Lee participated in five interviews in year three. (No interviews were conducted with Lee in year two, only professional development meetings.) My methods evolved as a result of observing Lee's teaching the WISE plant unit for a second time, as a result the number of interviews with Alice expanded. Both teachers were asked to reflect on changes in their pedagogical practices (in both the content area and in general) and to comment on the fifth-graders' conceptions around key science ideas. Post interviews were coordinated with repeated science lessons observed across time, anchoring the analysis of practice around the Scaffolded Knowledge Integration framework (Linn, 1995; Linn & Eylon, 1996; Linn & Hsi, 2000).

These teacher interviews also served as professional development activities for the teachers, because they required Lee and Alice to constantly reflect on their practices and pedagogical content knowledge over the three year span. Teachers' thinking can be made visible when they have opportunities to add new ideas to their repertoire, link ideas, and make distinctions among scientific ideas across time (Davis, 2004).

Table 3.1. Summary of Data Sources for Lee.

Time Period	Focus of Data Collection	Method	Type of Data	Frequency of Data Collected
Spring 2000[a]	Teacher's background, instructional practices and curriculum goals	Interview	Audiotape and transcript	1
	Classroom instruction	Direct observations	Videotapes and transcripts	7[b]
	Professional development meeting with Lee and other teachers after the WISE run (i.e., discussion about teacher's prior experience, student learning and science content)	Direct observation and facilitation	Audiotape and transcript	1
Spring 2001[c]	Classroom instruction	Direct observations	Videotapes and transcripts	11[d]
	Customization workshop with the teacher on the plant curriculum, including discussion of instructional practices, curriculum goals, and students' conceptions about the science content	Direct observation and facilitation	Videotape and transcript	1
Spring 2003[e]	Professional development meetings prior to running WISE (i.e., struggles teacher faced with district policies, lesson planning)	Direct observations and facilitation	Audiotapes and transcripts	2
	Teacher's reflections on instructional practices, curriculum goals and students' conceptions of the science content; retrospective interviews on teaching and pedagogical conceptions	Interviews	Audiotapes and transcripts	4
	Classroom instruction	Direct observations	Videotapes and transcripts	13[f]

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[a] Spring 2000 represents year 1.

[b] Williams observed Lee teaching a total of seven lessons across five and a half weeks in year 1 (Spring 2000) during the implementation of the WISE plant project.

[c] Spring 2001 represents year 2.

[d] Williams observed Lee teaching a total of eleven lessons across eight weeks in year 2 (Spring 2001) during the implementation of the WISE plant project.

[e] Spring 2003 represents year 3. Lee did not run WISE in the Spring of 2002.

[f] Williams observed Lee teaching a total of thirteen lessons across eleven weeks in year 3 (Spring 2003) during the implementation of the WISE plant project.

Table 3.2. Summary of Data Sources for Alice.

Time Period	Focus of Data Collection	Method	Type of Data	Frequency of Data Collected
Spring 2001[a]	Teacher's background experiences teaching technology and science, instructional practices, and curriculum goals	Interview	Audiotape and transcript	1
	Classroom instruction	Direct observations	Videotapes and transcripts	6[b]
	Reflections on teaching practice	Self-report	Written artifacts	5
	Professional development meetings with 5th grade teachers (i.e., lesson planning; reflection on WISE experiences, student learning and science content)	Direct observations and facilitation	Audiotapes and transcripts	5
Spring 2002[c]	Teacher's reflections on instructional practices, curriculum goals, and students' conceptions of the science content; retrospective interviews on teaching and pedagogical conceptions	Interviews	Audiotapes and transcripts	5
	Classroom instruction	Direct observations	Videotapes and transcripts	13[d]
	Professional development meetings (i.e., lesson planning; reflection on students' conceptions and science ideas)	Direct observations and facilitation	Audiotapes and transcripts	3
Spring 2003[e]	Teacher's reflections on instructional practices, curriculum goals, and students' conceptions of the science content; retrospective interviews on teaching and pedagogical conceptions	Interviews	Audiotapes and transcripts	4
	Classroom instruction	Direct observations	Videotapes and transcripts	13[f]
	Professional development practices of 5th grade teachers (i.e., lesson planning, and discussion of students' science ideas)	Direct observations and facilitation	Audiotapes and transcripts	2

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[a] Spring 2001 represents year 1.

[b] Williams observed Alice teaching a total of six lessons across five weeks in year 1 (Spring 2001) during the implementation of the WISE plant project.

[c] Spring 2002 represents year 2.

[d] Williams observed Alice teaching a total of thirteen lessons across eight weeks in year 2 (Spring 2002) during the implementation of the WISE plant project.

[e] Spring 2003 represents year 3.

[f] Williams observed Alice teaching a total of thirteen lessons across eight weeks in year 3 (Spring 2003) during the implementation of the WISE plant project.

Data Analysis Procedures

This section discusses various analytic techniques that allow interpretations and comparisons to be made from the data, as opposed to providing a descriptive analysis (Strauss & Corbin, 1990). These techniques enable me to make some generalizations about trajectories of change of elementary school teachers who have learned to teach inquiry science using technology-based curriculum. Below I discuss the analysis of this data, before proceeding to the interpretation section.

Organizing the Data

As mentioned at the onset of the chapter, I divided my research into three sub-questions in order to trace how two teachers learn to make their students' thinking visible across time using WISE and how they respond to students' ideas to promote complex thinking about plant growth and development. I coded transcripts of classroom observations (i.e., from the videotapes) to identify patterns of change in Lee and Alice's classroom teaching and to document what new or enhanced practices emerged. In Figure 3.2, I illustrate my coding method by providing examples taken from practice. I will discuss these themes in more depth later in this chapter, as well as provide interpretations in chapter 7. I analyzed the interview data and teacher-meeting data to identify patterns of change in the teachers' pedagogical content knowledge. Retrospective interview transcripts and transcripts of professional development meetings were examined to provide insight into what factors encouraged or supported the teachers' development.

I used the qualitative software program NVivo to organize and code the large body of data. Individual projects (databases) were created for both case studies.

Transcripts of classroom observations were coded for questioning patterns. Interview transcripts were coded into themes across the three year time period, which were based on the inquiry science teaching model. I used NVivo's search features to search interviews, classroom observations, and teacher meetings for key words or phrases. The search features also allowed quick retrieval of all coded data for the purposes of developing text reports and identifying emerging patterns in both Lee and Alice's classroom practices and pedagogical conceptions.

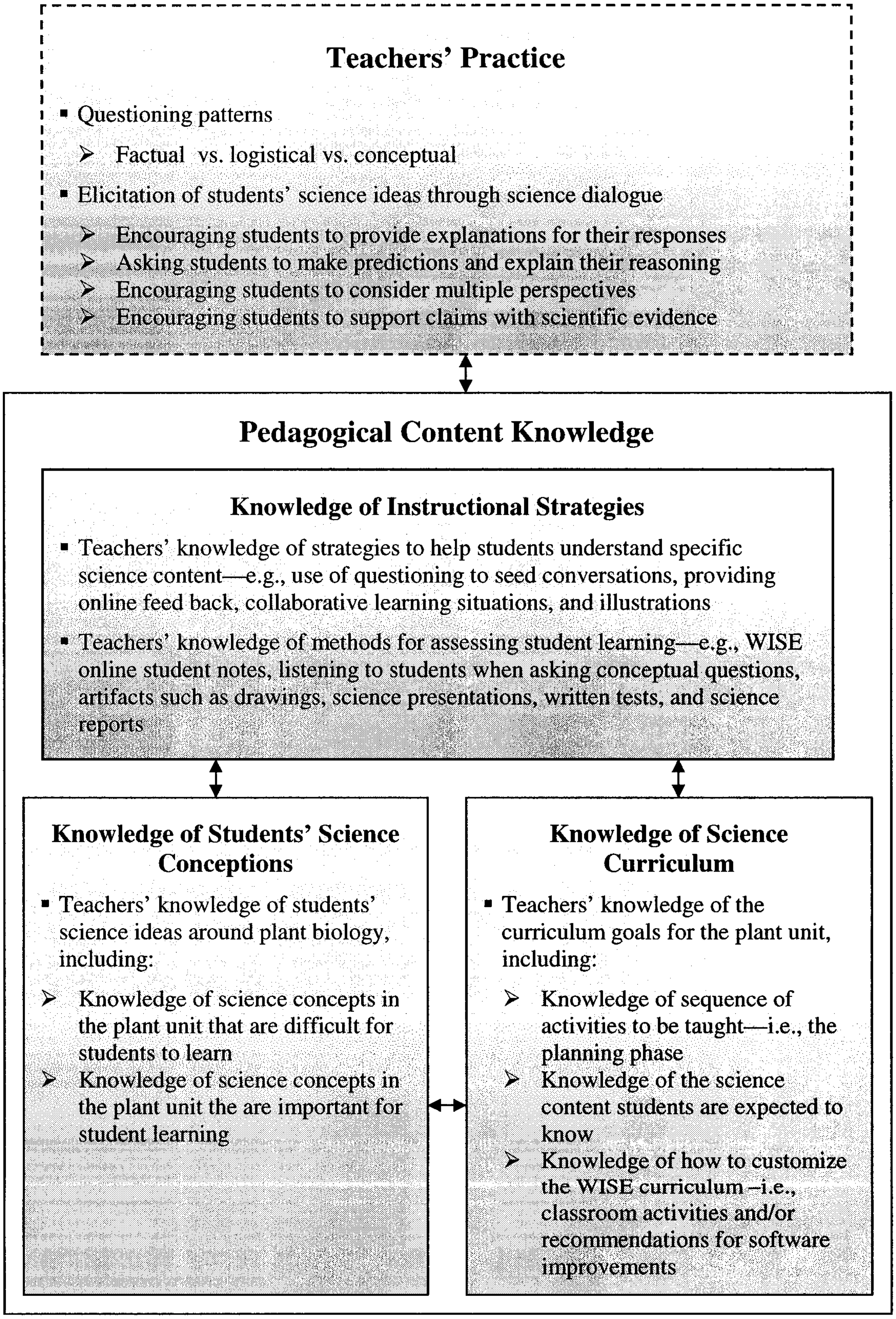
Method of Analysis

This section describes the specific methods used for analyzing the two dimensions, *teachers' practice* and *pedagogical content knowledge*. Below I discuss how I code for these two variables—practice and knowledge.

Teachers' Practice

To capture the trajectory of change in the ways elementary teachers come to make students' scientific thinking visible through the use of technology over time, I analyzed the data in two ways: (a) Questioning Patterns—categorization of methods of questioning for key topics/lessons that occurred in Lee and Alice's practice across all three years, and (b) Science Dialogue—an analysis of the ways Lee and Alice elicited students' ideas in science dialogues with small groups during their second and third year of teaching the WISE plant curriculum. As Linn and Hsi (2000) point out, eliciting students' prior knowledge about a scientific topic and encouraging them to connect existing and new ideas can promote knowledge integration. However, some logistical and factual questions are appropriate. Figure 3.1 below shows how I transformed the aforementioned categories—questioning patterns and science dialogue into a coding scheme.

These two analytic strategies, questioning patterns and elicitation of students' ideas through science dialogues, allowed me to trace how the teachers' classroom practices shift over time and to identify the emergence of new/enhanced practices as they implement the WISE plant curriculum. Specifically, I used the first analytic method to capture what kind of questioning strategies the teachers used to get at students' non-normative and normative scientific ideas (i.e., prior knowledge) about plant growth. The second analytic method enabled me to analyze particular interactions between the teachers and students, including how the teachers helped students to add new ideas to their repertoire, sort ideas, and reconcile ideas that appeared contradictory.



Teachers' Practice

- Questioning patterns
    - ➢ Factual vs. logistical vs. conceptual
- Elicitation of students' science ideas through science dialogue
    - ➢ Encouraging students to provide explanations for their responses
    - ➢ Asking students to make predictions and explain their reasoning
    - ➢ Encouraging students to consider multiple perspectives
    - ➢ Encouraging students to support claims with scientific evidence

Pedagogical Content Knowledge

Knowledge of Instructional Strategies

- Teachers' knowledge of strategies to help students understand specific science content—e.g., use of questioning to seed conversations, providing online feed back, collaborative learning situations, and illustrations
- Teachers' knowledge of methods for assessing student learning—e.g., WISE online student notes, listening to students when asking conceptual questions, artifacts such as drawings, science presentations, written tests, and science reports

Knowledge of Students' Science Conceptions

- Teachers' knowledge of students' science ideas around plant biology, including:
    - ➢ Knowledge of science concepts in the plant unit that are difficult for students to learn
    - ➢ Knowledge of science concepts in the plant unit the are important for student learning

Knowledge of Science Curriculum

- Teachers' knowledge of the curriculum goals for the plant unit, including:
    - ➢ Knowledge of sequence of activities to be taught—i.e., the planning phase
    - ➢ Knowledge of the science content students are expected to know
    - ➢ Knowledge of how to customize the WISE curriculum –i.e., classroom activities and/or recommendations for software improvements

Figure 3.1. Inquiry Science Teaching Model.

Questioning Patterns. I analyzed how Lee and Alice used questioning in the context of WISE evidence and students' online notes to elicit students' science ideas across the three years. I categorized their use of questioning for key lessons/topics, *Photosynthesis* (for Lee) and *Comparing Plants' Life Cycles* and *Graphing Data* (for Alice) as highlighted in Tables 4.3 and 4.4 in chapter 4. Later on in this section, I discuss my rationale for including just three out of the six lesson/topics as part of my analysis of Lee and Alice's[1] practice each year. Below I discuss the type of category system used to interpret the teachers' questioning patterns.

Questions were coded into three categories (refer to Figure 3.2 for an example of my coding scheme for teachers' questioning patterns): (a) logistical, (b) factual, and (c) conceptual. Questions that asked students about management or procedural issues were coded as logistical. Examples of logistical questions included: 'Did you save your note?' or 'Did you take a note?' Questions that required students to recall content knowledge without asking them to reflect were coded as factual (e.g., 'what are the parts of a life cycle?'). Questions that asked students to make predictions, provide explanations for their responses, and justify their conclusions with evidence were coded as conceptual questioning (e.g., 'What do you think would happen if a plant could photosynthesize, store energy all the time? Would it grow faster? How do you know this?').

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[1] Alice also taught *nutrients* in years 1, 2 and 3, but I combined this topic with the *Comparing plants' life* cycles lesson.

Intercoder Agreement. To avoid coder bias and to determine whether the coding scheme for the teachers' questioning patterns is reliable, a coder was trained to code questions, and intercoder agreement was calculated. The coders were me and another researcher.

The other coder was trained by giving him a sample set of teachers' questions and coding forms. After the sample was coded independently, we discussed it to address any discrepancies. After the other coder felt comfortable with the procedure, I provided him with random samples of the teachers' questions, which we both coded. We agreed on 98% of the questions.

Teacher	**Example of Teachers' Questioning Patterns**	**Codes**
Lee	*Fascinating photosynthesis*, did you do that activity?	L=Logistical
	Does anyone know the definition of photosynthesis?	F=Factual
	You talked about them [plants] storing food that they made in the summertime, and then living off of that during the winter. What else do we know that does that? Is there another example of a living thing that does that?	C=Conceptual
Alice	Did you read *Let's compare lifecycles*?	L=Logistical
	What are the parts of a life cycle?	F=Factual
	What do you think Marie? Do you think scientists prefer to grow plants with long life cycles or short life cycles? Why?	C=Conceptual

Figure 3.2. Illustration of Coding Method for Teachers' Practice.

The approach I used for determining which science lessons to include in my analysis entailed capturing which key science topics were taught the most by the teachers using WISE software in year one. As shown in Table 4.2 in chapter 4, Alice only taught two of the six science topics with technology in year one, *Comparing plants' Life Cycles* and *Graphing Data*. It is noteworthy to mention that the *Nutrients* topic was taught with technology as well, but it was only taught as part of the *Comparing plants life cycles'* topic. The remaining four topics were taught by Alice in whole class discussion offline (i.e., students in Alice's science class also grew plants under varied conditions each year). As a result, I analyzed those two focal topics across the three year time span. As shown in Table 4.1, in year one, Lee taught the science topics (five out of six) in small and whole class discussion which did not include the WISE software. He left his students to work on WISE investigations primarily without guidance. This difference in how the science topics in WISE were taught in year one in both Lee and Alice's classroom necessitated two different approaches for determining which classroom observations to include in the analysis. Therefore, I counted the number of times each of the six science topics appeared throughout all lessons that were taught by Lee during the three years (refer to Figure 3.3 below). Out of the six topics, I observed Lee teaching photosynthesis 13 times across the three year period (see Figure 3.5). Since this is the most frequently occurring topic, I used this as a criterion for my selection of observations for analysis.

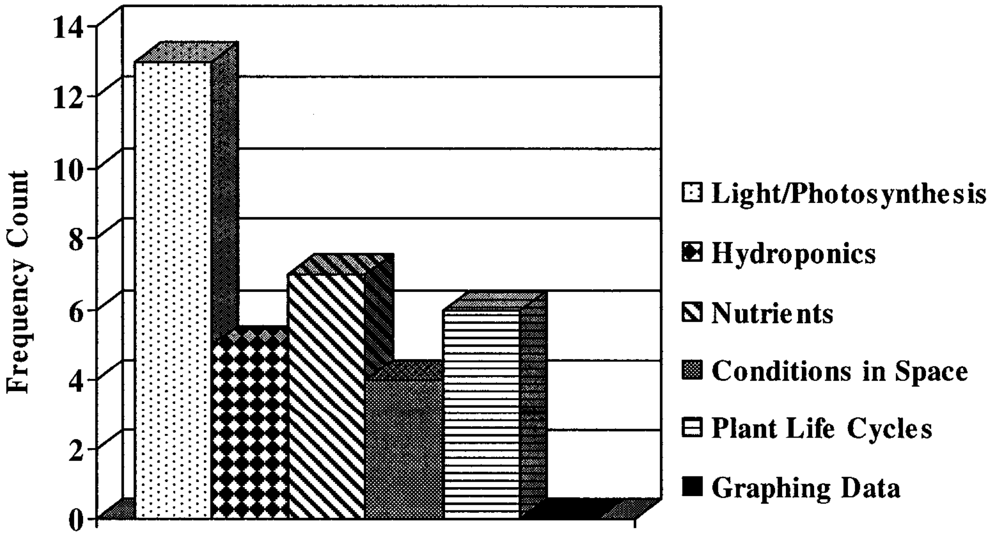

Figure 3.3. Core Science Topics taught in the WISE Plants Curriculum by Lee during Three Years.

Science Dialogue. I traced how Lee and Alice made students' scientific thinking visible by analyzing discourse patterns in the focal lessons—*Light/photosynthesis*, *Comparing plants' life cycles* and *Graphing data* in years one through three. I examined how the teachers engaged students in more science dialogues (i.e., by encouraging students to sort out scientific ideas and connect new ideas with prior ideas) in small groups, a strategy that I believe promotes knowledge integration. I began the coding process by watching videos of each of the focal lessons in years one, two and three. At the same time, I read transcripts along with watching the videos of classroom dialogues. I defined a single dialogue as talk the first time an utterance (a word) transpired between a given student or group of students and the teacher from beginning to end. I coded this dialogue as logistic dialogue or science dialogue. I defined a teacher-student dialogue as a logistic dialogue if it focused on management and procedural issues. I defined a teacher-student dialogue as a science dialogue if it met one or more of the following criteria: (a) the teachers encouraged students to provide explanations for their responses, (b) the teachers asked students to make predictions and explain their reasoning, (c) the teachers encouraged students to support claims with evidence, and (c) the teachers encouraged students to challenge each other's perspectives. These criteria enabled me to capture how the teachers helped students sort out their scientific ideas and link ideas. I analyzed each dialogue as the teacher moved to ongoing groups. After watching each video and reading the corresponding transcript, which denotes where every dialogue begins and ends, I then summed up the total of logistic and science dialogues (separately and in combination).

Finally, I validated my account of the observation-based changes in the teachers' practices across time through retrospective interviews that solicited teachers' own accounts of the changes in their instructional practices, and their own attributions for the factors that led to those changes (Myerhoff, 1980).

Teachers' Pedagogical Content Knowledge

To capture the trajectories of change of elementary school teachers who are learning to teach a science curriculum using an inquiry approach in WISE, I analyzed the relationship between the teachers' practices and their pedagogical content knowledge. I used the knowledge integration perspective to frame the analytic tools used for understanding development in the teachers' pedagogical content knowledge. As Davis (2004) points out, the knowledge integration perspective has mostly been used to analyze students' cognition in the domain of science, but is applicable to all learners (i.e., both students and teachers).

First, I used *open coding* procedures (Emerson, Fretz & Shaw, 1995; Strauss & Corbin, 1990), which entailed reading transcripts line by line and identifying themes and patterns in the data. I coded all of the interview transcripts. The data were then categorized into three categories. These categories are referred to in the inquiry science teaching model (refer to figure 3.1), as components of pedagogical content knowledge (i.e., teachers' knowledge of instructional strategies teachers' knowledge of students' science conceptions, and teachers' science curriculum knowledge).

After I used *open coding*, I employed *axial coding* (e.g., identifying the phenomenon, context, intervening conditions such as time and teaching experience, action/interaction strategies, outcomes or consequences) to put the data back together in a more organized fashion (Strauss & Corbin, 1990). In order to trace changes in each category of pedagogical content knowledge, I concurrently looked for evidence of the following knowledge integration processes for teachers (Linn & Hsi, 2000): (a) adding new ideas to their repertoire, (b) sorting ideas, (c) reconciling ideas that appear contradictory, and (d) integrating preexisting and new ideas. Table 3.3 shows how I looked for evidence of the knowledge integration processes after identifying the categories of pedagogical content knowledge.

Table 3.3. A Sample Coding Scheme for Teachers' Pedagogical Content Knowledge (PCK).

Teacher	Knowledge Integration Processes	Category of PCK	Examples
Lee	Adding ideas	Knowledge of students' science conceptions	In year one, Lee provided examples of students' science conceptions not within the scope of the plant curriculum (e.g., erosion, water cycle). By year three, Lee discussed students' science conceptions—i.e., prior knowledge and non-normative ideas specific to the plant unit within a framework of interrelated ideas.
	Sorting and reconciling ideas	Knowledge of science curriculum	Prior to implementing WISE in the classroom in year one, Lee participated in the design process for the plant curriculum. Lee experienced tension between making the plant unit a debate or a critique project. He was able to sort out these conflicting ideas over time through his participation in an online discussion with a scientist-partner.
	Integrating ideas (i.e., adding new ideas to preexisting ideas in repertoire)	Knowledge of instructional strategies	In year one, Lee continuously emphasized the importance of listening to students in a generic sense (the role of communication in assessing student learning). In year two, Lee considered a new assessment method—an online quiz. He took a traditional technique and built it into WISE. By year three, Lee viewed both informal assessments (e.g., listening) and formal assessments (e.g., quizzes) as critical for assessing student understanding.

Factors Supporting Teachers' Development

After identifying the trajectories of change in both Lee and Alice's practices and knowledge, I traced what factors encouraged or supported their development. Factors were categorized as external or internal. Providing social supports to teachers were considered external factors. I considered the social supports I provided for the teachers, such as scaffolding them in reflecting on their practices and knowledge, assisting them with curriculum customizations, and putting scaffolds in place to support their learning—i.e., online interactions with scientists (refer to chapter 1, the section called Role of

Researcher for additional examples). As discussed in chapter 1, collaborative learning situations such as discussions can provide teachers with opportunities to offer explanations, interpretations and resolutions supported by a peer, researcher, or a scientist. WISE also provides social supports to teachers by giving them detailed accounts of student learning and by providing them with the capability to respond electronically to students' online work (Slotta, 2004). In chapters 5 and 6, I discuss how Lee and Alice use students' online notes and WISE evidence to monitor students' learning over time. Internal factors are the result of an in individual analyzing his or her own actions—teachers' own reflection process.

Student Progress

Although not the main focus of this dissertation, I have also examined these teachers' students' progress across the three year time frame through an analysis of their students' in-class-work (WISE online notes). These student results serve to validate the impact of teacher performance observations. These student results and data analyses are presented in chapter 4.

To evaluate progress in students' understanding of plant development, I analyzed students' WISE notes across the three year time span. As previously mentioned, the plant unit consists of six science topics—*light/photosynthesis, hydroponics (water), nutrients, comparing plants' life cycles, conditions in space, and graphing data*. The core theme for the plant unit is *Light/photosynthesis.* I focus on the trajectory of student ideas about why plants need light to make their food and to survive. I chose to focus the analysis around the topic *Photosynthesis/light* because it is the most complex topic in the plant unit and the other five topics fit within this one topic. Research shows that *photosynthesis* is one topic in biology that students tend to hold alternative conceptions about (e.g., Anderson, Sheldon, & Dubay, 1990; Lumpe & Staver, 1995). Lumpe and Staver (1995) highlight several alternative conceptions that school age children commonly hold about *photosynthesis*: (a) *plants need sunlight, but fail to understand why this is important in the photosynthesis process (the normative idea is that during photosynthesis, energy from the sun is changed into energy in the form of food, commonly referred to as glucose or sugar or starch),* (b) *photosynthesis keeps plants green,* (c) *food for plants include water, air, minerals, soil, and light,* (d) *light is used to keep plants warm.* Also, *Light/photosynthesis* is a fundamental concept that underlies the *life science* standard for fifth grade set forth by the National Science Education Standards (NRC, 1996).

The same online assessment items (referring to the students' WISE notes) were analyzed for three different cohorts of student in both Lee and Alice's classroom over the three year time period. Offline pre/post- tests were also administered to students in both teachers' science classes. However, these items needed better alignment due to changes in the questions across subsequent years. As a result, the WISE students' notes were used in this analysis. Students are required to work collaboratively (preferably in pairs of two) on WISE projects. Therefore, I could only analyze student work in a group format.

During the curriculum enactment phase, the WISE software prompted students to answer the following two assessment items relating to *Light/photosynthesis*: (a) *Suppose you are passing by a tree and happen to look up and notice that most or all of the leaves have turned orange/brown and are falling to the ground. Why does this happen?* and (b) *Write a statement explaining what would happen to plants if they didn't have any light?* These two WISE online note questions were coded for knowledge integration. I developed a knowledge integration scale ranging from 0-4 to code students' explanations—see details in Figure 3.6 (Williams & Linn, 2002). My knowledge integration scale was based on the earlier work by Clark and Linn (2003). The scale used in this study was designed to assess how students linked scientific ideas about plants' need for light to make food and to survive. Responses coded as Level 0 indicated that no answers were given or the question was repeated. Although not shown in Figure 3.4 below, students were also given partial credits. For example, responses that provided partially normative answers were coded as Level 1.5 and responses that provided normative answers with partial explanations were coded as Level 2.5. Responses that provided normative answers with sophisticated explanations (expert like) were coded as Level 3 and Level 4. These two levels describe students' answers that have explicit linkage between ideas. For example, a Level 4 answer to the online note asking *Write a statement explaining what would happen to plants if they didn't have any light?* is:

> *If plants didn't have any light, then the water and carbon dioxide would not be able to mix and make glucose. Plants use glucose as food for energy and as a building block to grow.*

Finally, each year prior to the enactment of the plant curriculum, an identical pre-online assessment item was administered to students in both Lee and Alice's classroom. The assessment question was as follows: *What do you think plants need in order to grow and what are the reasons for your answer(s)?* Although this pre-assessment item was broad in scope, it provided me with baseline data on the students' prior knowledge regarding the focal topic *Light/photosynthesis* at the onset of plant unit.

Plants in Space Curriculum

Rubric used to assess students' online notes in WISE

0 – No answer or repeated the question

1 – Explanation(s) irrelevant to what the question asks

2 – Normative answer, but no explanations are provided

3 – Normative answer with one explanation (include linkage between ideas)

4 – Normative answer with two or more explanations (include linkage between ideas)

Figure 3.4. Knowledge Integration (KI) Scale.

Intercoder Agreement. To avoid coder bias and to determine whether the coding scheme for the online pre- and post- assessment items is reliable, a coder was trained to code students' responses, and intercoder agreement was calculated. The coders were me and another researcher.

The other coder was trained by giving him a sample set of students' responses and coding forms. After the sample was coded independently, we discussed it to address any discrepancies. After the other coder felt comfortable with the procedure, I provided him with random samples of students' responses. We agreed on the scores (i.e., pre and post responses) for 94% of the students.

CHAPTER 4

TEACHERS' CUSTOMIZATION OF *PLANTS IN SPACE:* EVALUATING THE EFFECT ON URBAN STUDENTS' PERFORMANCE ACROSS THREE YEARS

Introduction

This chapter explores how teaching science inquiry projects with technology like the Web-based Inquiry Science Environment (WISE) can give teachers new insights into student thinking. The technology captures students' reflections, plans, discourse and results, so teachers have a detailed record of how each student group makes sense of the project (Slotta, 2004). The project guides student activities, leaving teachers the opportunity to interact with small groups and to diagnose difficulties. The chapters following this one discuss how two teachers learn to make their students' thinking visible and how they respond to students' ideas to promote complex thinking about plant growth when using a technology-enhanced learning environment over time. However, it is important to understand the context in which the two teachers, Lee and Alice, implemented the plant project before discussing specific changes in the teachers' practices and understandings. This chapter examines students' progress across the three year time frame, by analyzing their students' in-class-work—i.e., WISE online notes. In many respects, these student results validate teacher performance observations.

Curriculum Coverage

Direct observations of Lee and Alice's teaching over the course of three years provide a portrait of the complexity involved in implementing the *Plants in Space* curriculum unit. This project can be characterized as complex for several reasons: (a) the teachers dealt with front end logistics such as getting students started with WISE (e.g., students creating passwords for log-in purposes, assisting students in learning how to navigate in the WISE software); (b) the curriculum incorporates use of the World Wide Web and hands-on exploration; (c) the teachers customized particular curriculum activities and made recommendations for software improvements; and (d) the teachers provided direct feedback to students as they critiqued online evidence about scientific phenomena. In addition, Lee took advantage of the electronic discussion forum feature in WISE for student dialogue with scientists, and utilized WISE online assessment tools for monitoring students' progress and providing feedback to students.

Tables 4.1 and 4.2 depict the sequence of key science topics taught by Lee and Alice during the WISE *Plants in Space* implementation in years one through three. The far left column in tables 4.1 and 4.2 lists the six key science topics for the plant curriculum unit. Also, the tables show the context and frequency for each topic broken down by year (referring to years one, two, and three). The context in which the topics occurred represents: WISE software (referring to online investigations), small group discussion offline, and/or whole class discussion offline.

In years one through three, Lee covered all of the key science topics except *graphing data*. Due to a network firewall implemented by the school district, Lee's students were unable to use the WISE graphing feature. Furthermore, in year one, the science topics were taught as part of whole class and small group reflection offline (see Table 4.1).

However in years two and three, Lee taught the five science topics during WISE online investigations (i.e., small group discussion and whole class reflection), and he taught three of the five topics, *light/photosynthesis*, *nutrients* and *comparing plants' life cycles*, for a longer period of time. Also, there was greater and more integrated use of technology in years two and three. For example, as shown in Table 4.1, Lee spent one to six class periods teaching the five science topics during WISE online. It is noteworthy to mention that these topics were not taught in isolation. As Lee introduced a science topic for the first time, he reintroduced a previously taught topic(s).

Table 4.1. Sequence of Key Science Topics taught in Lee's Classroom.

	Year One[a]		Year Two[b]		Year Three[c]	
Topic	Context	Frequency	Context	Frequency	Context	Frequency
Light/ photosynthesis	▪ Students worked on WISE mostly without the teacher's guidance ▪ Small group and whole class discussion offline	4 Classes	▪ WISE software ▪ Small group and whole class discussion offline	5 classes	▪ WISE software ▪ Small group and whole class discussion offline	6 classes
Hydroponics	▪ Students worked on WISE mostly without the teacher's guidance ▪ Small group and whole class discussion offline	2 classes	▪ WISE software	2 classes	▪ WISE software	2 classes
Conditions in Space	▪ Whole class discussion offline ▪ Students mostly worked on WISE software without teacher's guidance	2 classes	▪ WISE software	1 class	▪ WISE software	1 class
Nutrients	▪ Students worked on WISE without the teacher's guidance	1 class	▪ WISE software	1 class	▪ WISE software ▪ Small group and whole class discussion offline	5 classes
Comparing Plants' Life Cycles	▪ Whole class and small group reflection offline ▪ Students mostly worked on WISE software without teacher's guidance	1 class	▪ WISE software ▪ Whole class discussion	2 classes	▪ WISE software ▪ Small group discussion offline	3 classes
Graphing Data	▪ N/A	0 classes	▪ N/A	0 classes	▪ N/A	0 classes

[a] Lee taught the WISE plant curriculum for a total of seven days (same as classes) across five and a half weeks in year 1.

[b] Lee taught the WISE plant curriculum for a total of eleven days (same as classes) across eight weeks in year 2.

[c] Lee taught the WISE plant curriculum for a total of thirteen days (same as classes) across eleven weeks in year 3.

Alice taught the six science topics across the three year time span, except *graphing data* which was not taught in year three (details discussed in chapter 6). Three of the six topics—*light/photosynthesis, hydroponic*s, and *conditions in space* were taught as part of whole class discussion offline in year one, and the remaining three topics—*nutrients, comparing plants' life cycles,* and *graphing data* were taught as part of the two WISE software projects (see Table 4.2). As discussed in the previous chapter, the *Nutrients* topic was taught as part of the *Comparing plants' life cycles* topic.

In contrast, in year two, Alice taught all six of the key science topics during WISE investigations. Alice also taught the topics across two other contexts—whole class and small group discussions, and she taught them for a longer period of time. Also, there was greater and more integrated use of technology in years two and three. Moreover, in year three Alice only taught the science topics during WISE investigations and small group discussions. Similar to Lee, Alice also did not teach these topics in isolation. In years one through three as Alice introduced a science topic for the first time, she reintroduced previously taught topic(s).

Table 4.2. Sequence of Key Science Topics taught in Alice's Classroom.

	Year One [a]		Year Two [b]		Year Three [b]	
Topic	Context	Frequency	Context	Frequency	Context	Frequency
Light/ photosynthesis	▪ Students worked on WISE without the teacher's guidance ▪ Whole class discussion offline	2 Classes	▪ WISE software ▪ Small group and whole class discussion offline	4 classes	▪ WISE software ▪ Small group discussion offline	5 classes
Hydroponics	▪ Students worked on WISE without the teacher's guidance ▪ Whole class discussion offline	1 class	▪ WISE software ▪ Small and whole class discussion offline	3 classes	▪ WISE software ▪ Small group discussion offline	4 classes
Conditions in Space	▪ Students worked on WISE without the teacher's guidance ▪ Whole class discussion offline	1 class	▪ WISE software ▪ Whole class discussion offline	1 class	▪ WISE software	1 class
Nutrients	▪ WISE software	1 class	▪ WISE software ▪ Small group and whole class discussion offline	3 classes	▪ WISE software ▪ Small group discussion offline	2 classes
Comparing Plants' Life Cycles	▪ WISE software	1 class	▪ WISE software ▪ Whole class discussion offline	3 classes	▪ WISE software ▪ Small & whole group discussion offline	4 classes
Graphing Data	▪ WISE software	1 class	▪ WISE software	1 class	▪ N/A	0 classes

[a] Alice taught the WISE plant curriculum for a total of six days (same as classes) across five weeks in year 1.

[b] Alice taught the WISE plant curriculum for a total of thirteen days (same as classes) across eight weeks in years 2 and 3.

In summary, both teachers left their students to work on WISE investigations primarily without guidance in year one. Also, there was greater and more integrated use of technology in both Alice and Lee's science classroom in years two and three. I will discuss these trends in more depth later in chapters 5 and 6. Below I discuss supplementary lessons and WISE software enhancements (referred to as customizations) that Lee and Alice implemented during the *Plants in Space* project run over the three year time period.

Teachers' Customizations to the *Plants in Space* Curriculum

Although Lee and Alice taught the five WISE activities described in the *Plants in Space* lesson plans (refer to Appendix A), they also made customizations to particular curriculum activities to meet the needs of their classes (i.e., to enhance students' understanding of key science topics). The teachers observed the students, which involved listening to them and looking at their in-class-work—WISE online notes (see chapters 5 and 6 for detail). This provided the best evidence of how the students were progressing. It is noteworthy to mention that each of the two WISE software projects—*What Makes Plants Grow?* and *How do Earth and Space Plants Grow?* consisted of five WISE activities (also refer to the WISE *Plants in Space* lesson plans in Appendix A). As a reminder, Figure 2.1 in chapter 2 provides a summary of the *Plants in Space* project activities.

Tables 4.3 and 4.4 provide a description of each lesson (i.e., the WISE activity and the curriculum customization when applicable) taught by Lee and Alice across the three years period. The context of which the lessons occurred is also described in Tables 4.3 and 4.4.

As shown in Figures 4.3 and 4.4, Lee and Alice designed classroom activities around the core science topic *Light/photosynthesis* to further teach their students about this complex topic. For example, Lee made enhancements to one of the WISE *Plants in Space* software projects. Lee added online questions to make the science more accessible and personally relevant to students such as: *Suppose you are passing by a tree and happen to look up and notice that most or all of the leaves have turned orange/brown and are falling to the ground. Why does this happen?" and "Write a statement explaining what would happen to plants if they didn't have any light?* These questions afforded students the opportunity to connect scientific concepts with spontaneous concepts, those which are acquired through children's everyday experiences (Vygotsky, 1972). Later in this chapter, I discuss why the *Light/photosynthesis* topic is considered to be a core theme in the plant curriculum unit.

In addition to the software customizations, Lee designed a Language Arts lesson called *Why do leaves change colors in the Fall?* which incorporated the topic *Light/photosynthesis* (refer to Table 4.3). He taught this lesson each of the three years during the implementation of WISE. In regards to the topic *Light/photosynthesis*, this was the only curriculum customization that Lee taught repeatedly. Students were asked to apply various comprehension techniques that they had been employing in reading. The purpose of this reflection activity was to provide students with the opportunity to connect the role of *light* with the concept of leaves changing colors in the Autumn (i.e., leaves acting as nature's food factories, the role of chlorophyll, ingredients necessary for the photosynthesis process). Lee indicated that he wanted students to make real world connections in understanding this relationship. For example, in an interview Lee stated:

> *So I want students to be able to say to an adult that they happen to be with, 'Mom and Dad, look at these leaves.' And not to just say, 'Oh, look at these pretty orange colors,' or 'that the leaves are brown and they fell off the tree.' I want them to be able to explain why this is happening. This is a part of the natural world. It doesn't just happen. There's a process, there's a reason that these leaves are on the ground, instead of being on the tree. There is a reason that this brown or this orange color has all of a sudden appeared. The orange color has always been there, but the chlorophyll was there and the green covered it up. The brown colors are made in the Fall, but come from waste left in the leaves. Well, now that the tree or the plant isn't going through photosynthesis, now there is no need for the chlorophyll.*

Likewise, Alice implemented two key customizations around the topic *Light/photosynthesis* over the course of the three year period (i.e., *A tree in four seasons' assessment activity* and *A news article writing project*). The *Tree in four season's activity* was an assessment measure Alice implemented in year two. The activity entailed students describing and illustrating what a tree looked like in each of the four seasons (i.e., winter, spring, summer and fall). The content goal for this activity was to assess students' understanding early on in the WISE project about the role of photosynthesis in tree/plant development, including their conceptions about why leaves change colors in different seasons.

As shown in Table 4.4, Alice did not implement the *Tree in four seasons'* activity in year three, but instead, she introduced a Language Arts lesson called *Plant Times*, the news article writing project on plants. Although the newspaper project focused on the key science theme—*Light/photosynthesis*, other topics such as hydroponics and the function of plants' roots were included in the write-up as well. As Alice introduced this customization, she solicited students' ideas on different parts of a newspaper (e.g., a headline story column, comics' column, a *Dear Plant* column, an opinion column).

Students worked on this writing project in collaborative pairs throughout the WISE *Plants in Space* unit, and were required to incorporate WISE online investigations and science experimentation. The class newspaper (entitled *Plant Times*) was published in Parker Elementary School News which went out to the entire community.

In short, both Lee and Alice created two key customization activities around the core science topic—*Light/photosynthesis* across the three year time span. Lee made the WISE software enhancement in year one and introduced the Language Arts customization lesson called *Why leaves change colors in the Fall*, in years one, two and three. Moreover, Alice did not integrate science (referring to the *Plants in Space* unit) as part of the domain of Language Arts until year three, when she implemented the news article writing project. Although Lee and Alice primarily designed classroom activities that focused on the topic—*Light/photosynthesis*, they introduced a couple other customizations as well (refer to Tables 4.3 and 4.4 for examples). The teachers chose to design activities around the topic *Light/photosynthesis* because they felt it was critical to students' understanding of plant growth and development. In the subsequent section, I also focus on the trajectory of student ideas about plants need light to make their food and to survive. I discuss why I chose to focus the analysis around the topic *Photosynthesis/light*.

Table 4.3. WISE in Practice: Description of Lessons taught by Lee across Three Years.

Lesson Number	Year One	Year Two	Year Three
1	KWHL activity (customized activity_—i.e., intro lesson to WISE (solicited students' prior knowledge about plants)	KWHL activity—i.e., intro lesson to WISE (solicited students' prior knowledge about plants)	KWHL activity—i.e., intro lesson to WISE (solicited students' prior knowledge about plants)
2	WISE software–*Fascinating photosynthesis evidence* (students worked independently); Students prepared responses for *online discussion* topic in a small group setting	KWHL activity continues; Getting started with WISE–teacher assists students with logging onto the WISE for the first time	KWHL activity (intro lesson to WISE) continues
3	WISE software–*fascinating photosynthesis* and *hydroponics* (teacher intervened on a couple of times—sound inaudible); Students prepared responses for *online discussion* topic in a small group setting	WISE software– Activity 1: *making predictions* (students worked independently)	WISE software – *Making predictions*
4	Whole class discussion of students' prior knowledge about *conditions in space* reflection on *hydroponics*, more *photosynthesis*; small group discussions on observations of species of plants growing under different conditions	Whole class reflection on the *making prediction* activity in WISE and solicitation of students' prior knowledge	WISE software – *Making predictions* (students worked independently); Teacher worked with small groups offline to discuss the goals for the plant unit and the final project goals (i.e., discussion of *comparing plants' life cycles*)
5	Whole class discussion on views about the use of technology in the classroom	Whole class review of *online discussion* and what do we know about *photosynthesis*; WISE software – *Fascinating photosynthesis* evidence (students work independently)	WISE software- teacher assisted students in understanding how to navigate in WISE; Offline discussion (small group format) about *plants' life cycles* offline [technical problems with class computers]
6	Language Arts lesson "Why do Leaves Change Colors?" –whole class reflection activity on *more photosynthesis evidence*	Whole class discussion on upcoming WISE module (II)and briefly review components of *fascinating photosynthesis* evidence; WISE software – *More photosynthesis, hydroponics* and the *online discussion* [sound	WISE software – *Fascinating photosynthesis, nutrients* (i.e., functions of plants' roots) evidence [online comments feature did not work]

		inaudible]	
7	WISE software– *Conditions in space* and *comparing plants life* cycles [concluding WISE software activities]; Whole class and small group reflection offline on these topics	WISE software – *Hydroponics* and *more photosynthesis evidence*	WISE software – *More photosynthesis* and *hydroponics* evidence [online comment feature did not work; technical problems with class computers]
8		Language Arts lesson “Why do Leaves Change Colors?” –whole class and small group reflection activity on *more photosynthesis evidence*	WISE software – *nutrients, hydroponics, fascinating photosynthesis*, and *more photosynthesis* evidence [teacher had students to revise completed WISE notes, thus taking into account his own line comments]
9		Teacher introduces WISE module II; WISE software – *More photosynthesis, comparing plants’ life cycles* and *conditions in space evidence* [end of WISE software activities]	WISE software –*more photosynthesis* and *nutrients*
10		Whole class discussion – students predicts which plant is earth and which is a Fast plant, i.e. *plants’ life cycles* (drawing on observations), thus connecting to WISE modules I and II	Language Arts lesson “Why do Leaves Change Colors?” – whole class and small group reflection activity on *more photosynthesis evidence*
11		Small group reflection offline on *Making sense of your data* WISE activity	Whole class review of overarching question for the WISE plant unit; students conducted observations of plants growing under different conditions
12			WISE software – complete all WISE I activities and revise notes (i.e., *photosynthesis, nutrients*); Small group interactions on writing project
13			WISE software – *comparing plants’ life cycles* and *conditions in space* [end of WISE software activities]; offline plant observations/measurements and writing assignment (i.e., *nutrients*)

Table 4.4. WISE in Practice: Description of Lessons taught by Alice across Three Years.

Lesson Number	Year One	Year Two	Year Three
1	Students worked independently in 3 different science centers (i.e., WISE); teacher worked with a small group of students in a reading center during the entire lesson	KWHL activity, a customized activity, in whole class format (solicited students prior knowledge about plants); Small group minilesson on photosynthesis; WISE online– Activity 1: *making predictions* (students worked independently)	KWHL activity in whole class format—i.e., intro lesson to WISE (solicited students' prior knowledge about plants)
2	Whole class reflection on the *photosynthesis process*	Small group minilesson on *photosynthesis* continued; WISE software– Activity 1: *making predictions* (students worked independently)	WISE software– *Making predications* (1st activity in WISE)
3	Students participated in a role playing activity on requirements for optimum plant growth	WISE software– *Hydroponics* and *nutrients*; Assessment–'Tree in Four Seasons' customization activity'	WISE software– *Making predictions*; student groups created illustrations of a *plant's life cycle*
4	Whole class reflection on the *photosynthesis*, *hydroponics*, and *conditions in space*	WISE software–*Fascinating photosynthesis*, *nutrients*, and *hydroponics*	WISE software– *Making predictions*, *Van Helmont* evidence, and *nutrients*
5	WISE software in computer lab–*Comparing plants' life cycles* and *nutrient s*	Students designed plant growth chambers in pairs of two	WISE software– *Fascinating photosynthesis*; student groups who completed their illustrations of a *plant's life cycle* without guidance; 'Newspaper project' customization activity (a couple of groups finished other two activities so they began project—focusing on key theme *photosynthesis* (i.e., function of plants' leaves and roots, and *hydroponics*)
6	Students observing plants and averaging data in small groups; Whole class review on *comparing plants' life cycles*; WISE software in computer lab–*Graphing your data* [end of WISE software activities]	WISE software – Students checked to make sure all activities were completed in the 1st WISE module; Conducting plant observations	WISE software in the lab– *Fascinating photosynthesis*, *hydroponics* and *more photosynthesis*
7		Reflection game in whole/small group settings– topics include *nutrients*, *Fascinating and more photosynthesis*, and *hydroponics*	WISE software–*more photosynthesis* and *hydroponics*

8		Teacher worked with students in small group to reflect on plants' observations; Averaging weekly plant data in collaborative groups	WISE software in the lab– *Hydroponics, more photosynthesis*, and *comparing plants' life cycles* (in WISE module II)
9		*WISE* software –*Comparing plants' life cycles*; Students conducted observations of plant growth	Newspaper activity in small groups– *Photosynthesis* and *hydroponics*; WISE software– *hydroponics* (i.e., lengthy discussion on its connection to *nutrients*)
10		WISE software –*Comparing plant life cycles* and *Conditions in Space;* plant observations; averaging weekly plant data	Plant observations; working in small groups on newspaper final project (offline)
11		Whole class reflection on observations– *compared plants' life cycles*	WISE software– *Comparing plants' life cycles* and *conditions in space* evidence [end of WISE software activities]
12		WISE software– *Graphing your data* and *making sense of your data*; averaging plant data [end of WISE software activities]	Small group collaboration on newspaper project
13		Students presented design projects	Whole class reflection on theories of plant species; revisited KWL activity

Students' Performance across Three Years

To evaluate progress in students' understanding of plant development, I analyzed students' WISE notes across the three year time span. As previously mentioned, the plant unit consists of six science topics—*light/photosynthesis, hydroponics (water), nutrients, comparing plants' life cycles, conditions in space, and graphing data*. The core theme for the plant unit is *Light/photosynthesis*. I focus on the trajectory of student ideas about why plants need light to make their food and to survive. I chose to focus the analysis around the topic *Photosynthesis/light* because it is the most complex topic in the plant unit and the other five topics fit within this one topic. Research shows that *photosynthesis* is one topic in biology that students tend to hold alternative conceptions about (e.g., Anderson, Sheldon, & Dubay, 1990; Lumpe & Staver, 1995). Lumpe and Staver (1995) highlight several alternative conceptions that school age children commonly hold about *photosynthesis*: (a) *plants need sunlight, but fail to understand why this is important in the photosynthesis process (the normative idea is that during photosynthesis, energy from the sun is changed into energy in the form of food, commonly referred to as glucose or sugar or starch),* (b) *photosynthesis keeps plants green,* (c) *food for plants include water, air, minerals, soil, and light,* (d) *light is used to keep plants warm.* Also, *Light/photosynthesis* is a fundamental concept that underlies the *life science* standard for fifth grade set forth by the National Science Education Standards (NRC, 1996).

The same online assessment items (referring to the students' WISE notes) were analyzed for three different cohorts of students in both Lee and Alice's classroom over the three year time period. Offline pre/post- tests were also administered to students in both teachers' science classes. However, these items needed better alignment due to changes in the questions across subsequent years. The WISE students' notes were used in this analysis because they provided more insight into students' thinking. Students are required to work collaboratively (preferably in pairs of two) on WISE projects. Therefore, I could only analyze student work in a group format.

During the curriculum enactment phase, the WISE software prompted students to answer the following two assessment items relating to *Light/photosynthesis*: (a) *Suppose you are passing by a tree and happen to look up and notice that most or all of the leaves have turned orange/brown and are falling to the ground. Why does this happen?* and (b) *Write a statement explaining what would happen to plants if they didn't have any light?* These two WISE online note questions were coded for knowledge integration. I developed a knowledge integration scale ranging from 0-4 to code students' explanations—see details in Figure 4.1 (Williams & Linn, 2002). My knowledge integration scale was based on the earlier work by Clark and Linn (2003). The scale used in this study was designed to assess how students linked scientific ideas about plants' need for light to make food and to survive. Responses coded as Level 0 indicated that no answers were given or the question was repeated. Although not shown in Figure 3.4 (refer to chapter 3), students were also given partial credits. For example, responses that provided partially normative answers were coded as Level 1.5 and responses that provided normative answers with partial explanations were coded as Level 2.5. Responses that provided normative answers with sophisticated explanations (expert like) were coded as Level 3 and Level 4. These two levels describe students' answers that have explicit linkage between ideas. For example, a Level 4 answer to the online note asking *Write a statement explaining what would happen to plants if they didn't have any light?* is:

If plants didn't have any light, then the water and carbon dioxide would not be able to mix and make glucose. Plants use glucose as food for energy and as a building block to grow.

Finally, each year prior to the enactment of the plant curriculum, an identical pre-online assessment item was administered to students in both Lee and Alice's classroom. The assessment question was as follows: *What do you think plants need in order to grow and what are the reasons for your answer(s)?* Although this pre-assessment item was broad in scope, it provided me with baseline data on the students' prior knowledge regarding the focal topic *Light/photosynthesis* at the onset of plant unit. It is noteworthy to mention that all students in both classrooms over the three year period mentioned *light* as a factor that plants need in order to grow. Students did mention other factors as well. However, I only focus on students' responses that pertain to the focal topic *light.*

In the next section, I examine both Lee and Alice's students' progress across the three year time frame, by analyzing their students' in-class-work—i.e., WISE online notes. For each analysis, I used a One-Way ANOVA test and the Tukey HSD multiple comparisons method. The multiple comparisons method was used to determine which pairs of means differ on the two online assessment items: (a) *Suppose you are passing by a tree and happen to look up and notice that most or all of the leaves have turned orange/brown and are falling to the ground. Why does this happen?* and (b) *Write a statement explaining what would happen to plants if they didn't have any light?*

Thus, prior to the enactment of the WISE plant curriculum unit, findings show that students in the two teachers' science classes held alternative conceptions about

Light/photosynthesis. A One-Way ANOVA test revealed that on the pre-online assessment item, *What do you thinking plants need in order to grow and what are the reasons for your answer(s)?* there was no statistically significant difference in student performance in Lee and Alice's class, F(2, 34) = .499, p = .612), and F(2, 30) = 1.690, p = .202, respectively. For example, typical student responses to the question included: (a) *plants need sun to keep them warm,* (b) *sun is important to plants because it is the plants' food,* and (c) *plants need sunlight so they will not get to cold.* These findings are consistent with those in the science literature (e.g., Anderson et al., 1990; Lumpe & Staver, 1995).

Students' Performance in Lee's Classroom

The mean knowledge integration score increased across the three years for the three cohorts of student-groups in Lee's science class for the WISE online note question, *Write a statement explaining what would happen to plants if they didn't have any light?* (see Table 4.5). The One-Way ANOVA test revealed a statistically significant difference in student performance between years one through three on the light question, F(2, 34) = 14.805, p < .0001. Tukey HSD procedure revealed no significant difference in student-groups' performance for years one and two (p = .093). However, when comparing years one and three groups and years two and three groups, the pairs of means differ significantly (p < .0001 and p = .003, respectively).

Table 4.5. Descriptive Statistics for WISE Student Note Questions in Lee's Class.

	Question 1[a]			Question 2[b]		
	Year 1	Year 2	Year 3 [c]	Year 1	Year 2	Year 3
No. of Student-Groups	14	14	9	14	14	9
Mean KI Scores	.857	1.571	2.889	1.179	1.393	2.889
SD	.6333	1.0351	.9280	.9325	1.2118	1.1667

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[a] Question 1: "Write a statement explaining what would happen to plants if they didn't have any light?"

[b] Question 2: "Suppose you are passing by a tree and happen to look up and notice that most of the leaves have turned orange/brown and are falling to the ground. Why does this happen?"

[c] The number of student-groups is lower in Lee's class for year three because he had fewer students (totaling 12 student-groups) and three student-groups were dropped due to leaving the project activities answered because of absenteeism.

The frequency distribution of knowledge integration scores in Table 4.6 also supports these findings. As shown in Table 4.6, in year one, almost 80% of the student-groups either provided no answers or provided answers irrelevant to what the question asked. No student-groups provided normative answers with explanations. In year two, 35% of the students either provided no answer or provided answers irrelevant to what the question asked. More than 50% of the students provided normative answers. In contrast, in year three, no student-groups left the question unanswered or provided explanations irrelevant to what the question asked. All student-groups provided normative answers and more than half provided at least one explanation to the answers. Figure 4.1 provides samples of student-groups' answers.

Question: Write a statement explaining what would happen to plants if they didn't have any light?"

	KI Score	*Year One Students' Responses*
Joe/Ricky :	1	If plants didn't have any light, they would stay the same.
Wil/David:	1	If plants didn't have any light nothing would happen, they would still grow.
Davis/Kim:	1	If plants didn't have any light, they would die because the water would have to seck [suck] down into the pot.
Joi/Catherine:	2	If plants didn't have any light, the plants wouldn't have a lot of color.
		Year Two Students' Responses
Kim/Mary:	1	If plants didn't have any light, they would become too moist and would get soggy.
Steve/Monique:	2	They would die.
William:	2	If plants didn't have light they would die.
Dawn/Jewels:	2	If the plants didn't have any light the plants' food production system will shut down.
		Year Three Students' Responses
Karen/Keshia:	2	Plants' leaves would turn brown and yellow, because they don't have any light.
Stephanie/Sam:	3	If plants didn't have any light, they wouldn't grow properly. They wouldn't grow properly because plants would grow [tall] towards the light.
Marjorie/Jessica:	4	If plants didn't have any light, then the water and carbon would not be able to mix and make glucose. Plants use glucose as food for energy and as a building block to grow.
Nick/Jim:	4	If plants didn't have any light, the plants would not function good because the plants need sunlight for their energy and without energy the photosynthesis [process] couldn't work.

Figure 4.1. Students' Ideas about Light in Years One through Three in Lee's Class.

WISE online note question about changes in the coloration of plants' leaves. The mean knowledge integration score increased over the three year time period for the second WISE online note question, *Suppose you are passing by a tree and happen to look up and notice that most of the leaves have turned orange/brown and are falling to the* *ground. Why does this happen*? (see Table 4.5). Students performed significantly better on this question from year one through year three, F(2, 34) = 7.341, p = .002. The multiple comparisons method revealed no significant difference in student-groups' performance on the light question in years one and two (p = .865). However, when comparing years one and three groups and years two and three groups, the pairs of means differ significantly (p = .003 and p = .009, respectively).

The frequency distribution of knowledge integration scores in Table 4.6 also supports these findings. A case in point, in year one, a little more than half of the student-groups either provided no answers to this question about the changes in the coloration of plants' leaves or provided answers irrelevant to what the question was asking. No student-groups provided normative answers with explanations. In year two similar to year one about 50% of the students either provided no responses to the question or provided answers irrelevant to what the question asked. Approximately 43% of the student-groups provided normative answers. In year 3, no student-groups left the question unanswered. More than 80% of the students provided normative answers to the question and about 55% of the groups provided at least one explanation to the answers. Figure 4.2 provides examples of students' responses for this question about changes in the coloration of plants' leaves.

Table 4.6. Distribution of Knowledge Integration (KI) Scores for Student-groups in Lee's Science Class.

	WISE Note Question 1[a]			WISE Note Question 2[b]		
	Frequency			Frequency		
KI Score	**Year 1**	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**
0	29%	21%	0%	29%	29%	0%
1	50%	14%	0%	29%	21%	11.1%
1.5	14%	7%	0%	7%	7%	0%
2	1%	36%	44.4%	21%	29%	33.3%
2.5	0%	7%	0%	14%	0%	0%
3	0%	14%	22.2%	0%	7%	11.1%
4	0%	0%	33.3%	0%	7%	44.4%

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[a] Question 1: "Write a statement explaining what would happen to plants if they didn't have any light?"

[b] Question: "Suppose you are passing by a tree and happen to look up and notice that most of the leaves have turned orange/brown and are falling to the ground. Why does this happen?"

In summary, over successive years of the project, students' in Lee's fifth grade classroom displayed a deeper understanding of the complex science topic. For example, as shown in Figure 4.1, students in years two and three expressed more ideas about the role of light in plants' growth and development across time. In addition to providing more elaborative responses for the question about light, they also made links between scientific ideas—e.g., plants make their own food internally and sunlight is part of the food production process—a pattern not typical of earlier years. These findings were also consistent with the student results on the question about changes in the coloration of plants' leaves (refer to Figure 4.2 for examples of students' conceptions).

Question: Suppose you are passing by a tree and happen to look up and notice that most of the leaves have turned orange/brown and are falling to the ground. Why does this happen?"

	KI Score	*Year One Students' Responses*
Don/Mark:	1	This would happen because it dies from the weather, especially Winter.
Dawn/Catherine:	1	The leaves would fall off the trees because the roots in the leaves get old and fall off.
Marie/Fae:	1	In different months for example Winter suck up all the carbon dioxide there for in the Fall they turn different colors.
Steve/Rob:	2	This would happen because this is something trees do every Fall.
		Year Two Students' Responses
Christian/Nathan:	1	The plants need to save their water for the Winter.
Anna/Erika:	1	Because Winter is short and dry.
Larry:	2	This would happen because it is Fall.
Kevin/Ann:	3	The plants don't get enough sunlight, which causes the leaves to lose their color.
		Year Three Students' Responses
Matt/Adrian:	2	This would happen because the glucose starts to get trapped into the leaves.
Monica/Andy:	2	This would happen because it was the beginning of the Autumn or Winter.
Karen/Keshia:	4	This happens because they [the plants' leaves] are not getting chlorophyll and they are not getting photosynthesis.
Marjorie/Jessica:	4	This would happen because the trees shut down their food [factories]. The chlorophyll disappears from the leaves and then the green in the leaves start to fade away.

Figure 4.2. Students' Ideas about Changes in Leaves Color in Years One through Three in Lee's Class.

Students' Performance in Alice's Classroom

With respect to year one through three students, the mean knowledge integration score increased for the WISE note question, *Write a statement explaining what would happen to plants if they didn't have any light?* (see Table 4.7). There was a statistically significant difference in student-groups performance between years one through three on the light question, F(2, 30) = 6.827, p = .004. The multiple comparisons procedure further show no significant difference in student-groups' performance for years one and two (p = .567). However, when comparing student-groups in years one and three and years two and three, the pairs of means differ significantly (p = .003 and p = .040, respectively).

Table 4.7. Descriptive Statistics for WISE Student Note Questions in Alice's Class.

	Question 1[a]			**Question 2**[b]		
	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
No. of Student-Groups	11	11	11	11	11	11
Mean KI Scores	1.864	2.227	3.136	1.727	2.727	3.091
SD	.7103	.8174	.9511	.6467	1.0090	1.1362

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[a] Question 1: "Write a statement explaining what would happen to plants if they didn't have any light?"

[b] Question 2: "Suppose you are passing by a tree and happen to look up and notice that most of the leaves have turned orange/brown and are falling to the ground. Why does this happen?"

The frequency distribution of knowledge integration scores in Table 4.8 also supports these findings. As shown in Table 4.8, no student-groups left the question blank in any given year. In year one, over 60% of the groups provided normative answers. Eighteen percent of the fifth-graders provided normative answers with one explanation. In year two, over 80% of the groups provided normative answers to this question about light, including a little more than a quarter of the students proving at least one explanation for their responses. On the contrary, in year three most of the students (82%) provided normative answers with one or more explanations. Figure 4.3 provides samples of student-groups' answers.

Table 4.8. Distribution of Knowledge Integration (KI) Scores for Student-groups in Alice's Science Class.

	WISE Note Question 1[a]			**WISE Note Question 2**[b]		
	Frequency			Frequency		
KI Score	**Year 1**	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**
0	0%	0%	0%	0%	0%	0%
1	37%	9%	9%	36%	9%	9%
1.5	9%	9%	0%	0%	0%	0%
2	46%	55%	9%	55%	36%	27%
2.5	0%	0%	0%	0%	0%	0%
3	18%	18%	36%	9%	27%	9%
4	0%	9%	46%	0%	27%	55%

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[a] Question 1: "Write a statement explaining what would happen to plants if they didn't have any light?"

[b] Question 2: "Suppose you are passing by a tree and happen to look up and notice that most of the leaves have turned orange/brown and are falling to the ground. Why does this happen?"

WISE online note question about changes in the coloration of plants' leaves. Similar to the question about light, the mean knowledge integration score also increased across the three year time span for this question as well. Students performed significantly better from year one to year three, F(2, 30) = 6.033, p = .006. The multiple comparisons procedure showed a statistically significant difference in mean scores for student-groups' in year one and year three (p = .006). However, it revealed a marginal difference for years one and two student-groups (p = .051). There was no significant difference in mean scores for student-groups in years two and three (p = .648).

The frequency distribution of knowledge integration scores in Table 4.8 also supports these findings. For example, no student-groups in Alice's class left the question—changes in the coloration of plant leaves unanswered for any given year. In year one, over half of the students provided normative answers to the question and only nine percent of the groups provided normative answers with one explanation. Thus, in years two and three, over half of the student-groups answered the question by providing normative answers with at least one explanation (year two = 54% and year three = 64%). Figure 4.4 provides examples of students' responses to this question about changes in the coloration of plants' leaves.

Students' responses became more elaborated on both questions across successive years of the project. In addition, by year three, students made more links between the scientific ideas in their repertoire. For example, in year three, a group of students (Joseph/Andy) responded to the question *Suppose you are passing by a tree and happen to look up and notice that most of the leaves have turned orange/brown and are falling to the ground. Why does this happen?* with:

> *This would happen because glucose gets trapped in the leaves because photosynthesis stops because the days get shorter in the Fall. Plants cannot collect as much sunlight, so then they can't make their food.*

Question: Write a statement explaining what would happen to plants if they didn't have any light?

	KI Score	*Year One Students' Responses*
Annie/Dan:	1	It probably won't grow.
Waldo/Kristy:	1	They wouldn't sprout or grow.
Gloria/Ethan:	2	If plants didn't have light, they would drown because the water won't evaporate. Also, they would need sun to do photosynthesis.
Carrie/Julie:	3	They will not get chlorfil [chlorophyll] and change colors...They won't be able to do photosynthesis and die.
		Year Two Students' Responses
Fae/Tai:	2	They would grow because they are searching for the light.
Tina/Brad:	2	The plants wouldn't have any chlorophyll.
Jim/Merriam:	3	If plants didn't have any light, they would grow to try to reach the light, but the color would not be a normal plant color (green).
Jill/Sue:	3	The plants will try to reach for the light, but will eventually die because they need sunlight to grow.
		Year Three Students' Responses
Albert:	2	If plants didn't have any light they will change colors.
Keith/Laura:	4	If plants didn't have any light...they would bend near the closest bit of sunlight. They would die sooner or later because they will not have the food they need.
Phil/Nicholas:	4	If plants didn't have any light the plants will not turn their color to green, and the leaves will get weaker. Soon the plants will die.
Ben/Ricky:	4	If plants didn't have any light, they would grow real fast, but they would die real soon. Sunlight gives plants the ability to make food. This is called photosynthesis.

Figure 4.3. Students' Ideas about Light in Years One through Three in Alice's Class.

Question: Suppose you are passing by a tree and happen to look up and notice that most of the leaves have turned orange/brown and are falling to the ground. Why does this happen?

	KI Score	*Year One Students' Responses*
Kal/Jose:	1	The tree does this because it hibernates. And the tree just cuts off the leaves.
Julie/Kim:	2	The plant stops photosynthesizing.
Annie/Dan:	2	The plant stops making food.
Janet/Alicia:	2	This would happen because the chlorophyll is going away.
		Year Two Students' Responses
Martin/Frank:	2	This would happen because they don't get enough sun and nutrients.
Lee/Peg:	3	Because it is Fall. In the Fall the days start getting shorter giving the plant has less time to collect light. The air gets colder.
Lori/Anthony:	3	This would happen because the sun comes out less so the plant gets less energy.
James/Niki:	4	This would happen because the days are getting shorter. So the tree is not getting enough sunlight and the sun gives the plant chlorophyll which gives the plant its green color. But it doesn't have enough chlorophyll and it changes to its original colors red and brown.
		Year Three Students' Responses
Maggie:	2	That means that it is another season and it is the season of Fall or Autumn.
Ann/Tony:	4	The sun goes down sooner and the plants don't have enough energy to supply food for the leaves. So chlorophyll supplies will become less and the leaves will become different colored.
Joseph/Andy:	4	This would happen because glucose gets trapped in the leaves because photosynthesis stops because the days get shorter in Fall. Plants cannot collect as much sunlight, so then they can't make their food.
Ron/Daniel:	4	Autumn is near and chlorophyll is becoming scarce. The inside colors of the plant is taking over the green color. The food left in the leaves become frozen and turns to red.

Figure 4.4. Students' Ideas about Light in Years One through Three in Alice's Class.

To conclude, student-groups in both teachers' classes performed significantly better in year three, compared to year one, on the two WISE online note questions, *Suppose you are passing by a tree and happen to look up and notice that most or all of the leaves have turned orange/brown and are falling to the ground. Why does this happen?* and *Write a statement explaining what would happen to plants if they didn't have any light?* Students made more links between scientific ideas. For example, over the successive years, they linked the color changes of the leaves to the reduction in the amount of chlorophyll and plants' inability to perform photosynthesis. The fifth-graders also expressed more ideas about why light is important to plants and how it is an integral part of the internal production of food.

Furthermore, no student-groups in Alice's science class, in any year, left the WISE note question about light and the question about changes in the colorations of plants' leaves unanswered. In addition, in years two and three, over 80% of the student-groups in Alice's class provided normative answers to these WISE note questions. With respect to the same questions, student-groups in Lee's science class made similar gains in understanding by year three.

In conclusion, my research demonstrates that the nature of student learning is enhanced by incorporating technology-based learning environments for instructors as well as students, which the instructors can customize to their classroom setting (Putnam & Borko, 2000).

CHAPTER 5

AN EXPERIENCED TEACHER'S LEARNING TRAJECTORY: TEACHING SCIENCE IN A WEB-BASED ENVIRONMENT

Introduction to Case Study Lee

In the previous chapter, I discussed the context in which the two elementary teachers, Lee and Alice, implemented the WISE plant project across the three year time span. Findings revealed that improvement in students' understanding over the course of three years followed the teachers' customizations to the instruction and software enhancements. In this chapter, I report how the initial teacher-partner, Lee, learned to teach inquiry science in a technology-based environment across time. I discuss changes in his practice and understanding, and examine what factors encouraged or supported his development. Understanding the teacher's development in both practice and pedagogical content knowledge can provide additional insight about the origin of the changes in student learning outcomes. Below I provide a brief overview of the specific methods used for analyzing the two dimensions—practice and knowledge, which were discussed in detail in chapter 3, before proceeding to the discussion section.

Indicators of Performance

Indicators of Teachers' Practice

As discussed in chapter 3, in order to capture the trajectory of change in the ways elementary teachers come to make students' scientific thinking visible through the use of technology over time, I analyzed two dimensions of teaching practice: (a) Questioning Patterns—categorization of methods of questioning for key topics/lessons that occurred in Lee's practice across all three years, and (b) Science Dialogue—an analysis of the ways Lee elicited students' science ideas in science dialogues with small groups during his second and third year of teaching the WISE plant curriculum. As Linn and Hsi (2000) point out, eliciting students' prior knowledge about a scientific topic and encouraging them to connect existing and new ideas can promote knowledge integration.

Questioning Patterns. Questions were coded into three categories (refer to Figure 3.2 in chapter 3 for my coding scheme): (a) logistical, (b) factual, and (c) conceptual. Questions that asked students about management or procedural issues were coded as logistical. Questions that required students to recall content knowledge without asking them to reflect were coded as factual. Questions that asked students to make predictions, provide explanations for their responses, and justify their conclusions with evidence were coded as conceptual questioning. Asking conceptually oriented questions help to make students' scientific thinking visible across time. However, some logistical and factual questions are appropriate.

Science Dialogue. I traced how Lee made students' scientific thinking visible by analyzing discourse patterns in the focal lesson—*Light/photosynthesis* in years one through three. I examined how he engaged students in more science dialogues (i.e., by encouraging students to sort out scientific ideas and connect new ideas with prior ideas) in small groups, a strategy that I believe promotes knowledge integration. I began the coding process by watching videos of each of the focal lessons in years one, two and three. At the same time, I read transcripts along with watching the videos of classroom dialogues. I defined a single dialogue as talk the first time an utterance (a word) transpired between a given student or group of students and the teacher from beginning to end. I coded this dialogue as logistic dialogue or science dialogue. I defined a teacher-student dialogue as a logistic dialogue if it focused on management and procedural issues. I defined a teacher student-dialogue as a science dialogue if it met one or more of the following criteria: (a) the teachers encouraged students to provide explanations for their responses, (b) the teachers asked students to make predictions and explain their reasoning, (c) the teachers encouraged students to support claims with evidence, and (d) the teachers encouraged students to challenge each other's perspectives. These criteria enabled me to capture how the teachers helped students sort out their scientific ideas and link ideas. I analyzed each dialogue as the teacher moved to ongoing groups. After watching each video and reading the corresponding transcript, which denotes where every dialogue begins and ends, I then summed up the total of logistic and science dialogues (separately and in combination).

Indicators of Teachers' Pedagogical Content Knowledge

I used the knowledge integration perspective to frame the analytic tools used for understanding development in the teacher's pedagogical content knowledge. Drawing off of the work of Grossman (1990), Magnusson et al. (1999), and Sherin (2002), I categorized Lee's pedagogical content knowledge into the three components: (a) teachers' knowledge of instructional strategies, (b) teachers' knowledge of students' science conceptions, and (c) teachers' knowledge of the science curriculum. In order to trace changes in each category, I concurrently looked for evidence of the following knowledge integration processes for teachers (Linn & Hsi, 2000): (a) adding new ideas to the repertoire, (b) sorting ideas, (c) reconciling ideas that appear contradictory, and (d) integrating preexisting and new ideas. Refer to Table 3.3 in chapter 3 for an example of how I looked for evidence of the knowledge integration processes after identifying the categories of pedagogical content knowledge.

Changes in Lee's Practice

In this section, I report findings from the two methods of analysis (i.e., categorization of questioning and science dialogue) to capture the changes in the ways Lee helped students make their thinking visible around key science ideas in the WISE plant curriculum from years one through three. Before discussing findings from the two methods of analysis, I provide a description of Lee's teaching across the three year period to set the context.

Descriptive Analysis

Prior to implementing WISE in year one, students in Lee's class had primarily used the computers for drawing and word processing purposes. They used computer applications such as Kids Pix and Microsoft Word on a limited scale. Lee stated in the initial interview that:

> *About four years ago, there was an opportunity that came along for the Silicon Valley PC Day II Grants and I wrote a grant. The grant was funded and I was awarded six PC's in the classroom. I was not sure how to use them. For the students, I never had these many before. I felt that just having them play games on the computers would not be a very effective use of technology and I was wondering about how I could get the students to use the computers to enhance the learning process. And then we got involved in Net Day to get the whole school wired for the Internet. I was fortunate enough to talk the Technology Services Department into helping fund getting Internet access out here in the portables. Although the portables are wired now, I still am faced with the dilemma of what to do [with a networked environment]. I don't know much about Internet projects.*

Although Lee had numerous years of experience with technology (i.e., a Master's Degree in Educational Technology and Instructional Design) prior to WISE, he remained open to the idea of learning new technological innovations. Not only was Lee open to new ideas, but he encouraged his students to do the same. During the initial interview, Lee further pointed out that:

> *Really one of my main goals as a teacher is instilling that sense of efficacy in my students. I want to enable them to take responsibility for their own learning, but to help them home their tools—that thinking process. So that when they approach a problem or situation, they will take the time to go through a systematic sort of procedure to come up with a solution. I would really like to turn students into life long learners. I want my students to always want to learn as long as they're on this earth. I want them to be thirsty for knowledge.*

Moreover, Lee did not believe in the notion that teaching is merely telling students things, but his goal as a teacher is to have his students think analytically, to become problem solvers. This entailed providing students with opportunities to make sense of things and not rely on him as the sole knowledge provider.

My initial observation of Lee implementing the WISE plant project in year one was consistent with his stated views of student learning. For example, as Lee introduced the plant curriculum for the first time, he began the project by soliciting the students' initial ideas about plant growth. He asked students, *What do you know about plants?* followed by *What are some things you would like to find out about?* as well as *What are some things that you would like to know that you don't know now that seems sort of a mystery for you?* A substantial amount of time was spent discussing the above questions. In a subsequent lesson, Lee encouraged his fifth grade students to reflect on the project goal (i.e., the WISE online investigations thus far). For example, he asked students to share what they had learned thus far in the WISE plant module, *What Makes Plants Grow:*

> **MARTIN:** *About the space plants up in the space thing.*
>
> **LEE:** *Um, space plants up in the space thing.*
>
> **MARTIN:** *Spaceship.*
>
> **LEE:** *So there was information there about plants and about space right. So why is this important? What do the plants have to do with being in space or being in outer space? Anybody remember? [Long pause—students exhibited confused facial expressions] So maybe we need to look at the introduction again when you're in your project?*
>
> **JANICE:** *They want to use photosynthesis.*
>
> **LEE:** *Excuse me?*
>
> **JANICE:** *Never mind.*
>
> **LEE:** *Does anyone remember what we're supposed to do eventually in the project? What is our goal? What are we trying to figure out?*

As students went back and forth discussing the project goal, one student said, *Can plants grow in space? That live here on the earth.* Lee then asked the students to think about what is the purpose *if plants could grow in space, how does that help us*. He probed their thinking process even further by asking them if they recalled the introduction activity in WISE discussing *what do plants growing in space have to do with astronauts*. Students did not respond because they were not certain. Lee rephrased the question as *so did the astronauts [referencing the introduction activity] say anything about wanting or needing plants?* Students mumbled in unison because they still did not understand. As a result, Lee stated:

> *If you don't remember that's ok. You can go back and check the introduction again. So maybe it's a good idea when we're going through the project from time to time we need to re-focus. We need to go back and confirm our reasons for being in the project in the first place. What are we trying to accomplish? What are we trying to look at?*

During this particular lesson and subsequent lessons in year one, Lee continuously encouraged the fifth-graders to support each other through working with their partner (example of the SKI tenet—providing social supports). He also encouraged the students to utilize other resources such as the Internet, dictionaries, and examples discussed in class. Even though Lee was an intricate part of the classroom community, he viewed himself as only a resource for knowledge. For the most part, Lee's teaching seemed consistent with his goal in year one.

As discussed in chapter 4, Lee taught the plant curriculum for a longer period of time each year over the course of the three years (5 ½ weeks in year one, 8 weeks in year two, and 11 weeks in year three). Out of the six key topics—*light/photosynthesis*, *hydroponics*, *conditions in space*, *nutrients*, *comparing plants' life cycles*, and *graphing data*, Lee cover all of the topics each year except *graphing data.* (Due to a networked firewall implemented by the school district, Lee's students were unable to use the WISE graphing feature.) Furthermore as discussed in chapter 4, Lee taught the five science topics across more contexts (WISE online investigations, small group discussion, and whole class reflection) over time, and there was greater and more integrated use of technology. Also, Lee taught the key science topics for a longer period of time. As Lee introduced a science topic for the first time, he reintroduced a previously taught topic(s).

Questioning Patterns of Class

Lesson: Photosynthesis (Comparison between Years One through Three)

I analyzed the focal topic, *Light/photosynthesis*. Refer to chapter 3 for the criteria used to determine which topic(s) to include in the analysis. As shown in Table 4.1 in chapter 4, Lee taught the topic, *Light/photosynthesis* over the course of four class periods in year one. However, two of the four lessons were not analyzed because the teacher left his students to work on WISE investigations primarily without any guidance, in addition to one of the lessons being inaudible. The two lessons that were analyzed were taught as part of offline reflection activities. In contrast, in years two and three, Lee taught the topic to the students during the activities in the *What Makes Plants Grow?* software project, in addition to incorporating it as part of small group and whole class reflection lessons. The topics were taught over five class periods in year two and six class periods in year three versus four class periods in year one.

An overall pattern of Lee's questioning strategies for the Light/photosynthesis lessons[1] *across years one through three.* In this section, I discuss Lee's overall questioning strategies for the *Light/photosynthesis* lessons (a total of 13) across the three year time period. Lee taught these lessons across three contexts—WISE investigations, small group discussion offline, and whole class discussion. At this point, I analyze the overall patterns for the 13 lessons and later on will examine the details inherent in these individual lessons.

As shown in Figure 5.1, in years one through three, Lee elicited students' science ideas primarily through conceptual questioning as he taught the thirteen *Light/photosynthesis* lessons. However, the number of conceptual questions asked increased each year. It is also important to point out that the number of class periods was greater across subsequent years. For example, out of 113 questions in year one, 74 of them were conceptual. Out of 190 questions in year two, 160 of them were conceptual. And out of the 365 questions

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[1] The *Light/photosynthesis* lessons were taught by Lee for approximately 35-45 minutes.

asked during the *Light/photosynthesis* lessons in year three, 287 of them were conceptual. Lee asked students questions such as: So if the plants stop making food in the Fall, how does that affect the chlorophyll? How is it now we see orange and yellow [colors in the plant leaves]? So the orange and yellows were not there [in the leaves] all along? and Why does the green not cover the orange and yellow colors up in the wintertime? Although the number of conceptual questions increased from year to year, the percentage of conceptual questions out of the total number of questions asked decreased slightly in year three. This occurred as a result of Lee's experiencing technology related problems due to several obsolete computer systems (e.g., minimum memory and inadequate Internet access). For example, Lee spent several class periods assisting students with logistical problems caused by these computer systems inadequacies. This included Lee asking questions such as *Is your computer working?* or *What happened? Everything is running really, really slow. It shouldn't take that long to load Netscape.* Also, Figure 5.1 shows that Lee asked students factual questions on few occasions over the course of the three year period (year one = 14%, year two = 2%, and year three = 0%).

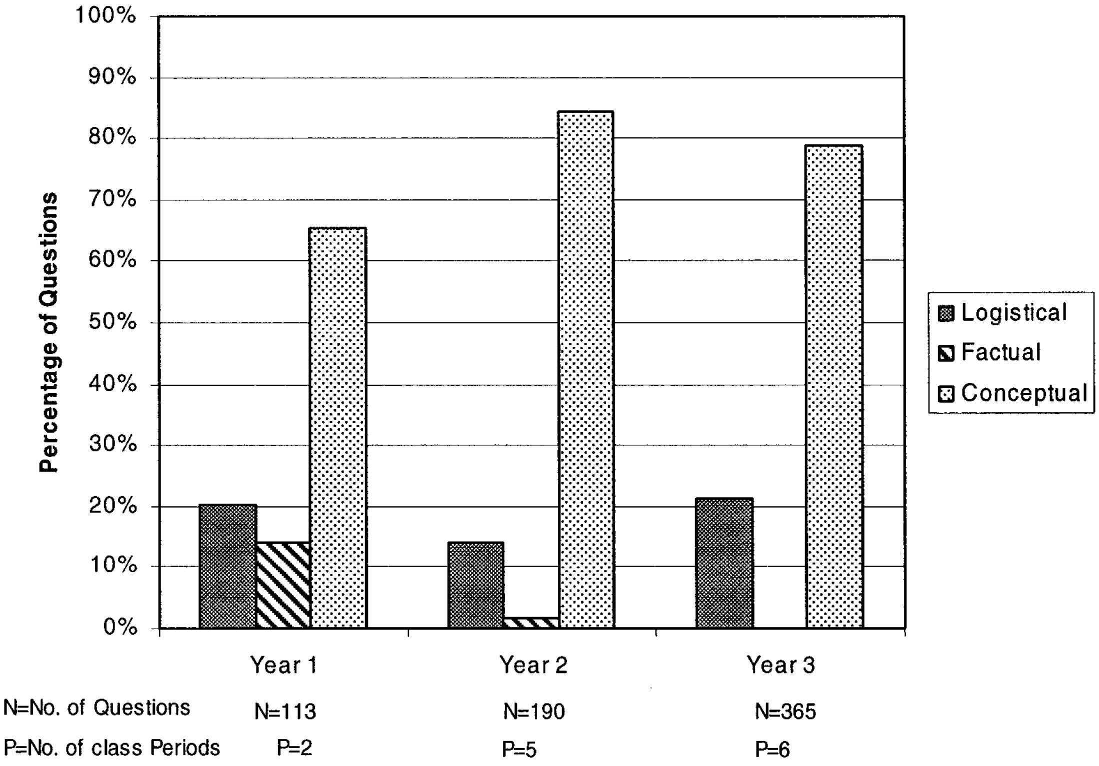

Figure 5.1. Lee's Overall Questioning Patterns in Years One through Three for the Thirteen WISE *Light/Photosynthesis* Lessons.

Detailed analysis of repeated curriculum customizations by Lee on the core science topic. As discussed in the previous chapter, Lee designed classroom activities around the core topic *Light/*photosynthesis to enhance students' understanding of the topic. For example, Lee designed a Language Arts lesson called *Why do leaves change colors in the Fall?* which incorporated the WISE investigation *More Photosynthesis.* This activity occurred offline after students had an opportunity to critique the online evidence *More Photosynthesis.* Lee taught this lesson each of the three years during the implementation of WISE. In regards to the topic *Light/photosynthesis*, this was the only curriculum customization that Lee taught repeatedly. I consider this Language Arts lesson a WISE customization because it was more than a reflection activity. Students were required to apply reading comprehension techniques (e.g., highlight unclear concepts, underline interesting concepts for further discussion) to understand science content in the *More Photosynthesis* evidence pages. This activity took place in both small group (pairs of two) and whole class instruction offline. Each pair of students was given a hardcopy of the WISE evidence pages to read about "Why do leaves change colors in the Fall." Below I discuss Lee's questioning strategies as he implemented this particular science lesson, including how he helped students to make their thinking visible across time around this complex science topic.

Year 1. In year one, about 44% of Lee's questioning was logistical (see Figure 5.2). This included questions such as *How many people underlined that?* or *Why did you highlight that?* These type of questions encouraged students just to follow specific procedures.

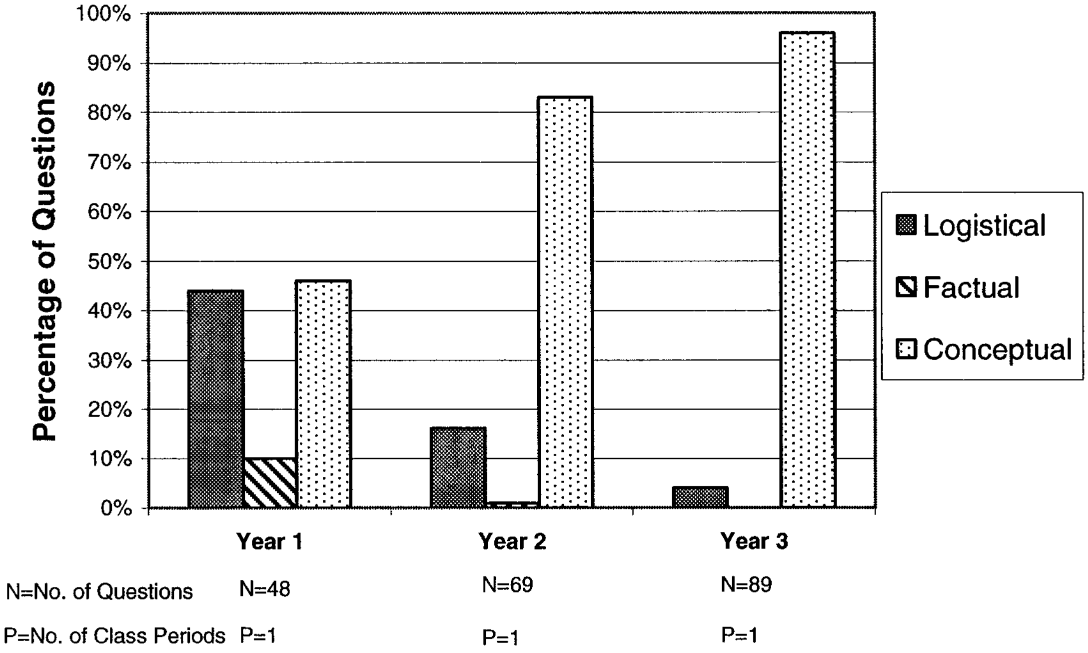

Figure 5.2. Lee's Questioning Strategies in Years One through Three for the *Why do Leaves change Colors in the Fall?* Lesson.

At the same time, 46% of Lee's questioning strategies were conceptual oriented. Lee asked students to make predictions and explain particular concepts in the text (referring to the printed WISE evidence page) in detail. For example, a student (Ricky) said to Lee, *I didn't understand.* Lee responded with, *Which part didn't you understand?* Ricky responded with, *the building block for growing.* Lee then asked Ricky if he had looked up the phrase or discussed it with his partner. After the student indicated that he had done all the above and still was confused, Lee then presented the question to the class for discussion. He asked student Rob, *Do you think you know what they [referring to the evidence page] mean by building for growing?...Now remember plants use glucose as food for energy and a building block for growing.* It is noteworthy to mention that not once during the lesson did Lee ask students to revisit the overarching question, *Why do* *leaves change colors in the Fall?* In fact, students were unable to connect new ideas to their prior understandings. Toward the end of the lesson, Lee tried to help students connect the concept *changes in the coloration of plants' leaves* with the concept *seasonal changes*, but the conversation steered further off course. Moreover, the topic of the conversation revolved around 'what caused the days to get shorter and shorter.'

Year 2. In contrast, in year two, Lee helped students to make their thinking visible through greater use of conceptual questioning strategies. As shown in Figure 5.2, 83% of the questioning was conceptual in year two, versus 46% in year one. He continued to ask students to make predictions, in addition to providing explanations for oral responses. Table 5.1 illustrates typical dialogue between Lee and his fifth grade students in year two. The episode below illustrates that Lee helped students to make their scientific thinking visible through encouraging them to connect science class ideas with personally relevant examples. In addition, as the students discussed the evidence in a whole class setting, Lee kept remaining them to keep the overarching question in mind. Lee also asked students to explain their reasoning. For example, after Kevin provided an initial explanation for his assertion, *plants need water to help with the process of photosynthesis*, Lee continued to probe his thinking even further. Later on in the lesson, Lee asked, *So if the plants stop making food in the Fall, how does that effect chlorophyll?* Gabriella responded with, *it [chlorophyll] goes a way.* Lee indicated that he was hearing some other terms being used as well. He then asked Kevin to repeat his comment. Kevin said, *the chloroplast might fade away.* Lee further asked Kevin to support his claim with evidence. Kevin indicated that he had heard this term in a video about plants that the class watched earlier in the school year. He went on to explain how plants leaves have many chloroplasts, thus indicating that a chloroplast is an organelle containing chlorophyll and is the place where photosynthesis occurs.

Table 5.1. Examples of Dialogue from the *Why do Leaves Change Colors?* Lesson in Year Two.

Conceptual Questioning Strategy

Part I
LEE: Have you seen this particular question before, *Why do leaves change colors in the Fall?*

CLASS: Yes.

LEE: Okay. William where have you seen this particular question before?

WILLIAM: On the WISE website (referring to the *More Photosynthesis* evidence).

LEE: I am going to give you a copy of the evidence. And what I'd like for you to do is to use the evidence to highlight just words or phrases that will help you answer this question [students worked on this activity with their partners]...

Part II
LEE: What was the question?

GRANT: Why do leaves change colors in the Fall?

LEE: That's an interesting question. If you're walking down the street, at least for me, I walk down the street and I see leaves on the tree, sometimes I see leaves on the ground. Are they usually green on the ground?

CLASS: No.

LEE: They are different colors. And it doesn't strike me as unusual or I don't really wonder about it. These are some things that we just kind of take for granted. But most things in nature can be explained in a scientific manner. And that's what we are looking to try to gain today, is a scientific understanding of why leaves change colors in the Fall. Who can read the first sentence for me? Erika.

ERIKA: 'Plants make their own food.'

LEE: 'Plants make their own food.' What does that have to do with the question?

ERIKA: They stop making food in the Fall which affects their color [the trees will rest, and live off the food they stored during the summer].

LEE: Do we need to highlight anything else?

KEVIN: Water.

LEE: Why water?

KEVIN: Because plants need water to help with the process of photosynthesis.

LEE: So why is that important?

KEVIN: Because if they didn't use photosynthesis, they wouldn't have food...

Year 3. In year three, when Lee taught the same lesson, the majority of his questioning consisted of conceptual questions (96%). Similar to year two, this entailed asking students to provide explanations for their responses. In addition to encouraging students to elaborate on their science ideas, he encouraged them to connect science ideas with other domains of knowledge such as social studies, thus making science more personally relevant (see Figure 5.3 below).

STUDENT GROUP A (Marcel and Gary): This paragraph [referring to the handout of the WISE evidence on *Why leaves change colors in the Fall?*] is mostly about how they use glucose.

LEE: Who used the glucose?

STUDENT GROUP A: The plants.

MARCEL: Glucose gets trapped in the leaves, and before it gets trapped the chlorophyll starts to disappear.

LEE: How does that affect the plant?

MARCEL: It starts to die.

GARY: It doesn't just die; it turns yellow, orange or brown, because the chlorophyll is green, and it [the green color] covers the yellows and oranges up during the summer.

STUDENT GROUP B (Matt): And brown colors come from tannin, a bare waste product, and [the] leaves' pigments are formed in the autumn from trapped glucose in the leaves.

LEE: Does anybody know about tannin? [Students said no in unison.] The Native Americans took seeds like acorns, and before they could eat the acorns they would have to get rid of this bitterness. They had a process to leech out or make sure that this tannin got out of the acorns before they could grind them and use them for food. A lot of plants have that.

Figure 5.3. Dialogue between Lee and Fifth Grade Students during the *Language Arts Lesson* in Year Three.

Lee also created a classroom environment where students' opinions were valued. As the above episode (Figure 5.3) illustrates, students felt comfortable interjecting into a conversation when appropriate and challenging each other's perspectives. As a number of researchers have pointed out, collaborative learning situations such as discussions can provide students with opportunities to offer explanations, interpretations, and resolutions supported by a peer or the instructor (e.g., Brown and Palincsar, 1989; Tharp and Gallimore, 1988). These sorts of interactions can also provide social supports for students, as pointed out by Linn and Hsi (2000).

Some logistical questions are appropriate. The small percentage of logistical questions posed by Lee during the changes in the coloration of plants' leaves lesson in year three included questions such as, Are *you guys talking about what you're reading? Okay and how are you deciding what you should highlight? So how far have you gotten?* Here the teacher is monitoring students' progress and encouraging them to stay on task.

Changes over time in Lee's understanding of the curriculum help to explain shifts in his pedagogy. During a retrospective interview in year three, I asked Lee to reflect on the differences (the observational-based changes/findings described above) in how he taught the *Why do leaves change colors in the Fall?* lesson in year three versus years one and two. Lee stated:

> *Well, I think a lot of it had to do with becoming familiar with the whole project, and also you and the WISE team members listening to my feed back, and then making modifications in the whole operation that made it easier for me to understand. I think that in turn made me want my students to understand, so that it's not just something to do [referring to the WISE curriculum unit]. For one thing, when you [referring to myself] would bring stuff back to me and we would sit down and look at some students' responses or you would ask how the interaction with the interface was going. I'd say 'Well, I think it would be better this way' and you would be able to modify questions or expand on questions in WISE. We took certain concepts and broke them down into smaller chunks so that students were able to understand. But also, I think your enthusiasm with the particular project and with science in the classroom using technology has played a large part in this whole process. Without this project, I don't know what we would be doing now.*

This example illustrates how the nature of teaching can be enhanced through teachers' participation in a curriculum partnership with other professionals. Not only did Lee suggest enhancements to the plant curriculum based on his classroom experience, but as discussed in chapter 4, he also made modifications to the WISE software as well.

In summary, Lee's teaching strategies became more conceptual oriented across time. Studying the questions by themselves gives a great deal of information over time, but studying the social context of the questions—the dialogues between the teacher and students and the questions—provides more intriguing data. In this next section, I discuss the dialogues between the teacher and students in years two and three in terms of how he used conceptual questioning to get at information.

Science Dialogues with Small Groups

Table 5.2 below illustrates the context in which Lee taught the focal topic—*Light/photosynthesis* across the three year time span. As shown in Table. 5.2., Lee always taught this topic in small group settings during WISE online investigations. Typically, students were paired in groups of two during the WISE investigations and remained in the assigned groups throughout the WISE project. Findings further show that science dialogues occurred within the context of WISE investigations except for one lesson (lesson 9). This occurred as a result of Lee's experiencing technology related problems due to several obsolete computer systems (e.g., minimum memory and inadequate Internet access) and a temporary glitch in the WISE software. Additionally, the actual number of science dialogues varied across lessons, which occurred as a result of the teacher determining that some student-groups required more scaffolding/guidance than others on a given day.

Table 5.2. Sequence of Activities in Lee's Classroom around the Focal Science Topic—*Light/Photosynthesis* in Years One through Three.

Year	Lesson #	Context	Total Dialogues with Small Groups	Logistic Dialogues	Science Dialogues
1	1	Small group interaction (8 students) without WISE & Whole group	1	0	1
	2[a]	Whole class discussion	0	0	0
2	3	Whole class discussion	0	0	0
	4	Whole class discussion	0	0	0
	5	WISE investigations	17	7	10
	6	Small group dialogues without WISE & Whole class discussion	10	3	7
	7	WISE investigations	36	15	21
3	8	WISE investigations	14	5	9
	9	WISE investigations—computer problems	20	20	0
	10	WISE investigations—computer problems	41	22	19
	11	WISE investigations—Non-WISE related issues	15	9	6
	12	Small group dialogues without WISE & Whole group	8	1	7
	13	WISE investigations	18	8	10

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[a] Two out of the four *Light/photosynthesis* lessons were not counted because, in the case of one lesson students worked independently on WISE, and in the case of the second lesson the sound was inaudible.

The total number of lessons (referring to the focal topic—*Light/photosynthesis*) that Lee taught with technology was greater than the lessons taught with whole class discussion only and small group in dialogues with whole class discussion. Because use of technology was associated with an increase in science dialogues with small groups from year one through year three, therefore I will illustrate examples of science dialogues in the context of WISE online investigations.

Year 2. Lee helped students to make their scientific thinking visible through encouraging them to reflect on science content during WISE investigations. He rotated back and forth among groups of students, providing them with ample time to reflect on their notes and WISE evidence. For example, Lee asked student Larry, *Did you read all of that information* [referring to the WISE *More Photosynthesis* evidence page]*?* Larry stated, *I read it yesterday*. Lee then pointed to the evidence page and asked Larry to provide a summary of the evidence page. Larry responded with, *It's* [referring to the online evidence page] *talking about carbon dioxide, and it's talking about the Fall and the leaves changing and stuff.* Lee probed Larry's thinking further by asking *why do leaves change colors?* Larry indicated that the leaves change colors because of the Fall season. Lee then challenged him to think about if the Fall is the only reason why leaves change colors. The teacher then moved to another group of students and later returns to Larry.

> **Lee:** *See here* [pointing to the WISE *More Photosynthesis* evidence page]. *What does it say right here?*
>
> **Larry:** *If you have extra time, you can read on to find out why leaves change colors in the Fall.*

The teacher suggested that Larry explores the evidence further if time permits or revisit the evidence during the next class period.

Lee moved to another group of students (Andy and Robert). The excerpt below depicts the interaction between Lee and Andy and Bob (Figure 5.4). Again, not only does Lee monitor students' progress by encouraging them to reflect on their in-class work, but he also urges them to stay on task.

LEE: Let me see where you guys are. I see your window changing and changing…

ANDY: I'm going back.

LEE: What is that? 'Plants get water from drinking water [the teacher is reading the students' responses to an online note].' From what drinking water are you talking about?

ROBERT: From a water hose.

LEE: Well, what about plants out in the forest where there is no water hose? Or the plants in the desert where there's no water hose.

ROBERT: They get water from rain.

LEE: Well, I don't see that on there [referring to their written evidence notes].

Figure 5.4. Science Dialogue between Lee and a Group of Fifth-Grade Students during the WISE *Light/Photosynthesis* Lesson (No. 5) in Year Two.

Of course, some logistical questions are appropriate, and he used some. I observed Lee on numerous occasions saying to students, *Stay on task folks. Stay on task.*

Analysis of the subsequent WISE online lesson taught by Lee on the topic *Light/photosynthesis* further shows that he continued to engage his students in year two in science dialogues.

Year 3. The episode highlighted in Figure 5.5 shows that in year three Lee continued to engage his students in science dialogues. He consistently monitored his students' learning process and encouraged them to provide explanations for their responses. He rotated back and forth among groups of students, providing them with ample time to reflect on their WISE notes and evidence.

Episode 1:

MARJORIE: That means putting together… [students discussing a WISE evidence page on photosynthesis with her partner, Jessica]

LEE: You guys…Don't be so loud, please. Just simply because the other people are close around you.

[Teacher then moves to two other groups and later returns to Jessica and Marjorie.]

Episode 2:

JESSICA: Learn more about how plants prepare for the winter [reading a section of the WISE evidence page called *More on Photosynthesis*].

LEE: So this seems to be an explanation about how plants do what?

JESSICA: Turn colors.

LEE: Let's go back up here [pointing to the WISE evidence page]. What does that say? Learn more about how plants prepare for the winter. Okay, so there's a question there. Did you guys get to the question about leaves turning colors and falling to the ground? You haven't gotten there?

STUDENTS: Umm.

LEE: So maybe what you need to do is go on and read this explanation about how plants prepare for winter. And then go the next activity and view the evidence.

[Lee moves to two other groups and later returns to Jessica and Marjorie.]

Episode 3:

LEE: What did you come up with?

JESSICA: This would happen [referring to leaves changing colors and falling to the ground] because they're not getting enough chlorophyll. They're not using photosynthesis.

LEE: So what does chlorophyll have to with this situation?

MARJORIE: Chlorophyll helps make the plants' leaves turn green.

LEE: Why aren't they getting chlorophyll?

MARJORIE: Because of the dry days?

LEE: What do the dry days have to do with chlorophyll?

JESSICA: It sucks out the chlorophyll.

JESSICA: It's autumn, too. [In the leaves, these pigments—bright colors are formed in the autumn from trapped glucose. The brightest colors are seen when late summer is dry, and autumn has bright sunny days and cool nights.]

LEE: It's autumn. And I'm just trying to understand this whole thing with the color and the chlorophyll and the photosynthesis. Because you mentioned something about the plants are not going through photosynthesis during the winter or is it the fall? Is that that what you said?

STUDENTS: Yes.

LEE: So how does that contribute to them losing their colors?

JESSICA: They [referring to the evidence] said plants' leaves turn yellowish brown and they fall into the ground.

LEE: Okay, you mentioned something about them [plants] not performing photosynthesis at that time. And I was wondering if the two were connected. Think about it

Figure 5.5. Science Dialogue between Lee and a Student-group during the WISE *Light/Photosynthesis* Lesson (No. 11) in Year Three.

Encouraging students to provide explanations for responses can provide them with opportunities to reorganize prior/new ideas, as well as to link science ideas. This episode (referring to Figure 5.5.) shows that the teacher was successful at getting students to explain their reasoning, in addition to having them draw on WISE evidence in doing so. Lee helped students make their thinking visible through use of conceptual questioning strategies. Moreover, this example illustrates how Lee often times refocused students' attention to what the given question in WISE was really asking.

In summary, Lee learned to make visible his students' scientific thinking around key science concepts through greater use of conceptual questioning strategies and by engaging them in more science dialogues across time. Additionally, in both years two and three, the Web-based Inquiry Science Environment (WISE) offered Lee new insights into his students' thinking through capturing their results and reflections. As shown in the above episodes, WISE provided him with a detailed record of how student-groups made sense of the project activities.

Lee's Pedagogical Content Knowledge

In this section, I discuss changes in Lee's pedagogical content knowledge across the three year time span as a way of understanding the changes in his practice. I am not by any means saying that changes in teachers' practices always follow changes in their knowledge or vice versa. As mentioned earlier, I conceptualize pedagogical content knowledge for science teaching as consisting of three components: (a) teachers' knowledge of instructional strategies, (b) teachers' knowledge of the science curriculum, and (c) teachers' knowledge of students' science conceptions. In order to trace changes in each category of pedagogical content knowledge, I concurrently looked for evidence of the following knowledge integration processes for teachers (Linn & Hsi, 2000): (a) adding new ideas to their repertoire, (b) sorting ideas, (c) reconciling ideas that appear contradictory, and (d) integrating preexisting and new ideas. In this section, I also discuss what factors such as the social supports I provided and the teacher's own reflections encouraged or supported Lee's development over time. The social supports provided by the researcher included: (a) scaffolding Lee in reflecting on his practice and knowledge, (b) assisting him with curriculum customizations, and (c) assisting Lee with putting other scaffolds in place to support his learning such as interactions with scientists via the Internet.

Teachers' Knowledge of Instructional Strategies

This component of pedagogical content knowledge—*teachers' knowledge of instructional strategies* consists of two sub-categories: teachers' knowledge of strategies to help students understand specific science content in the WISE *Plants in Space* curriculum, and teachers' knowledge of methods for assessing student learning in *Plants in Space*.

Strategies to help students understand specific science content. Prior to implementing WISE for the first time in year one, Lee emphasized the importance of asking students questions as a way to promote learning. Lee stated:

> *I feel that teaching and learning is not so much as telling students things, but rather to ask them thought provoking questions. There are some students who by observations I sort of know who usually picks up rather quickly and there are students who raise their hands all the time. But I want to include all the students, so I use a random type of questioning. I pull names out of a hat so to speak and students never know when their name will be pulled. I bounce questions back and forth from student to student. If one student makes a statement or observation, I'll ask another*

> *student what they think or how they would respond. I try to get the students to talk amongst themselves, not necessarily just talk to me all the time…I try to group my students so that not all the strong students are in one group. I try to have a good mix of boys and girls, students with average skills and understandings and students with stronger skills and understandings and students who may be struggling with a concept or don't have such good study skills or work habits. So, it takes a while to sort of get to know the students. But once they are in groups and I can talk to them as a group—asking them questions.*

This example also illustrates that Lee placed much value on the notion of "equity" in his classroom, in addition to considering use of questioning as method to promote student learning. However, his initial conception of questioning did not focus on the use of questioning as a strategy to enhance students' understanding around specific science content in the *Plants in Space* curriculum unit.

It was not until year two that Lee revised his initial conception, use of questioning as a strategy to help students learn in general, to asking students questions specific to the science content in WISE (see Figure 5.6 below). However, he did not revisit the remaining two initial conceptions—equity in the classroom and student collaboration—until his third year of teaching WISE. During a WISE customization meeting that I facilitated in year two, Lee stated, *I want to ask them [students] questions—this could be like 'brain joggers.' I could ask them in an informal discussion.* "Brain joggers" are guided questions that required students to reflect on previously learned information. He then went on to provide examples of content related questions that he planned to ask students during whole class reflection:

> *I have questions that I would like to just pose to you. You don't have to answer them online. But this is just the topic of the discussion. You know, can plants grow without sunlight? Why is water important? What's the difference between where plants get their food and where*

> *people get their food? And then we are going to cover this in the food chains and food webs.*

This excerpt also reveals Lee's intention to ask students content related questions that required them to make distinctions between science ideas such as *plants getting food and people getting food.*

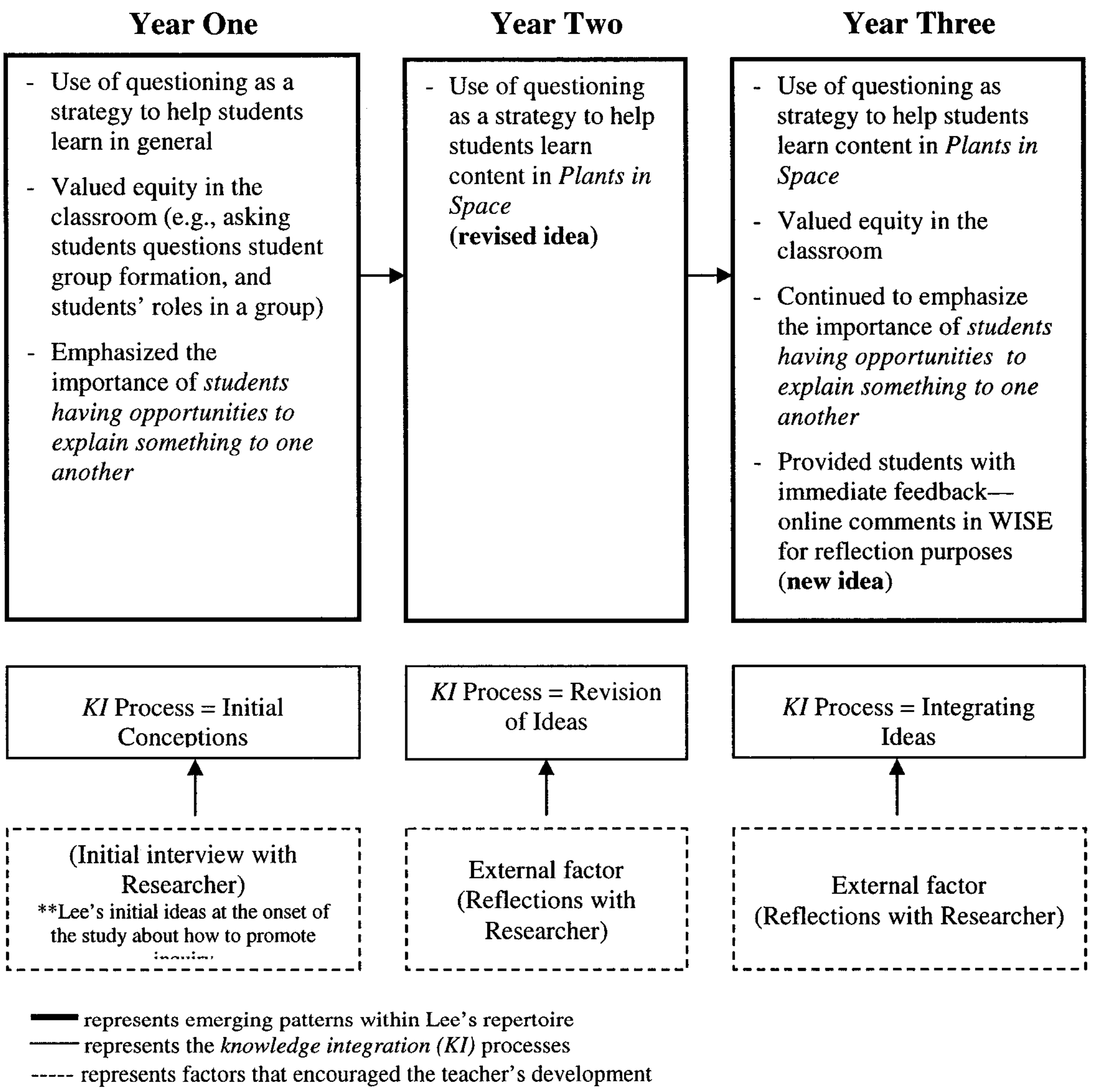


Figure 5.6. Lee's Knowledge of Strategies to Help Students Understand Specific Science Content in *Plants in Space*.

Observations of Lee's teaching in year two reflected this metacognitive process. For example, during the second WISE lesson, Lee asked students, *So let's go back to the beginning of the [WISE] project. There was a question asked of you, what was that question at the beginning of the project?* Meg responded with, *What do plants need in order to grow?* Various students replied in unison, *energy and sunlight.* The teacher then asked, *Why do they need sunlight?* A female student responded with, *The sunlight, it turns some kind of chemical in the plants. The chemical helps the plants produce food.* Other students indicated that plants need water, carbon dioxide, and oxygen in order to survive. Lee was aware that some students held a set of normative and non-normative scientific views (e.g., plants give off oxygen in the photosynthesis process as opposed to needing oxygen for survival). As a result, he emphasized to the class, *When you're [referring to the entire class] on the computers, I need you to [take another] look at all of your responses.*

Thus on numerous occasions in year three (i.e., prior to the implementation of WISE and during the WISE project run), Lee shows an integrated understanding of specific strategies necessary to help students comprehend science content in WISE *Plants in Space* (refer to Figure 5.6 above). Not only did the revised idea—use of questioning as a strategy to help students learn content in *Plants in Space*—resurface in Lee's repertoire, but his initial conceptions from year one regarding equity in the classroom and student collaboration reappeared as well. Lee exclaimed, *I like to give students a sense of empowerment that they can think, that they can reason, and they do already have a certain amount of data. And all they need to do is process it to turn it into information, which in turn will come out as knowledge.* Moreover in year three, he added a new idea to his repertoire—providing students with immediate feed back through the WISE online comment feature. It is most compelling to see that changes in Lee's knowledge of instructional strategies also reflected changes in his practice. For example, in year three, Lee taught three lessons (referring to lessons 8, 9 and 10 in Table 5.2) for approximately 30-40 minutes over three class periods, which required students to revise their WISE notes while at the same time take into account his online comments, see Figure 5.7 below. The examples in Figure 5.7 also support the previous findings in that, in year three, Lee focused on encouraging students to support claims with evidence, make predictions, and to explain their reasoning.

Professional development activities. Factors that supported Lee's development in year three included the supports I provided, such as repeatedly scaffolding him in reflecting on his practice. As a case in point, prior to implementing the WISE plant curriculum in year three, I asked Lee what strategies he would use to make complex scientific ideas in the plant curriculum comprehensible to his fifth grade students. Again, Lee emphasized that he felt students learn best by not telling them everything, but rather asking them thought provoking questions about difficult ideas in the science unit. He further explained that *the Soil for Supper* activity [referring to the Van Helmont evidence page] in the WISE software project is concerned with a difficult concept for students to grasp. Lee's rationale for this assertion was that some students believed 'plants eat dirt' and that 'the plants get energy from the dirt.' Figure 5.7 shows actual examples of Lee asking a student-group (Stephanie and Sam) thought provoking questions about their response to the Van Helmont note question in WISE, which occurred during the implementation of *Plants in Space*. This example further illustrates that the teacher's pedagogical conceptions matched his classroom practices.

Student-Groups	**WISE Activity**	**Students' Online Work (i.e., WISE note questions and students' responses)**	**Teacher Comments**
Nick - Jim	1	*What do you think plants need in order to grow? What are the reasons for your answers?* Response: We think plants need water, soil, sunlight and insects. Plants need water for the roots to take nutrients in to grow. Plants need soil so you can put water in it for the roots to take in. Plants need sunlight so that photosynthesis can work. They need insects for protein to grow large, strong and healthy.	Please explain this in more detail. How do plants use sunlight in the photosynthesis process? What role do insects play?
Marcel - Gary	1	*Why do you think the shorter plant and the taller plant might be growing differently?* Response: We think the two plants might be growing differently because some plants don't need sunlight. Some plants lives in the desert. Some plants live in the depths of the ocean.	I thought all plants needed sunlight, but I could be wrong. Can you give examples or evidence to support your answer?
Stephanie - Sam	2	*Mr. Van Helmont found that only 2 ounces (1/8 of a pound) of soil was gone after 5 years. If the tree does not get all of its energy from the soil, where does it come from?* Response: A tree can also get energy from water and sunlight because they are forms of food for the plants.	Are you sure that water and sunlight are food for plants? Do plants eat water and sunlight? Do plants eat food at all? If so, how does that work?
Karen-Keshia	3	*What are some benefits of growing plants hydroponicly?* Response: You can grow more plants in smaller spaces—examples a green house or a living room.	Can you please give more details to this thought?

Figure 5.7. A Sample of Lee's Online Comments to Student-Groups' WISE Notes in Year Three.

In a subsequent interview in year three, I asked Lee why he decided to provide each pair of students with online comments to their WISE notes this year. Lee stated:

> *Well, once again, I believe in feed back, immediate feed back. And it's because I want them to reflect. I'm not sure if I had the ability before. Was it [the WISE online feature] there? Yeah, I guess last year [referring to year two] it was there, and I didn't use it last year.*

I then asked Lee why he didn't use the WISE online comment feature last year. He responded:

> *So I don't remember having that feature. And when I saw that [referring to year three], I got excited about that because when they go back to the project after they've been off, they go back and they see that, 'Well, he's written us something...' If students do some work and then they don't have an audience, no evidence that anyone cares about what they did, then there's no incentive for them. Believe it or not, it took me a long time to get to this understanding. But students for the most part, really want to achieve and most of the time their efforts are validated by the teacher in the classroom. So I think it is important that I touch base with students as much as possible. The more reflecting they do, the better the quality of their knowledge, the better the quality of their understanding, the better the quality of their learning.*

I probed Lee's thinking further by asking him to elaborate on what were some of his goals for asking students' questions such as the ones depicted in Figure 5.7. Lee said,

> *Well, it's like 'prove yourself!' I don't want them to make statements that they can't back up, and I don't want them making statements that are too general. Now, for instance the first one [referring to a group of students online comments]: 'One has more sunlight or more water.' Okay, so there's more sunlight. What does that have to do with a plant growing? You've said more sunlight or more water. What does that have to do with anything? Explain it in more detail. Why is it then that if this plant doesn't get enough water, or if it gets too much water, it will be adversely affected? I like students to be able to determine where a response or statement is reasonable or accurate...*

Providing Lee with opportunities to reflect on his practice across time contributed to his development in pedagogical content knowledge—i.e., *knowledge of instructional strategies.*

Methods for assessing student learning. Figure 5.8 illustrates Lee's knowledge integration processes with respect to effective methods for assessing student learning. I asked Lee on several occasions in years one through three how did he know if his students were learning science. As shown in Figure 5.8, he viewed listening (an informal method of assessment) as the primary method for assessing students' understanding in science. For example, Lee stated:

> *Really more than anything else they talk about it. And I listen to them not just in the classroom but they talk about it when they're outside. They may talk about things like when it's raining they may use vocabulary that we learned from the water...they start talking about the amount of precipitation that's falling. Or they may notice how water is flowing downhill or they may make mention of the amount of erosion that they can observe coming from the upper yard. When I talk to them they're not shy about talking about science and what they know about science. And they talk about it not just in the concept of the learning environment but they talk about it in terms of their everyday life.*

In year two, Lee added a new idea to his repertoire regarding assessing students' science learning—use of a more formal method of assessment such as a WISE online quiz (refer to Figure 5.8). His previously held belief regarding listening as the primarily method for assessing students' science knowledge did not reappear in his repertoire until year three. This change in year two occurred as a result of Lee self-reflecting on the WISE plant curriculum unit prior to a meeting we had scheduled. He explored the entire WISE *Plants in Space* project in-depth and wrote down in a note book specific activities he planned to implement when teaching WISE again, as well as possible questions for a WISE online quiz. This written artifact consisted of the following ideas: (a) a reminder to himself to create of a list of vocabulary words for his fifth-graders to learn, (b) a list of notes to develop possible assessment items to be added to WISE, (c) a list of conceptual questions related to WISE evidence that he planned to ask students (e.g., *Why is water important to plants? What is the function of the nutrient solution in the hydroponic process? When would it be too much or not enough sunlight for plants in space?*), and (d) a note to himself to think about the following question— *How do I communicate with students?* It is noteworthy to mention that I did not encourage Lee to go through this self-reflection process beforehand. However, by scheduling the meeting, I provided Lee with an opportunity to reflect on his teaching practices.

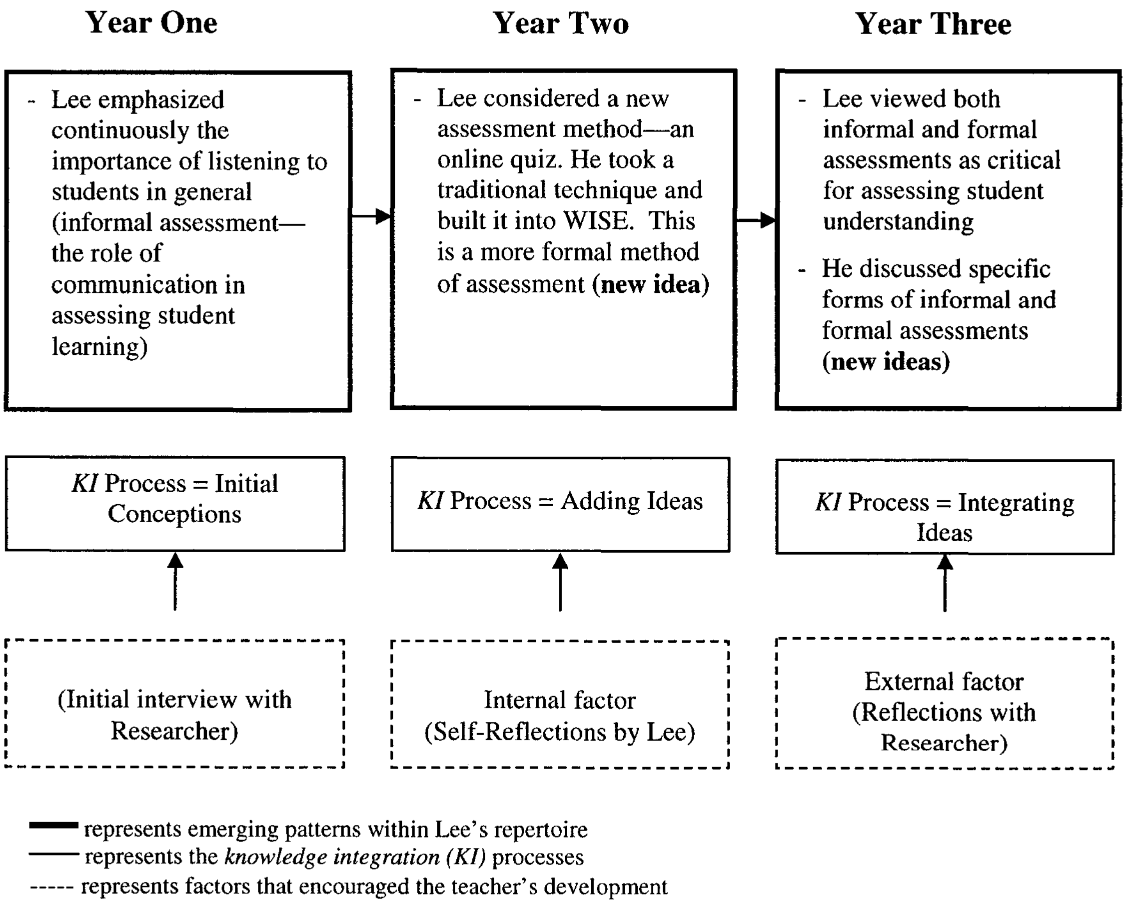


Figure 5.8. Lee's Knowledge of Methods for Assessing Student Learning in *Plants in Space*.

Later in a meeting with Lee, I pointed out that a number of the questions he planned to ask students about WISE evidence focused on water and nutrients. Lee replied, *I'm trying to get at whether they understand that the plants are getting the nutrients from an outside source [referring to growing plants hydroponicly]. The plants get the nutrients from the soil, but [in this case] there is no soil. 'So what is the function of this'? I think a lot of them haven't thought that through.* I observed Lee in year two teaching the two topics—water and nutrients on a few occasions (i.e., water twice and nutrients once). Lee began the process of asking students the sort of questions he wrote on the paper artifact. For example, Lee asked his students questions such as: *What's the difference between a hydroponic garden and a regular garden? So Douglas said you don't need soil in a hydroponic garden? So how is that true?* In addition, as shown earlier in Table 4.1, Lee allocated more time teaching these two topics in year three.

As shown in Figure 5.8, in year three, Lee integrated his initial conception of assessing students' learning primarily through listening with the more recent idea of formal assessment. He viewed both of these methods as critical for assessing students' science understanding. Lee also added new ideas to his repertoire, which included emphasizing even more specific forms of assessment measures. As a case in point, in an interview prior to the WISE run in year three, I asked Lee how he would measure students' understanding. Lee stated:

> *Well, there are different ways of assessing students. They can do it in art form, they can do it in an essay, and they can do it with answering questions, interview questions. Sometimes it's just very informal, like asking questions. Sometimes I make a quiz based on concepts that I think are very important that they should know by the end of a unit or at the end of a lesson. Sometimes it's*

> *an actual physical model. So I try to employ as many as are reasonably feasible within the environment and the time that we have to work with…It could be a small group activity with students assessing one another. Many times students are harder on themselves than I might be. And, certainly, the classmate assessments are important because these are their peers. When your peers acknowledge your achievements and your accomplishments, many times it goes further in boosting self-confidence and self-esteem than if I was to give them a letter grade.*

I then asked Lee what specifics he would look for in using these multiple forms of assessments. He responded, *If given a multiple choice, can they choose a correct response? Can they articulate a concept verbally? Can they write a story with a particular concept embedded in character actions, character traits, and things of that nature? I really like art. Because everyone is not a good writer, but it just means that you're not a good writer, it doesn't mean that they don't understand a particular concept.* As discussed earlier in this chapter, in year three, Lee helped make visible his students' scientific thinking around the key topic *Light/photosynthesis* through greater use of conceptual questioning and engaging them in more science dialogues. In addition, he required student-groups to construct a story as a final project for younger audiences (first, second and third grade students) around key themes in the *Plants in Space* unit.

The analysis of Lee's *knowledge of instructional strategies* shows him engaging in the knowledge integration processes of adding ideas to his repertoire, revising ideas, and integrating ideas (preexisting and new ideas) after his first year of teaching WISE.

Professional development activities. Providing Lee with repeated opportunities to reflect on his teaching contributed to his development in both knowledge and practice, as well as his own self-reflection. For example, as a result of me scheduling a meeting with Lee in year two, he self-reflected on the WISE *Plants in Space* curriculum. This entailed

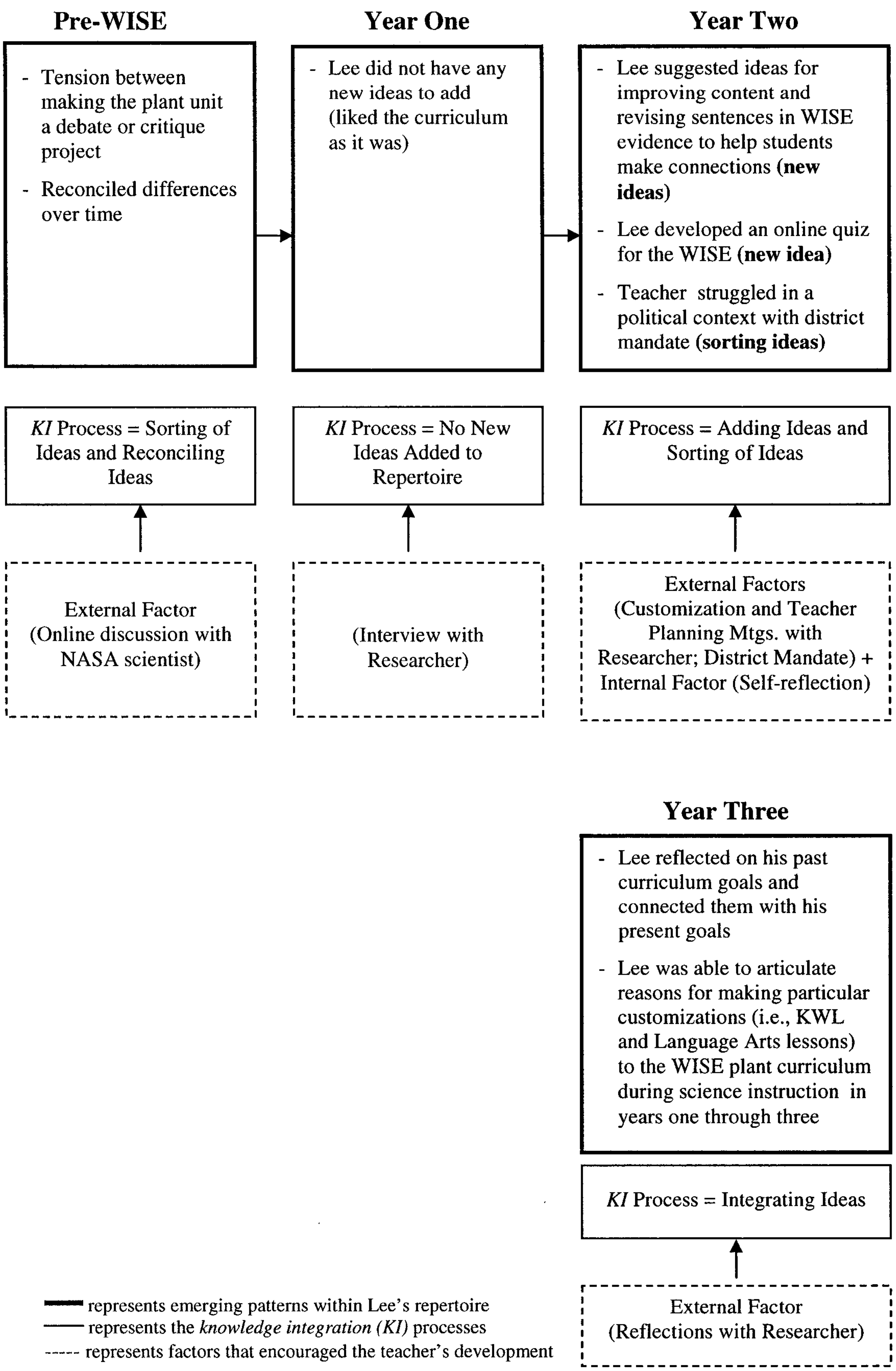
Lee exploring the entire WISE plant unit in-depth beforehand and writing down specific activities he planned to implement when teaching WISE again (i.e., the online quiz questions).

Teachers' Knowledge of Science Curriculum

I define this component of pedagogical content knowledge as teachers' knowledge of the curriculum goals for the WISE plant unit, which includes their knowledge of WISE activities to be taught, science content students are expected to know, and ideas for customization to WISE and their instructional practices.

As discussed in chapter 3, Lee was a co-developer of the WISE *Plant in Space* curriculum and participated in the re-design process. Figure 5.9 below illustrates the evolution of Lee's science curriculum knowledge over the three year time span. Please note that this representation is comprised of four time points instead of three. The Pre-WISE time point represents Lee's knowledge during the design process of *Plants in Space*, which occurred prior to his initial implementation of WISE in year one.

In year one, Lee indicated on several occasions that he was happy with the current version of *Plants in Space* and did not have any new ideas to add from a software enhancement standpoint (see Figure 5.9). However, during the WISE run in year one, Lee ended up designing supplementary classroom activities such as the Language Arts lesson called *Why do leaves change colors in the Fall?* and a WISE introduction activity called *KWHL* (refer to Table 4.3 in chapter 4 for details) which were both implemented in years two and three as well. The *KWHL* offline introduction lesson consisted of Lee soliciting students' initial conceptions about plants prior to the implementation of WISE *Plants in Space,* including what things they would like to find out further about plants.



Pre-WISE

- Tension between making the plant unit a debate or critique project
- Reconciled differences over time

KI Process = Sorting of Ideas and Reconciling Ideas

External Factor (Online discussion with NASA scientist)

Year One

- Lee did not have any new ideas to add (liked the curriculum as it was)

KI Process = No New Ideas Added to Repertoire

(Interview with Researcher)

Year Two

- Lee suggested ideas for improving content and revising sentences in WISE evidence to help students make connections **(new ideas)**
- Lee developed an online quiz for the WISE **(new idea)**
- Teacher struggled in a political context with district mandate **(sorting ideas)**

KI Process = Adding Ideas and Sorting of Ideas

External Factors (Customization and Teacher Planning Mtgs. with Researcher; District Mandate) + Internal Factor (Self-reflection)

Year Three

- Lee reflected on his past curriculum goals and connected them with his present goals
- Lee was able to articulate reasons for making particular customizations (i.e., KWL and Language Arts lessons) to the WISE plant curriculum during science instruction in years one through three

KI Process = Integrating Ideas

External Factor (Reflections with Researcher)

▬ represents emerging patterns within Lee's repertoire
—— represents the *knowledge integration (KI)* processes
----- represents factors that encouraged the teacher's development

Figure 5.9. Lee's Knowledge of the Science Curriculum for *Plants in Space*.

ONLINE DISCUSSION I: WHAT TYPE OF WISE UNIT TO DESIGN?

MICHELLE: *Should this unit be a critique or a debate project? Please refer to the WISE Project Overview site at: http://wise.berkeley.edu/WISE/pages/overview.html#projs.*

Lee: Based on my experience with fifth grade students, I think the unit should allow students to debate their ideas. I have found that mediated debate gives them the opportunity to air their views in a socially accepted manner and take risks. Students are very creative, but many times they lack a vehicle to express themselves. For fifth graders, the critique format may not provide the same type of stimulation that a debate format would. Students working in small groups, with clear objectives and the right resources will come up with some amazing observations, theories, problems, and solutions. The opportunity to debate their theories and conclusions with other groups provides a transfer of knowledge that should benefit all involved. This knowledge can be articulated through the design unit.

Scientist K: Thanks Lee. Do you think students would be interested in debating what conditions would promote faster growth in plants? For example, present them two different lighting conditions and have them make a prediction as to which one would grow faster. Then present them with evidence pages and a hands-on activity. They would then explain reasons for what they found and later use this information in a design unit.

Lee: I'm not sure that a debate would serve the purpose of preparing students for the design unit. The more I think about it, perhaps more of an inquiry based lesson would be more appropriate. Students' prior knowledge needs to be established. What do students know about plants? What do students know about space?/gravity?/the importance of oxygen? What do students know about phototropism? What are their thoughts on the importance of having plants in space? So the first unit should focus on developing and reinforcing the concepts they will need to engage in activities in the design unit. I'll be posting an outline to get us started later today, so stay tuned…

Scientist K: After investigating further, I keep coming up with the following dilemma—a debate can only focus on one factor of the effects of light on plant growth, whereas a critique can cover multiple factors. Because we will want to incorporate multiple factors of light and plant growth in the design unit, a critique format may be better suited to our needs. Specific factors to be investigated could include: wave length, intensity, direction of light and time exposure. We could also do a debate unit in which students examine photosynthesis and which of two different light intensities would produce faster plant growth, or something similar to that. For a critique project, the cognitive goal would be to investigate light, plant growth and the relationship between the two. Students would be presented with websites addressing three factors of plant growth concerning light; amount, wavelength and direction. They could then make predictions as to what they think will happen to a plant why you vary these three factors of light. Students would then observe data from their experiments and from Internet evidence. From this they will formulate questions as to why their observations do or do not differ from their prediction.

Lee: I think I now have a better idea of how a critique format would look. I was thinking students would read information on a topic or topics. Then they would dissect the information and report out in some fashion. I think what you have described is going in the right direction.

Figure 5.10. Example from the Online Discussion between Lee and a NASA Scientist during the Design Phase of *Plants in Space*.

As shown in Figure 5.9, in year two, Lee discussed new curriculum ideas such improving the content and revising sentences in WISE evidence to help students make connections and the WISE online quiz. He also sorted out ideas of how to implement WISE in year three due to a district mandate which required elementary teachers to place great emphasis on Language Arts and Reading. These changes occurred as a result of Lee's participation in the WISE customization meeting in year two and a teacher planning meeting prior to the WISE run in year three (discussed in the *Professional Development Activities* section).

Also as shown in Figure 5.9, in year three, Lee integrated ideas within his repertoire, which included reflecting on his past WISE plant curriculum goals and determining his next steps. During an interview immediately prior to the implementation of *Plants in Space*, I asked Lee to reflect on his past curriculum goals (referring to years one and two). Lee said,

> *I think during the past two years, I spent a lot of time trying to really get to know the project itself. I think that last year [year two] of running it, I though that it was important that the students really understood the photosynthesis process, and what plants did and how plants were important to us for our survival. I think that to a certain extent, that goal was met..*

I then asked Lee if he would not mind elaborating further on his past goals as well as to comment on his present goals. Lee responded with,

> *Well, it went pretty well [referring to year two]. Once the students got into the second part of the project, I think I was able to see by then what they were writing and if they were getting an understanding of the food-making process. And the fact that plants were the only living things that could actually make their own food and how that relationship was so important to us. I think we got into the nutritional concept and students were able to see that the further removed that we were from the actual*

> *producer of the food, the more we had to take in, and the fewer benefits we would get.*
>
> *[This year], I would like to be able to have students understand the specific function of the different parts of plants. For instance, the leaves, and the fact that's where the photosynthesis actually takes place, and that the leaves are separate from the roots,, and the roots have their purpose, and the leaves have their, but then put them all together. I would like to be able to have students really internalize those concepts, and to be more appreciative of our environment, and how important it is that we keep it safe so that the valuable living things are still around to help us continue to survive.*

Professional development activities. My initial role in the partnership design process was to create an online community for the team to develop and design the plant curriculum unit. Therefore as shown in Figure 5.10, during the Pre-WISE time point, I posted a topic on the WISE discussion forum called *What type of WISE Unit to Design?* Initially, Lee responded to the topic by emphasizing the need for a WISE project that allows students to debate their scientific views. In response to Scientist K's question, Lee struggled with the idea of making the plant unit a debate or a critique project. After Lee went back and forth for a period of time with Scientist K, he was finally able to sort out his ideas and reconciled this tension.

Other factors that supported Lee's development in *knowledge of the science curriculum* included: (a) his participation in the WISE customization meeting in year two, and (b) his participation in a teacher planning meeting prior to the WISE run in year three. I facilitated both of these meetings. The goal for the WISE customization meeting was to solicit Lee's input on the two *Plants in Space* software projects. For example, Lee stated, *The question [referring to the WISE student online discussion], 'Can plants where you live grow in the desert?' So I was just wondering if it wouldn't be clearer if we* *change the 'live' to 'grow?'... 'Can plants that grow where you live, grow in the desert?'* I agreed with Lee's suggestion, and we immediately made this change to the WISE software. As discussed earlier, Lee also suggested during this meeting that additional assessment items be added to WISE on the core science topic *Light/photosynthesis*. Again taking Lee's suggestions into consideration, we added this online quiz to the software interface on the spot (see example of the discussion between Lee and I in Figure 5.11 below).

Lee and I met after the WISE implementation in year two to discuss the logistics for the subsequent WISE run. Initially, Lee was considering implementing *Plants in Space* in the Fall as opposed to the Spring, which was his most preferable time. However over the course of the meeting, he decided against the Fall time frame. He changed his mind as a result of finding himself for the first time struggling in a political context with the district mandate requiring all elementary school teachers to allocate most of their instructional time to teaching Reading and Language Arts. Much of the remaining instructional time was to be allocated to the teaching of Mathematics. It was expected that Science, Social Studies and Physical Education could fit in when and wherever possible. Having known Lee for several years, this was the first time I had ever seen him frustrated. He felt as though it would be a disservice to the students to teach WISE for only 45 minutes or so for two days a week if that. Lee exclaimed, *Really, the whole thing is boggling my mind in terms of how to manage the time. Because right now, I don't even think that the hour a day is enough time for two days a week [to teach science]. I don't think that's enough time.* Our meeting lasted for about an hour. After Lee considered for a lengthy period of time how he could possibly allocate quality time to the teaching of science and justify it if questioned, he decided to wait until the spring and teach the plant unit. His rationale for this entailed connecting the *Plant in Space* unit to the literature theme *Back to the Stars*, which would be taught during the spring. This provided Lee the leverage to teach Science during Independent Writing Time for approximately 45-60 minutes for at least three days per week.

LEE: I walked through [the curriculum] and it really makes a lot more sense to me now. But anyway, I wrote down some observations. I wrote down some questions.

MICHELLE: This one is an essay [reading from the teacher's hand-written notes].

LEE: So this 'explains the process of photosynthesis' is a short essay… 'What is the job of chlorophyll in photosynthesis?' This could be the short essay…Even though WISE have them take a note after each activity, we could have something like this. At least for me, I would have an opportunity to go and look [at their work early on]. This would give me a basis for assessment.

MICHELLE: Are the notes good [referring to the WISE evidence notes]?

LEE: I think the notes are good.

MICHELLE: You want that to be the multiple choice?

LEE: Yes, one question at a time. And then the possible answers. 'What two helpers do plants use in photosynthesis?'

Figure 5.11. Excerpt from WISE Customization Meeting in Year Two.

Teachers' Knowledge of Students' Science Conceptions

Figure 5.12 shows how Lee integrates his understandings of students' science ideas in the plant curriculum unit over time. In the interview prior to implementing WISE in year one, Lee primarily provided examples of students' science conceptions not within the scope of the plant curriculum—e.g., the water cycle and erosion (refer to the above example presented in the *methods for assessing student learning* section).

Thus in year two, Lee began to articulate his students' science conceptions within the context of the *Plants in Space* unit. For example, Lee indicated that he did not think many students were grasping fully the concept of *hydroponic—meaning the process of growing plants with water only.* He further pointed out that this concept challenged students' views of plant growth and development around the role of soil. Lee also stated,

> *So I think it would really be appropriate to give students a heads-up on LEDs (light-emitting diodes). I remember trying to get students to understand that the LEDs only produce red and blue light because that's what the plant uses. The plant doesn't use white light. And even though it comes in…It doesn't use white light. White light is like a waste product, and they talked about that in the second project, that one reason that the LEDs are more appropriate is because they don't produce white light.*

LEDs are similar to fluorescent lights, but use less energy. NASA scientists used these on board of space shuttles. This is an alternative light source for plants. Students in Lee's classroom actually used fluorescent lights to grow their plants. Although Lee discussed concepts in WISE that he viewed as difficult for student to understand, he did not discuss students' conceptions within a framework of interrelated ideas.

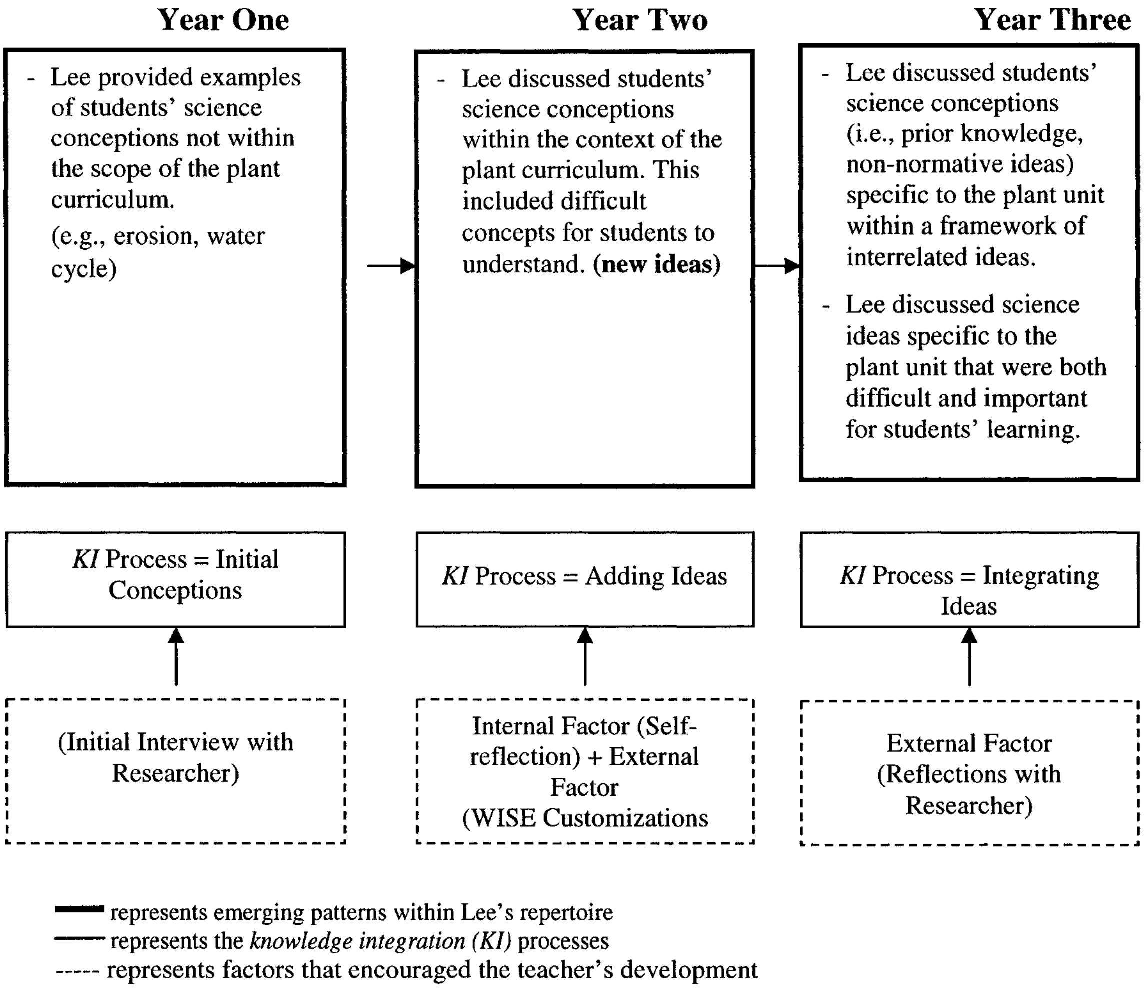


Figure 5.12. Lee's Knowledge of Students' Science Conceptions.

In year three, Lee discussed students' science ideas (i.e., prior knowledge, non-normative ideas) specific to the plant unit and within a framework of interrelated ideas. As shown in Figure 5.12, he also discussed science ideas that were both important and difficult for students' learning. Prior to implementing WISE in year three, I asked Lee what particular concepts (e.g., water, photosynthesis, function of the leaves) in the plant curriculum he viewed as important for student learning.

Lee stated,

> *That's a hard one, because I really think that all of them are important for them [students] to learn. Even though they are separate components, I think that it's really important for them to see that they are all part of a process, this ongoing process. An I think it's important for them to realize how vitally important plants are too, not only to the astronauts that were going to be in space, but to us here on earth, and how much we depend on plants for all the reasons that they mentioned when we did our brainstorming.*

In a subsequent interview, I asked Lee if he thought students [referring to students in his year three science class] understood how critical water was to a plant's existence. Lee replied,

> *I have to answer that most of them do. And the reason I say that is because they've been very concerned and they've been very conscious of the plants, and whether they were dry and whether they needed water. And I asked them, well, why are you watering the plant? 'Well, it's dry.' Well, so? And then they would say, 'Well, it will help the plant grow.' Well, how is it going to help the plant grow? 'Cause it makes it healthy.' Well, how does it make it healthy? What's it doing to make it healthy? 'Well, it's giving it nutrients.' I said, yeah, well how is it getting the nutrients? So we get to... so that the more I dig and the more I pry, the more they have to come up with. 'Well, it's coming through the roots.'*

Not only was Lee aware of his students' science conceptions within a framework of interrelated ideas, but he also provided evidence of students' responses to his conceptual questioning in class. At the end of this interview, I asked Lee a couple of follow up questions regarding a prior conversation—e.g., whether or not students had begun to internalize concepts such as the function of plants' leaves and the photosynthesis process. Lee said,

> *You know, I really think I can say yes to that. And I say that because they've really gotten into looking at the plants every day. And even one day where we were really rushed for time and we didn't have a lot of time to do both... you know, we only have a few minutes before it's time to go out to lunch. And they opted to stay and look, because they*

> *wanted to look at their plants, because they wanted to see what changes had taken place from the day before. And I said, 'Well, you know, nothing probably happened very much.' And they wanted to see anyway. And during their observations, they made reference to the color of the leaves. And when I was talking about describing the color of the leaves, they were saying, 'Why is it taking place?' That it had been green and now it's yellow. And when the plant was dying, they were talking about how it had... Well, it just completed the lifecycle and they were using phrases, and they were using concepts, and they were actually having conversations amongst each other to reinforce that whole process that the plant was actually going through.*
>
> *But I think maybe what's more important is that some of the plants died. And they were very concerned that this living thing died. And they didn't want to accept this plant dying. We have a group of students who like to play in the bushes and things like that, and I've had to remind them not to grab the foliage and pull leaves and things. And I've not had to do that. As a matter of fact, since I've been on yard duty since we've been doing this project, I've heard them tell other students from other classes that, 'Hey, we need the plants. We need those plants. You shouldn't be pulling the leaves off. You shouldn't be breaking them.'*
>
> *So I think to take it a little further, we would need to have some conversations about things like global warming and the destruction of the rain forest, and how that's affecting not only the quality of the human life, but the quality of the animals that live in the rain forest and how that whole thing is just kind of pushing the animals out of their natural habitat, which is going to impact ours, and damage our resources or reduce our resources.*

This excerpt exemplifies Lee's knowledge of his students' science ideas about plant growth both inside and outside of the classroom context. It also illustrates the relationship between Lee's *knowledge of students' science conceptions* and his *knowledge of instructional strategies*. For example, the role of communication in assessing students' learning (i.e., listening) continued to permeate in Lee's repertoire even as he discussed students' science ideas.

A Summary of Lee's Learning Trajectory

In conclusion, findings show that Lee's questioning patterns became more conceptually oriented across subsequent years, and he engaged in more science dialogues with small groups of students in his second and third year of teaching WISE. Lee also developed in pedagogical content knowledge from years one through three. The results further show integration of the knowledge integration processes by Lee's third year of teaching the WISE plant curriculum unit. Factors such as the social supports provided by the researcher and self-reflections by Lee contributed to his development in practice and knowledge. The social supports provided by the researcher included: (a) scaffolding Lee in reflecting on his practice and knowledge, (b) assisting him with curriculum customizations, and (c) assisting Lee with putting other scaffolds in place to support his learning such as interactions with scientists via the Internet. In chapter 1, I defined a trajectory very generally as a pathway that teachers take over time when implementing the inquiry science curriculum, WISE. Based on the evidence presented in this chapter, a trajectory constitutes changes in the teachers' practices and knowledge as they are influenced by external and internal professional development supports. As in the case of an experienced teacher (Lee) in computer technology, teaching, and science, implementing a technology-enhanced curriculum for the first time allows further development in both knowledge and practice.

WISE supports teachers by providing them with the capability to respond electronically to students' online work as in the case of Lee and by giving detailed accounts of student learning. As shown in chapter 5, teachers contribute to students' knowledge integration process by asking them to reflect on scientific evidence in the projects, make links between scientific ideas, explain their reasoning, and provide evidence to support claims. Thus, science becomes accessible to all students when instruction affords them the opportunity to connect science class information to personally relevant experiences and prior knowledge. In *Plants in Space*, students grew plants and connected those experiences to concepts like *photosynthesis*.

CHAPTER 6

A NOVICE TEACHER'S LEARNING TRAJECTORY: TEACHING SCIENCE IN A WEB-BASED ENVIRONMENT

Introduction to Case Study Alice

In the previous chapter, I discussed how an experienced teacher and participant in developing WISE *Plants in Space*, Lee, learned to teach inquiry science in a technology-based environment across a three year time span. Findings showed that Lee's questioning patterns became more conceptual oriented over subsequent years and that he engaged in more science dialogues with students in years two and three. Results further revealed that Lee developed in pedagogical content knowledge across time. In this chapter, I report how a novice teacher, Alice, learned to teach the same science unit, *Plants in Space*, using an inquiry approach supported by WISE over three years. I discuss changes in Alice's teaching and understanding, and examine what factors encouraged or supported her development over time.

Changes in Alice's Practice

In this section, I report findings from the two methods of analysis (i.e., questioning patterns and science dialogue) to capture the changes in the ways Alice helped students make their scientific thinking visible from years one through three. Similar to the Lee, I will provide a description of Alice's teaching across the three year period to set the context, before discussing findings from the two methods of analysis.

Descriptive Analysis

Alice indicated in the initial interview that, *prior to WISE as far as technology goes, I just learned from others or self-discovery. I just played on the computer or figured out how to do things. I don't have much background in technology*. She further pointed out that her knowledge in science was limited, but she was willing to learn with her fifth grade students. Alice also indicated that the main goal she had in respect to student learning in general and within the domain of science *is to teach the kids to problem-solve and become independent thinkers and learners. And to become problem-solvers, [I want them] to try to figure things out without having to ask. I want them to have a love for learning, including students learning and employing the scientific method.* She later emphasized the importance of students being able to figure out problems by themselves with clues from her when necessary, but not providing them with the answers up front. In other words, Alice did not believe in the notion that teaching is merely telling students' things, but her goal as a teacher is to have her students think analytically, to become problem solvers. Thus her goal was to provide students with opportunities to make sense of things and not rely on her as the sole knowledge provider.

The first observation of Alice's implementation of the WISE project was different with her stated views on student learning. There were two simultaneous activities taking place on this day, a science activity and a language arts activity unrelated to science. The science activity consisted of students conducting observations in several centers: (a) a computer center, (b) a leaves investigation center, and (c) a soil investigation center. Alice exclusively focused her time with the language arts group, providing little or no guidance to the science center. Some of the students in the science centers seemed confused and unsure of the goals, although each center was provided with a paper artifact highlighting goals/problem(s) along with the materials for exploration. Responding to the need for student support, I inevitably became a participant in the classroom, rotating among the groups monitoring students' progress. After this initial observation and interaction, Alice was not observed leaving her students to learn without some form of guidance during the rest of year one. For example, as discussed in chapter 4, Alice taught three of the key science topics as part of whole class discussion offline in year one, and the remaining topics were taught as part of the two WISE software projects. In years two and three, Alice continued to provide guidance to the students as they completed the WISE online activities.

In summary, Alice started out believing that she should not assist the students with problem solving techniques. She confused problem solving techniques with providing the students with the anticipated answers. She learned that guidance with regards to techniques enables the students to problem solve on their own. Alice developed trajectories for guiding problem solving techniques with my mentoring.

Additionally, as discussed in chapter 4, Alice taught the WISE plant curriculum for a total of five weeks in year one, eight weeks in year two, and eight weeks in year three. She covered the six key science topics—*photosynthesis, hydroponics, nutrients, comparing plants' life cycles, and graphing data* in years one and two. In year three, Alice taught all the topics except *Graphing data* (see details below). Similar to Lee, in years two and three, Alice taught the key science topics across more contexts (WISE online investigations, small group discussion, and whole class reflection), and she taught the topics for a longer period of time. Thus, as reported in chapter 4, there was greater and more integrated use of technology. However, in this dissertation, I analyzed the focal topics, *Comparing plants' life cycles* and *Graphing data*. Refer to chapter 3 for the criteria used to determine which topic(s) to include in the analysis.

Questioning Patterns of Class

Lesson: Comparing Plants Life Cycles (comparison between Years One through Three)

As shown in Table 4.2 in chapter 4, Alice taught the topic *Comparing plants' life cycles* over the course of four class periods in year three versus three class periods in year two and one class period in year one. In year one, students completed much of the online investigations for this topic in the two WISE software projects, including a significant portion of this lesson, on their own. In contrast, in years two and three, Alice taught the topic to students during the activities in the *How do Earth and Space Plants Grow?* software projects, in addition to incorporating it as part of small and whole group discussion offline.

Below I discuss Alice's overall questioning strategies for the *Comparing plants' life cycles* lessons (a total of 8) across the three year time span. Alice taught these lessons across three contexts—WISE investigations, small group discussion offline, and whole class discussion. At this point, I discuss the overall patterns for the eight lessons and later on will examine the details inherent in these individual lessons.

An overall pattern of Alice's questioning strategies for the Comparing plants' life cycles lessons across years one through three. Similar to Lee, Alice taught the focal topic lessons—*Comparing plants' life cycles* (i.e., *the Graphing data* lessons) for approximately 35-45 minutes. As shown in Figure 6.1, Alice's overall questioning strategies became more conceptual oriented across subsequent years. In year one, Alice primarily asked students logistical questions (56% logistical, 14% factual, and 30% conceptual) when teaching this key science topic. This included questions such as: *What activity are you on? Okay, did you read 'Let's compare lifecycles?' Did you read all of it? and Did you guys discuss that?* The aforementioned questions primarily asked students about procedural issues rather than asking them to make predictions, provide explanations for their responses, or justify their conclusions with evidence. In this regard, this reflects the inconsistencies in Alice's emphasis on techniques with regards to her teaching approach. As previously mentioned, one of Alice's main goals at the onset of the study was to have her students to become problem-solvers and independent thinkers and learners. She wanted her students to try to figure things out without having to ask. At the same time, Alice believed in providing students with guidance when necessary, but without providing them with the answers. Alice's questioning patterns in year one further illustrated the transformation in her beliefs about the roles of students and teachers.

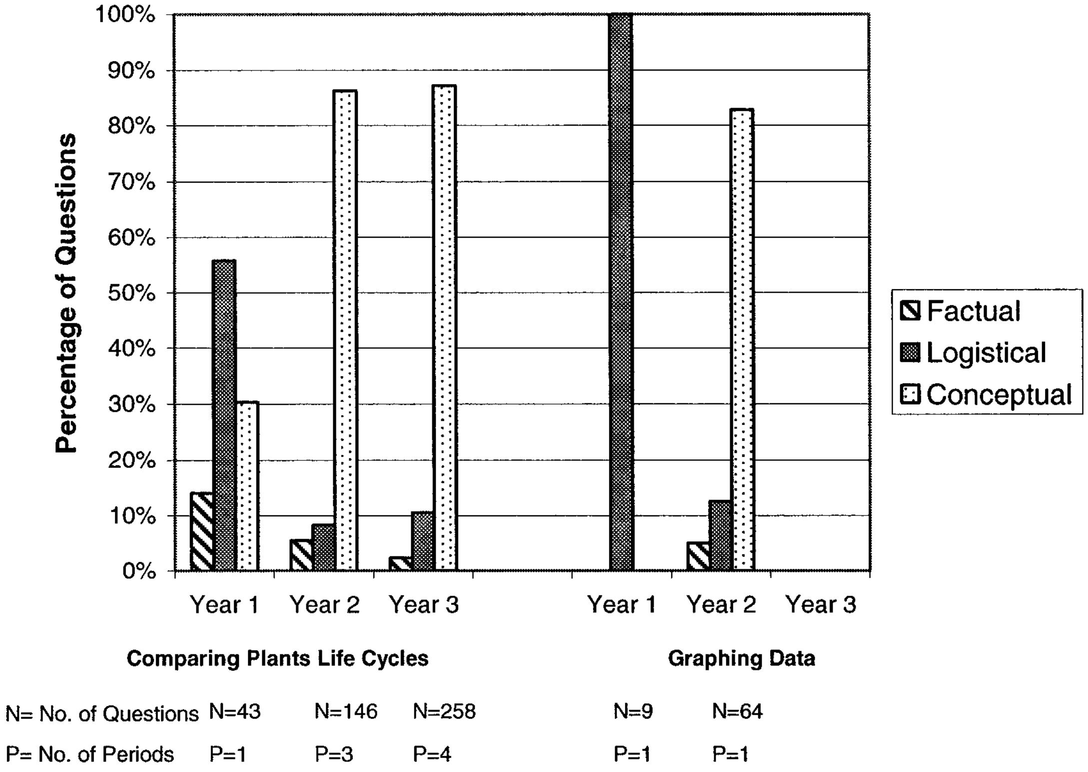


Figure 6.1. Alice's Overall Questioning Patterns in Years One through Three for the *Comparing Plants' Life Cycles* and *Graphing Data* Lessons.

In contrast, in years two and three, over 80% of Alice's overall questioning was conceptual. Examples of conceptual questions during the second and third year were: *(a) Have you noticed that some earth plants sprout faster than others? (b) Oh really. Why do you think that is? and (c) Do you think scientists prefer to grow plants with long life cycles or short life cycles [referring to NASA scientists on a space shuttle]? and Why?*

Detailed analysis of the Comparing Plants' Life Cycles taught by Alice. In this section, I explore how Alice used questioning in the context of WISE evidence and students' online notes to elicit their science ideas around the topic *Comparing plants' life cycles* across all three years. Because this science topic was taught the most using the WISE software, the analysis focuses only on the lessons that were taught with technology. I will discuss the *Comparing plants' life cycles* lessons that were taught in small group and whole class discussion offline later in this chapter.

In year one, about half of Alice's questioning was logistical (see Figure 6.2). This included questions such as '*Did you look at this?* or *Did you save your note?* These type of questions encouraged students just to follow specific procedures for using WISE. Alice used WISE students' notes/evidence as a leveraging point for getting students to recall procedures.

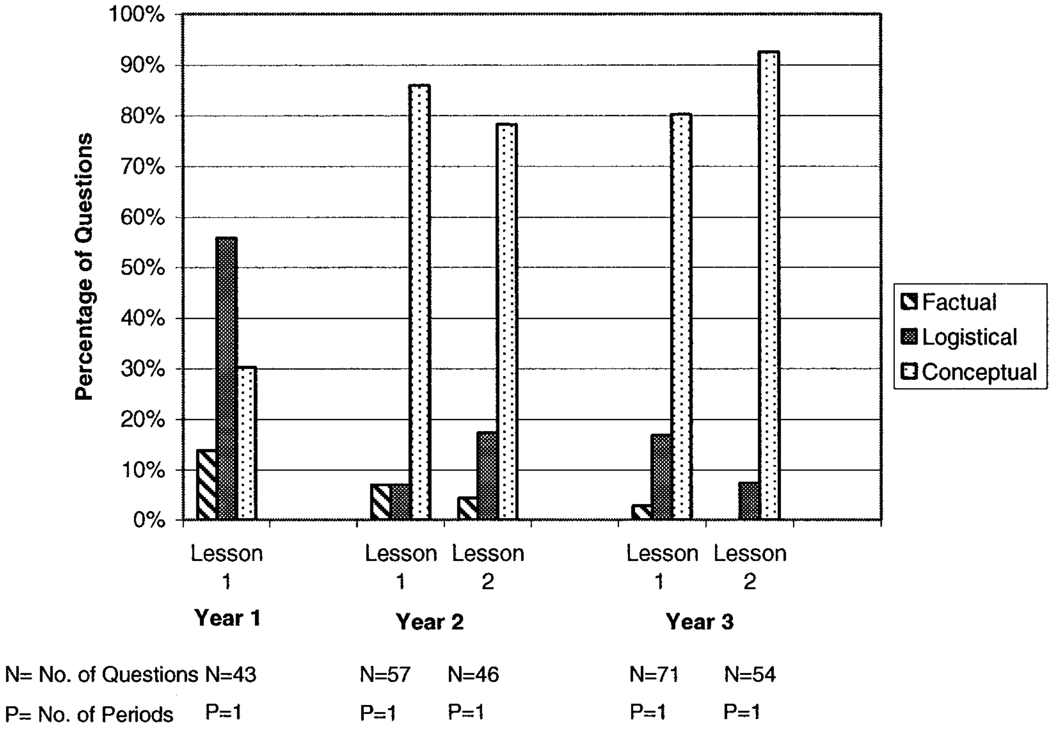


Figure 6.2. Alice's Method of Questioning in Years One through Three for the *Comparing Plants' Life Cycles* Lessons taught on WISE.

However, there were instances in year one where Alice began to ask students conceptual questions that required them to make predictions, but the conversations were not as in-depth as in year two. For example, in year one, a student (Bob) asked Alice, *Why are space plants supposed to grow faster?* Alice responded with, *Why do you think?* Bob responded with, *I have no clue. Maybe it was the forces' lights, I don't know…* Alice then left this student and went to another group and began asking the students what activity were they on.

Changes over time in Alice's understanding of the science help to explain shifts in her pedagogy. In Alice's written reflections after this lesson, she indicated that the class discussed what plants would work well in space (e.g., small plants because they do not need as much energy and would save space; fast growing plants for research and limited time in space; plants that have a fast life cycle). However, she later stated that, *During this discussion we focused on the life cycle, what it was, what happens, etc. We used science books which had a good visual of a pine cone and its life cycle. I tried to relate the life cycle with their experiment and why this was important. Again, only some of my students made the connection.* Moreover, at the end of the WISE *Plants in Space* curriculum unit, Alice still felt that her students did not understand why they were growing two different species of plants hydroponicly (i.e. what were the benefits) and how this connected to the concept of a plant's life cycle. She attributed the students' lack of understanding to her own emerging understanding of the subject matter.

Years 2 and 3. In year two, Alice helped students to make their scientific thinking visible through greater use of conceptual questioning. As shown in Figure 6.2, 86% of the questioning (referring to Lesson #1) was conceptual in year two, versus 30% in year one. She asked students to make predictions and to provide explanations for both written and oral responses. Table 6.1 illustrates an example of dialogue between Alice and her fifth grade students in year two for the topic *Comparing plants' life cycles.* As shown in Table

6.1, in year two, Alice helped students to make their scientific thinking visible by providing cognitive guidance. For example, she encouraged students to make predictions, provide explanations for their responses, and challenge each other's perspectives. In contrast, in year one, Alice primarily asked students about procedural issues.

Table 6.1. Examples of Dialogue from the *Comparing Plants' Life Cycles* and *Graphing Data* Lessons in Years One Through Three.

Lesson	Year 1 (logistical questioning)	Year 2 (conceptual questioning)	Year 3 (conceptual questioning)
WISE—Comparing plants' life cycles	**ALICE:** Did you take a note? **ARIAN:** Yeah, we took a note. **ALICE:** Did you save your note?	**ALICE:** Do you guys think that in space plants should have a shorter or longer life cycle? [referring to students in group 2] **STUDENTS IN GROUP 2:** Long. **ALICE:** Why? **STUDENTS IN GROUP 2:** So they could last longer and scientists could learn how they grow. **ALICE:** What do you think [referring to students in Group 1]? **JULIE** [Group 1 student]: We think shorter because they're only out there for so long. **ALICE:** How do you respond to that [asking students in Group 2]?... **STUDENT IN GROUP 2:** Uh. I don't know. **ALICE:** Well, she is saying it is shorter because they are not up there that long. What do you think about that? **STUDENT IN GROUP 2:** Well, I think they should still have one to see how long it could grow…	**ALICE:** 'Have you ever grown an earth plant such as flowers, lettuce, beans, etc?' [she is reading from an online WISE note prompt] **KEVIN:** A kidney bean. **ALICE:** How long did it take for the seed to begin to grow? **KEVIN:** About five days. **ALICE:** So do you think that some plants grow faster than others? **KEVIN:** Yeah. **ALICE:** Why do you think that is, they grow faster than others? **KEVIN:** Because some plants might have soil to grow in? **ALICE:** Okay, but what if they all have soil in them? Do you think some grow faster than others? **KEVIN:** Yeah. **ALICE:** Why? **KEVIN:** Because if you already pre-grown them in a pot, because they already sprouted. Then they might grow faster than the others that haven't been pre-grown.

WISE—Graphing Data	**ALICE:** Do you see 'save' anywhere? Read everything on the page.	**ALICE:** What do you think would happen if a plant could photosynthesize, store energy all the time? Would it grow faster? [Alice reading questions from WISE notes] … **ALICE:** How do you know this? Can you tell which of your plants may do this? **TOM:** The one that's growing the radish. **ALICE:** Why is it the one that's growing the radish? **TOM:** Because it's growing faster than the other one… **ALICE:** How do you determine the growth of it?	

In year two, similar to Lee, Alice created a classroom environment where students' opinions were valued. She asked students questions to encourage them to challenge each other's perspectives. Of course, some logistical questions are appropriate and she used some. The small percentage of logistical questions posed by Alice during this initial 'life cycle' lesson in year two included questions such as, *Did you pay attention to activity 2? It is going to give you major clues in this whole experiment. Go back and read activity 2.* At this point in time, students have designed their plant growth chambers which entailed growing the two types of plants, AstroPlants and earth plants, under the different durations of light. In order for students to predict which plant is which and which crop would be most suitable for NASA scientists to take on a space flight mission, they must integrate their understandings of Web evidence such as *Growing AstroPlants* and *Growing Earth Plants* with their own quantitative results (i.e., height, number of leaves, number of flowers) and qualitative findings (i.e., differences in their plants' appearances).

The topic *Comparing plants' life cycles* also emerged as part of two other lessons in year two, both a lesson using the WISE software and a whole class reflection lesson on students' plant observations. Given that I am interested in Alice's use of the WISE software to teach this core science topic, I will focus on the online activity. The results are consistent with the above findings. Findings indicate that Alice asked a total of 46 questions during this second enactment of the lesson in year two. Seventy-eight percent of her questioning consisted of conceptual questions (i.e., 17% logistical questions and 4% factual questions). Similar to the initial *Comparing plants' life cycles* lesson, Alice encouraged students to make predictions, elaborate on science ideas, and connect science class ideas with personally relevant experiences.

As shown in Figure 6.2, in year three, Alice continued to make students' thinking visible by asking conceptual questions when teaching the topic *Comparing plants' life cycles*. Table 6.1 above illustrates an example of dialogue between Alice and her fifth grade students during this third enactment for the *Comparing plants' life cycles* lesson. Similar to year two, Alice continued to provide her students with cognitive guidance. She encouraged them to make predications and provide explanations for their responses.

Changes over time in Alice's understanding of how students were conceptualizing the science content help to explain shifts in her pedagogy. In year two, I asked Alice to reflect on the differences in how she taught WISE (i.e., the *Comparing plants' life cycles* lesson) in year two versus year one. I quoted Alice's earlier reflections about student understanding. Alice stated, *Last year, I didn't think they [referring to year one students]* *made the connection between the why…which one was a earth [plant] and which one was a space plant, and the whole life cycle [concept]. And this year, they [referring to year two students] are making it.* Alice based her conclusion on the conversations she had been hearing during the WISE lessons. *One example would be when they're talking, immediately half of them noticed it was a radish that was growing [referring to plant B]… 'Well, that has to be the earth plant.' I think a lot of them are thinking in space you can't grow vegetables because there's no air. A lot of them have mentioned that.* This example illustrates that Alice was aware of how her students were conceptualizing the science content in year two, which in turn helped her to make their scientific thinking more visible.

Lesson: Graphing Data (comparison between year one and year two)

Alice taught the *Graphing data* lessons as part of the *How do Earth and Space Plants Grow?* software project in a single class period in both year one and year two, which is the first and only time the topic emerged. Figure 6.1 reflects Alice's decision to replace the *Graphing data* lesson in year three with the Language Arts lesson called *Plant Times*, a news article writing project (refer to chapter 4 for additional detail on this curriculum customization). This class newspaper was sent out to the entire Parker Elementary School community.

Alice's teaching practices with respect to the *Graphing data* lesson resembled more of a WISE orientation in year two, as opposed to a logistics orientation in year one. She utilized features of the WISE software (i.e., online graphing tool, WISE evidence pages, and students' online notes) to monitor students' learning, and she interacted with students in small groups. Over time, Alice incorporated the *Graphing data* topic as part of other WISE online investigations to help students to integrate their understanding of plant growth and development.

As shown in Figure 6.1, during the *Graphing data* lesson in year one, Alice elicited students' science ideas entirely through logistical questioning. Out of nine questions, all of them were logistical (see Table 6.1 above for an example). The number of questions asked in total by Alice in year one during the *Graphing data* lesson is also substantially lower than the corresponding lesson in year two.

There may be several contributing factors to changes in both the number and type of questions asked by the teacher across the two years. First, Alice experienced technology problems with the WISE graphing feature (i.e., the graphing tool would not allow students to save their average plants' heights) in year one, whereas the technology worked well in year two. As a result, Alice constantly asked students to resubmit their data online, followed by if the data was saved or not. The graphing feature is a tool in the WISE plant project that allows students to graph plants' heights across four weeks. Second, although Alice preplanned for logistical issues in both year one and year two, she still encountered logistical problems (i.e., students did not know how to use the functions in the graphing tool) in year one. In year two, Alice analyzed logistical problems with me on how she planned to introduce the *Graphing data* activity to her students, and asked me to provide guidance as she explored the online graphing feature. Finally, during Alice's first year of teaching this lesson, she taught it as a stand alone feature of WISE, whereas in year two, she taught the graphing activity along with other online investigations within the *How do Earth and Space Plants Grow*? software project, which required the fifth-graders to extrapolate from their observations. These other online WISE activities asked students to look at their date and extrapolate from it. Alice followed up by asking students to elaborate on their responses. Observations of Alice's teaching in year one further revealed that she was extremely quiet during the lesson in year one, thus moving back and forth among the small groups of students in the computer lab silently looking over their shoulders.

However in year two, when she taught the same lesson, 84% of Alice's questioning consisted of conceptual questions. This entailed asking students to make predictions and support claims with evidence. Figure 6.3 illustrates her use of questions as she lead a discussion with a group of students about their online responses to the question 'Which plant do they think would be bigger Fast plants or earth plants?':

ALICE: [reading the students responses in their online notes] 'We think the fast plants would be 12-hour, because it's average and it's 13, and it is growing flowers faster.'

ALICE: Which ones do you think would be bigger—Fast Plants or earth plants?

SAM: Earth plants.

ALICE: If one plant is bigger, does that mean it's growing faster?

SAM: No, but it will get to be bigger, maybe, possibly.

ALICE: Why?

SAM: Because...I don't know. I'm not sure. That's just my hypothesis.

ALICE: What's your hypothesis?

SAM: Earth plants, it [they] will be bigger, but it's [they are] growing pretty close to [Fast Plants].

ALICE: Why is that?

SAM: I don't know...It's just that.

ALICE: Well, you have to be able to back up your hypothesis. You can't just say things and say, 'Oh, I don't know, it's because I think so.' You have to know and give reasons...Support your answer.

Figure 6.3. Dialogue between Alice and a Fifth Grade Student during the WISE *Graphing Data* Lesson in Year Two.

This example supports the previous findings in that, over time, Alice focused less on the logistics of tasks and more on teaching for science inquiry (i.e., encouraging students to make predictions, encouraging students to support claims with evidence). Again, Alice insisted that students support their conclusions with some form of evidence/proof. In other words, she wanted them to understand that simply resorting to the common expression 'take my word for it' does not lay the ground work for a convincing argument. Additionally, this example also illustrates how Alice often times refocused students' attention to what the given question was really asking.

In sum, Alice's teaching strategies became more conceptual oriented across time. As mentioned in the prior chapter, studying the questions by themselves gives a great deal of information over time, but studying the social context of the questions—the dialogues between the teacher and students and the questions—provides more intriguing data. In this next section, I discuss the dialogues between Alice and her students in years two and three with regards to how she used conceptual questioning to get at information.

Science Dialogues with Small Groups

Comparing Plants' Life Cycles Lessons in Years Two and Three

Table 6.2 below illustrates the context in which Alice taught the focal topics, *Comparing plants' life* cycles and *Graphing* data. Alice always taught these topics in small group settings during WISE online investigations. Typically, students were paired in groups of two during the WISE investigations and remained in the assigned groups throughout the WISE project. As shown in Table 6.2, science dialogues occurred within the context of WISE investigations except for the *Graphing* data lesson (lesson 2) in year one. This finding is discussed in greater detail in the subsequent section.

Table 6.2. Sequence of Activities in Alice's Classroom around the Focal Science Topics—*Comparing Plants' Life Cycles* and *Graphing Data* in Years One through Three.

Year	Lesson #	Context	Total Dialogues	Logistic Dialogues	Science Dialogues
1	1	WISE investigations	26	23	3
	2[a]	WISE investigations	16	16	0
2	3	WISE investigations	19	10	9
	4	WISE investigations & Whole class discussion	13	4	9
	5	Whole class discussion	0	0	0
	6[a]	WISE investigations & Whole class discussion	20	9	11
3	7	WISE investigations & Small group dialogues without WISE—logistical problems (students encountered difficulties logging onto WISE for the first time)	17	8	9
	8	WISE investigations—technical problems with WISE	21	14	7
	9	Small group dialogues without WISE	16	3	13
	10	WISE investigations	15	7	8

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[a] This is the *Graphing Data* lesson.

As shown in Table 6.2, Alice engaged students in more science dialogues during her second and third year of teaching the WISE plant growth project. I defined a single dialogue as talk the first time an utterance (a word) transpired between a given student or group of students and the teacher from beginning to end. I coded this dialogue as logistic dialogue or science dialogue. I defined a teacher-student dialogue as a logistic dialogue if it focused on management and procedural issues. I defined a teacher-student dialogue as a science dialogue if it met one or more of the following criteria: (a) the teachers encouraged students to provide explanations for their responses, (b) the teachers asked students to make predictions and explain their reasoning, (c) the teachers encouraged students to support claims with evidence, and (d) the teachers encouraged students to challenge each other's perspectives. These criteria enabled me to capture how the teachers helped students sort out their scientific ideas and link ideas. At the same time, the actual number of science dialogues varied across lessons as a result of the teacher determining that some student-groups required more scaffolding/guidance than others on a given day. In addition, some of the variability in the number of science dialogues was due to Alice's experiencing technology related problems due to logistical problems (i.e., students encountered difficulties logging onto WISE initially) and a temporary glitch in the WISE software.

The total number of lessons (referring to the two focal topics lessons) that Alice taught with technology was greater than the lessons taught with whole class discussion only and small group dialogues with whole class discussion. Again, because use of technology was associated with an increase in science dialogue from year one through three, therefore I will illustrate examples of science dialogue in the context of WISE online investigations.

Year 2. Over the course of this lesson, Alice rotated back and forth among groups of students, providing them with ample time to reflect on their notes and evidence, including making revisions to the notes. Alice did not allow students to take the easy way out by resorting to 'I don't know' in order to avoid thinking critically about questions she asked concerning WISE evidence and their WISE notes. For example, Alice asked student Timothy (a student working alone because his partner was absent), *Do you think scientists prefer to grow plants with long life cycles or short life cycles on shuttles?* Timothy stated, *I don't know*. Alice then responded with, *Then you need to go back and read it [referring to the comparing plants' life cycles online activity which discusses AstroPlants and regular earth plants.]*. Alice then moved to another group of students and later returns to Timothy. The excerpt below depicts the follow-up interaction:

TIMOTHY: I think so because um…

ALICE: What do you think? Do you think scientists prefer to grow plants with long life cycles or short life cycles on a shuttle?

TIMOTHY: I think they prefer short ones cause sometimes they out live their owners.

ALICE: Cause they out live their owners. So why do you think short life cycles?

TIMOTHY: Because AstroPlants have extremely short life cycles and AstroPlants can grow in a very small area—a large amount in a very small area. [student is drawing on evidence from WISE]

ALICE: So why do you think short life cycles would be better?

TIMOTHY: Because you can grow more and more and more why you are still in outer space. You are going to have to wait for a long time to grow [a longer life cycle plant].

Figure 6.4. Science Dialogue between Alice and a Fifth Grade Student during the WISE *Comparing Plants' Life Cycles* Lesson in Year Two.

Encouraging students to reflect on science content in WISE evidence can provide them with opportunities to reorganize prior/new ideas, as well as connect new and prior science ideas. This episode shows that the teacher was successful at soliciting Timothy's predictions, while at the same time getting him to take into account the WISE evidence he was critiquing. Not only did Alice require Timothy to make predictions and draw on WISE evidence in doing so, but she also required him to explain his reasoning. After Timothy provided an initial explanation for his assertion, Alice continued to probe his thinking even further. Alice left Timothy again to ponder and visit four other groups, including revisiting one group twice. After a period of time, she returned to Timothy and began to read with him the evidence page called 'Growing Earth Plants.' Alice's method of questioning in relation to WISE investigations/notes provided opportunities for Timothy to continue to make predictions, and to sort out his science ideas and connect them with personally relevant experiences.

Analysis of the subsequent WISE online lesson taught by Alice on the topic *Comparing plants' life cycles* further show that she continued to engage her students in year two in science dialogue, as in the following excerpt from a discussion between Alice and Christian.

CHRISTIAN:	Can you tell which plant is space plant and which is earth plant? [referencing class experiment]
ALICE:	Can you tell?
CHRISTIAN:	Yes.
ALICE:	How?
CHRISTIAN:	Because I already said.
ALICE:	What did you say? Because it has vegetables. It has food growing on it. [referencing a previous conversation with student]
CHRISTIAN:	It has red stuff on it? [student said that the plant with the red stuff is the earth plant, i.e., radish]
ALICE:	You think they can't grow food in space?
CHRISTIAN:	No, because there is no air.
CHRISTIAN:	'Space in Space.' [student is reading evidence title and points the teacher attention to the picture of NASA scientists onboard a space shuttle]
ALICE:	No Christian, if there is no air in space. How come those people don't have anything on their faces? [teacher referring to the visualization on the WISE evidence page]
CHRISTIAN:	Cause they are in a space ship.
ALICE:	So, where the plants?
CHRISTIAN:	There are no plants…[in space].
ALICE:	Christian, if you brought plants up in space, wouldn't they be in the shuttle too? They aren't going to just dump them out the window and float around in space.
CHRISTIAN:	Oh. Oh. I thought they were doing it out in space, like with their space suits on.

Figure 6.5 . Science Dialogue between Alice and a Fifth Grade Student during the WISE *Comparing Plants' Life Cycles* Lesson in Year Two.

This is a case where both teacher and student were really thinking along the same lines, but where a term (i.e., space) had a different meaning for them. For example, Christian's assumption was that the word 'space' represented a place outside the space shuttle, whereas Alice was using the word to reference a place that included the inside of the space shuttle. This example further illustrates the importance of science dialogue between students and teachers, because such dialogues can provide opportunities for individuals to sort out their science ideas and resolve miscommunications, and achieve common understandings.

Year 3. Analysis of the WISE online lessons taught by Alice on the topic *Comparing plants' life cycles* further shows that she continued to engage her students in year three in science dialogues, as in the following excerpt from a discussion between Alice and Ann. For example, during the third WISE investigation on *Comparing plants' life cycle* in year three, Alice said to student Ann, *Are you done with everything? Okay, let's see.* Alice read aloud Ann's online response to the WISE note, 'Which of your plants do you think would be bigger or taller, the Fast plants or the earth plants?' '*We think Fast plants would be shorter, because Fast plants don't get as much nutrients and light as earth plants do.' Why is that?* Ann said, *Because they're grown hydroponicly. And they don't get as much nutrients.* Alice asked, *So when they're grown hydroponicly, they don't get as much nutrients?* Ann replied, *Because the earth plants have a lot of soil around them. So they have a lot of nutrients.* Alice suggested that Ann revisit the WISE evidence page called "Can Plants Grow in Water Alone?." The evidence page discusses the benefits of growing plants hydroponicly. Hydroponicly grown plants do not have to grow their roots out long to search for their nutrients, compared to plants grown in regular soil since gardeners have control of the nutrients. Plants nutrients are in constant supply directly under them. Alice then moved to another group of students and later returns to Ann. The excerpt below depicts the follow-up interaction (Figure 6.6).

ALICE: 'We think the NASA space plant will grow faster because of the LEDs that the plants use in space to grow. The fluorescent lights give it enough energy to grow faster than the earth plants [the teacher is reading the students online response].'

Do you think they'll grow faster under fluorescent lights? What do fluorescent lights do?

ANN: The fluorescent lights take the place of the sun, so they'll get energy.

ALICE: So which plant do you think will grow faster?

ANN: NASA one [referring to the AstroPlants].

ALICE: Why?

ANN: It went through the lifecycle fast.

ALICE: Well, you think about it. And if you need to, re-read what it says there [referring to the WISE evidence page called 'Energy is limited on the space shuttle].

Figure 6.6. Science Dialogue between Alice and a Fifth Grade Student during the WISE *Comparing Plants' Life Cycles* Lesson in Year Three.

The above teacher-student science dialogue in years two and three illustrates that Alice helped students to make their scientific thinking visible through eliciting their science ideas and encouraging them to connect new and prior ideas as well as using technological supports in the WISE interface (i.e., WISE evidence pages and students' online notes). In particular, the episodes demonstrate how technology-enhanced learning environments such as WISE can affect teachers' practices. WISE gave Alice new insights into her students' thinking through capturing their results and reflections. In each instance, Alice had a detailed record of how student-groups made sense of the project activities. Analysis of successive WISE online lessons taught by Alice in year three revealed comparable findings.

Graphing Data Lesson in Year Two

The episode highlighted in Table 6.1 also shows that in year two Alice continued to engage students in science dialogue. Analysis from video showed that out of sixteen teacher-student dialogues in year one, there were no science dialogues. In contrast, in year two, eleven out of twenty dialogues were science dialogues.

In summary, Alice learned to make visible her students' scientific thinking around key science concepts, *Comparing plants' life cycles and Graphing data*, through greater use of conceptual questioning and by engaging them in more science dialogues across time. Changes over time in Alice's understanding of the science and understanding of how students were conceptualizing the content also helped to explain shifts in her pedagogy.

For Alice, use of technology was associated with an increase in science dialogues with small groups in successive years. More specifically, WISE features supported students' knowledge integration through requiring them to critique scientific evidence, construct explanations, and make predictions. As a result of WISE capturing students' ideas (referring students' responses to WISE online note questions) and giving the teacher detailed accounts of these student ideas, Alice was able to make students' scientific thinking visible around the focal science topics through conceptual questioning and by engaging them in more science dialogues across time. This involved the teacher encouraging her students to: (a) reflect on the science content in *Plants in Space*, (b) challenge each other's perspectives, (c) connect new and prior science ideas, (d) make predictions, and (e) support claims with evidence.

Alice's Pedagogical Content Knowledge

In this section, I discuss changes in Alice's pedagogical content knowledge across the three year time period as a way of understanding the changes in her teaching practice. Similar to Lee, I used the knowledge integration perspective. I look at teacher knowledge in a variety of topic areas to capture pedagogical content knowledge—*knowledge of instructional strategies*, *knowledge of the science curriculum*, and *knowledge of students' science conceptions* to understand development in Alice's pedagogical content knowledge. Also, this section discusses what factors supported Alice's development across time. As in the case of Lee, I consider the social supports I provided Alice such as scaffolding her in reflecting on her practice and knowledge, assisting her with WISE plant curriculum customizations, and providing mentoring during her first year of teaching WISE by her request.

Teachers' Knowledge of Instructional Strategies

As discussed in the prior chapter, this component of pedagogical content knowledge—*teachers' knowledge of instructional strategies* consists of two sub-categories: teachers' knowledge of strategies to help students understand specific content in the WISE plant curriculum unit, and teachers' knowledge of methods for assessing student learning specific to the plant unit. Below I trace development in Alice's knowledge as it relates to the aforementioned categories.

Strategies to help students understand specific science content. Figure 6.7 illustrates the evolution of Alice's knowledge of particular strategies to help students understand specific science content in *Plants in Space* over the three year time frame. Prior to the first enactment of WISE (referring to year one), Alice emphasized the importance of asking students questions as a way to promote learning. For example, Alice stated, *Asking questions allow students to reflect. I think reflection helps students understand science. I ask questions to see if they have an understanding. When the questions are more complicated, they [RSP/SCC students] just don't understand. So I just simplify them.* Alice further stated:

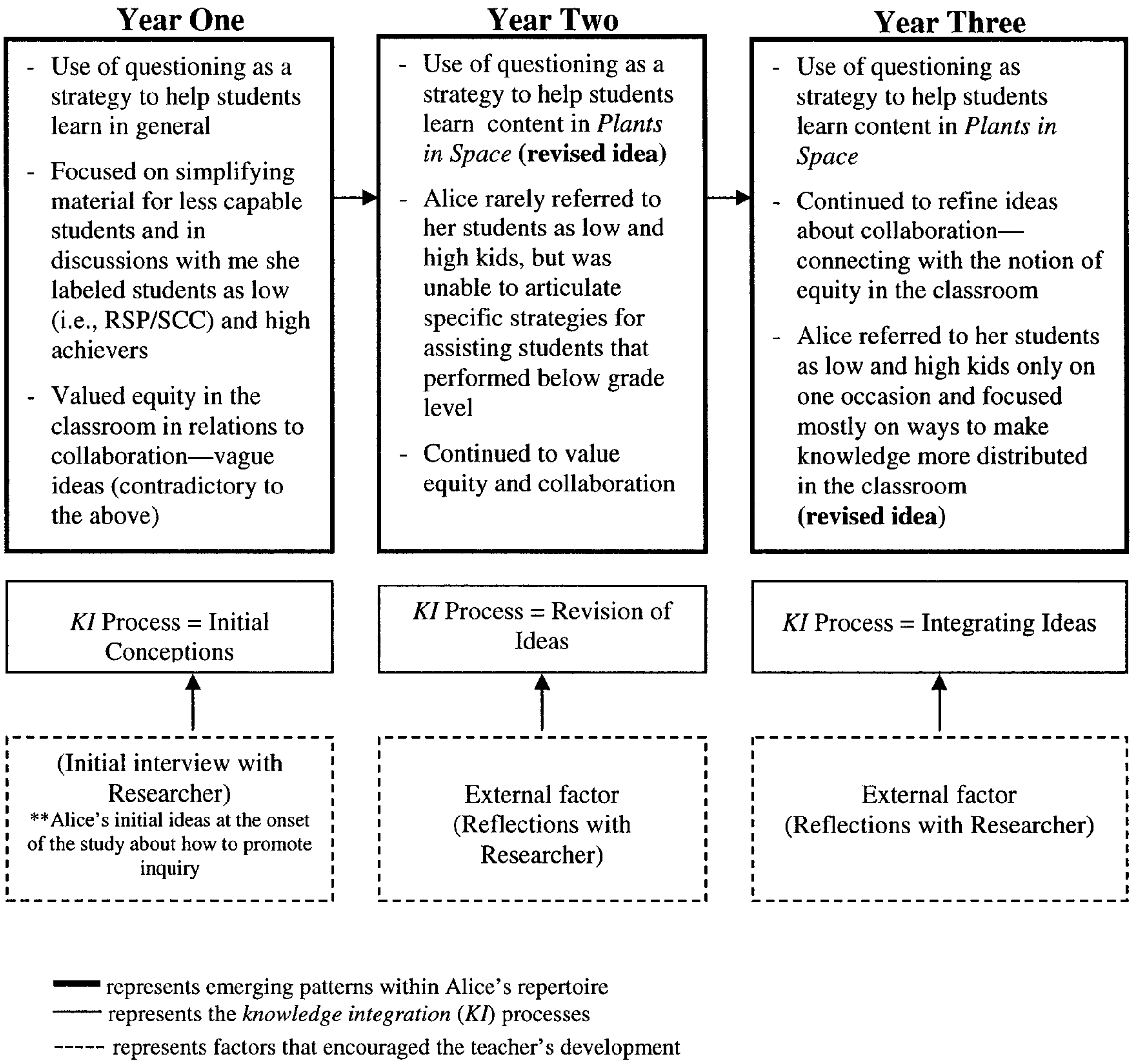
> *I just try to simplify for them [referring to questions she asks the RSP/SCC students]. That's what they understand. And like on the computers, the WISE Program…I have the period of high/low and the high students have to read to the low students, because the low students are unable to read it. And then they try to explain it a little better, which is good for the high students…My low students really struggle with the reading [i.e., the questions in the WISE project]. I have definitely way below 5th grade readers in here.*

Alice's initial conception of questioning did not focus on the use of questioning as a strategy to enhance students' understanding around specific science content in the plant unit. The above example also points out that Alice used *labeling* (a second preconception) when referring to students perceived achievement levels.

Later on during this initial interview, Alice emphasized:

> *You're only as strong as your weakest person. So they [referring to all fifth grade students] need to make sure that everyone understands. Like right now, for colonies…They're in colonies and everyone has a job and they need to do it, but you need to make sure everyone's doing their job. You need to make sure everyone understands. So the whole group is in it together. You can't do it individually, you'll never succeed. I really try to make sure that eveyone is participating and everyone is learning.*

This excerpt illustrates some inconsistencies in Alice's reportorire of ideas. She seemed to value equity in the classroom in relation to student collaboration. On the other hand, Alice referred to some of her students as *high kids and low kids* with regards to their perceived achievement ability.



Year One	Year Two	Year Three
- Use of questioning as a strategy to help students learn in general - Focused on simplifying material for less capable students and in discussions with me she labeled students as low (i.e., RSP/SCC) and high achievers - Valued equity in the classroom in relations to collaboration—vague ideas (contradictory to the above)	- Use of questioning as a strategy to help students learn content in *Plants in Space* **(revised idea)** - Alice rarely referred to her students as low and high kids, but was unable to articulate specific strategies for assisting students that performed below grade level - Continued to value equity and collaboration	- Use of questioning as strategy to help students learn content in *Plants in Space* - Continued to refine ideas about collaboration—connecting with the notion of equity in the classroom - Alice referred to her students as low and high kids only on one occasion and focused mostly on ways to make knowledge more distributed in the classroom **(revised idea)**
KI Process = Initial Conceptions	*KI* Process = Revision of Ideas	*KI* Process = Integrating Ideas
(Initial interview with Researcher) **Alice's initial ideas at the onset of the study about how to promote inquiry	External factor (Reflections with Researcher)	External factor (Reflections with Researcher)

━━ represents emerging patterns within Alice's repertoire

—— represents the *knowledge integration* (*KI*) processes

----- represents factors that encouraged the teacher's development

Figure 6.7. Alice's Knowledge of Strategies to Help Students Understand Specific Science Content in *Plants in Space*.

Observations of Alice's teaching in year one revealed that in some cases her practice emulated her pedagogical beliefs. For example, Alice did require her students to work in collaborative groups (in pairs of two) over the course of the WISE project. However, as discussed earlier in the chapter, Alice left her students to work on WISE investigations primarily without guidance in year one, except for the focal topic lessons—*Comparing plants' life cycles* and *Graphing data.* Additionally, Alice was never observed during science class instruction referring to students as *high and low kids.*

It was not until year two that Alice revised her initial conception—use of questioning as a strategy to help students learn in general, to asking students questions specific to the science content in the WISE plant curriculum unit (refer to Figure 6.7). For example, Alice indicated during a reflection interview in year two that she used questioning as a strategy to help her students learn specific concepts in the plant unit such as the *conditions of space* investigations and the *plant life cycle* concept. Alice went on to say, *I kind of prompted them...when they talked about faster life cycles [referring to plants]. That's one of the questions [in WISE] that asked 'Why do you want a faster life cycle [plant in space].' A lot of them said 'because they wanted to do lots of experiments in space.' I asked a lot of them what are the benefits of that?*

It is most compelling to see that changes in Alice's knowledge of instructional strategies also reflected changes in her practice. For example, as discussed earlier in the chapter, the majority of Alice's questioning strategies were conceptual in year two versus majority being logistical in year one. This involved Alice asking students questions that required them to make predictions and provide explanations for both written and oral responses.

The remaining two initial conceptions (equity and collaboration) remained in Alice's repertoire of ideas in year two. In discussions with me in year two, Alice rarely referred to her students as *high kids and low kids* with regards to their perceived achievement ability. However, she was unable to articulate her strategies for assisting students that performed below grade level.

In year three, Alice's initial conceptions from year one regarding equity in the classroom and student collaboration remained in her repertoire (refer to Figure 6.7). Although, Alice persisted in occasionally using *labeling* when referring to students' perceived achievement levels, she began to think deeply about how to better assist all students regardless of their achievement level (i.e., second language learners and students with language disabilities). For example, during an interview prior to this third WISE enactment, I asked Alice what strategies would she use to make a complex idea such as 'why do leaves change color in the fall and its relationship with photosynthesis' understandable to students this year. Alice stated, *For lower kids or the second language learners, I'd like to try to use more visuals. For the higher learners, they can go beyond, like use resources such as going online or use books I have here.*

In a later interview with Alice, I indicated that I had been observing her spending more time with pairs of students and individual students during the WISE online investigations this year in comparison to the prior years. Alice replied, *I have a deeper understanding [of the science content and the curriculum], so I can ask more questions.* Alice further pointed out that she decided to take this year's class to science camp earlier (during the WISE project run), in order to provide them with more background knowledge on plants and the forests. I followed-up by asking her what kind of activities specific to plants these students took part in during science camp. Alice said, *They learned about photosynthesis and the weather. They went on hikes and learned about different kinds of trees, what they need, and what the environment provides them.* She went on to say that the students mostly participated in field investigations, which involved learning about trees such as the Bay Leaf and the Laurel and what their characteristics are and how to identify them. I then asked Alice if the science camp staff incorporated as part of the investigations and discussions concepts such as photosynthesis. Alice replied with, *well, how the forest survives because they have to make their own food.* The aforementioned examples illustrate Alice's thinking process with respect to making science more accessible to all learners by spending more time with individual students and providing them with real world learning experiences. These examples also illustrate equity and collaboration being employed both inside and outside of the classroom walls.

Professional development activities. Factors that supported Alice's development in years two and three included the supports I provided such as repeatedly scaffolding her in reflecting on her practice. As previously discussed, in year two, Alice rarely labeled her students as *low kids* and *high kids.* And in year three, Alice referred to her students as *low kids* and *high kids* only on one occasion and focused mostly on ways to make knowledge more distributed in the classroom. For example, during an initial teacher meeting with Alice in year two, I indicated that I had heard her on several occasions encouraging her students to collaborate and asked *Why do you do this?* Alice replied, *I think collaboration promotes good discussion. I paired students as high-low. I think the higher one actually helps the other person [referring to the less advanced student].* I follow-up by asking, *Do you think there are cases where the less advanced student also helps the more advanced student?* Alice then stated, *Oh, absolutely. Absolutely. Yeah, definitely…If the higher kids are the ones explaining it, they're learning as they try to explain it.* Direct interaction between the teacher and I lead to the teacher abandoning her use of labels regarding her students' perceived inherent intelligence (high and low students).

Thus, providing Alice with opportunities to reflect on her practice across time contributed to her development in pedagogical content knowledge—i.e., *knowledge of instructional strategies.*

Methods for assessing student learning. Figure 6.8 illustrates Alice's knowledge integration processes with respect to effective methods for assessing student learning over time. In year one, I asked Alice how she knew if her students were learning science. In year one, Alice viewed listening as the primary method for assessing students' understandings in science. For example, Alice stated, *I know if my students are learning science through listening to them in their groups, and seeing what they're talking about.* However, when I probed her further in year one, she was unable to provide additional detail.

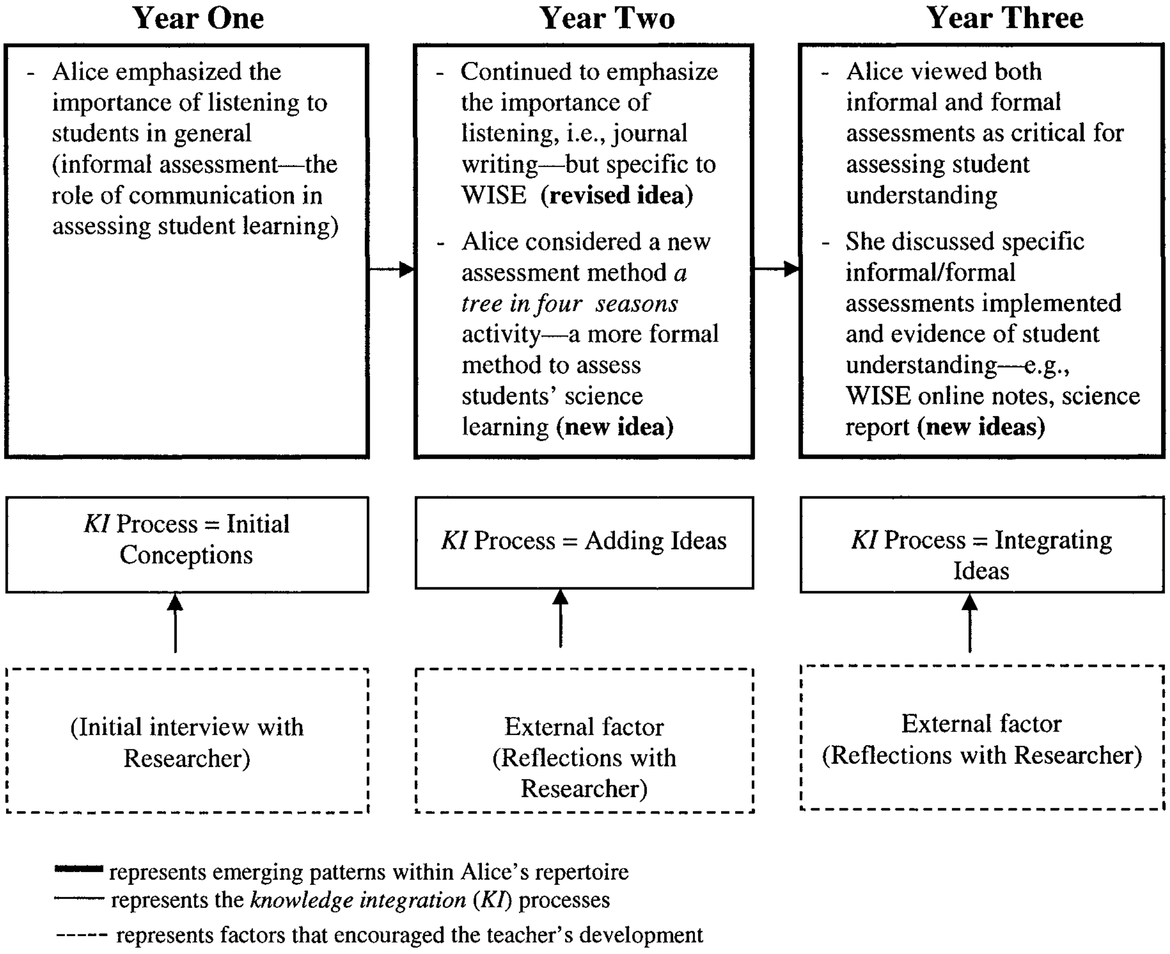


Figure 6.8. Alice's Knowledge of Methods for Assessing Student Learning in *Plants in Space*.

In year two, Alice added a new idea to her repertoire regarding assessing students' science knowledge. She introduced a formal assessment called *A tree in four seasons' activity*. As discussed in chapter 4, this activity entailed students describing and illustrating the appearance of a tree in each of the four seasons (i.e., winter, spring, summer and fall). The content goal for this activity was to assess students' understanding early on in the WISE project about the role of photosynthesis in plant development. After asking Alice why she chose to teach this particular activity, I then asked her what were some of the conceptions students had thus far about plant growth and development.

Alice said, *they mentioned how photosynthesis shuts down. And they stored the food for [the fall and winter months]. The leaves fall off the trees when there's no sun, the day are shorter.*

Additionally, as shown in Figure 6.8 above, Alice continued to view listening as an important technique to get at students' science understandings. However, she discussed this technique as it related to specific science content in WISE. Alice explained that she could tell when students really understand by listening to their answers and observing them in class (i.e., looking at their journals, asking questions, and observing their body language). For example, Alice indicated that she pays attention to how students draw conclusions when asked questions such as: *Why is the photosynthesis process important to plant survival? Why do plants' leaves change colors? and How does that relate to photosynthesis?*

In year three, Alice viewed both informal and formal assessments as critical for assessing students' science learning. Alice added new ideas to her repertoire, which included emphasizing more specific forms of assessment measures. In an interview prior to the WISE enactment in year three, I asked Alice how she would measure students' understanding. Alice stated,

> *By listening and talking with students. By [looking at] their WISE notes on the computer…Well, they just finished their science report from the unit [students grew beans in different growth mediums] before WISE. That was a really good assessment. I found it was really hard for a lot of students to make conclusions. So, this is a perfect opportunity, this project [referring to Plants in Space], for students to draw conclusions by figuring out which plant is which and why.*

The analysis of Alice's *knowledge of instructional strategies* (i.e., knowledge of strategies to help students understand specific science content in *Plants in Space* and knowledge of methods for assessing student learning in *Plants in Space*) shows her engaging in the knowledge integration processes of adding ideas to her repertoire, revising ideas, and integrating ideas after her first year of teaching WISE. Providing Alice with repeated opportunities to reflect on her teaching contributed to her development in knowledge.

Teachers' Knowledge of Science Curriculum

In year one, Alice indicated during an interview with me that she was happy with the current version of *Plants in Space* and did not have any new ideas to add (see Figure 6.9). However, Alice ended up designing a supplementary classroom lesson called a *KWHL* activity (a WISE offline introduction activity). The *KWHL* activity consisted of Alice soliciting students' initial conceptions about plants prior to the implementation of WISE Plants in Space, including what things they would like to find out further about plants.

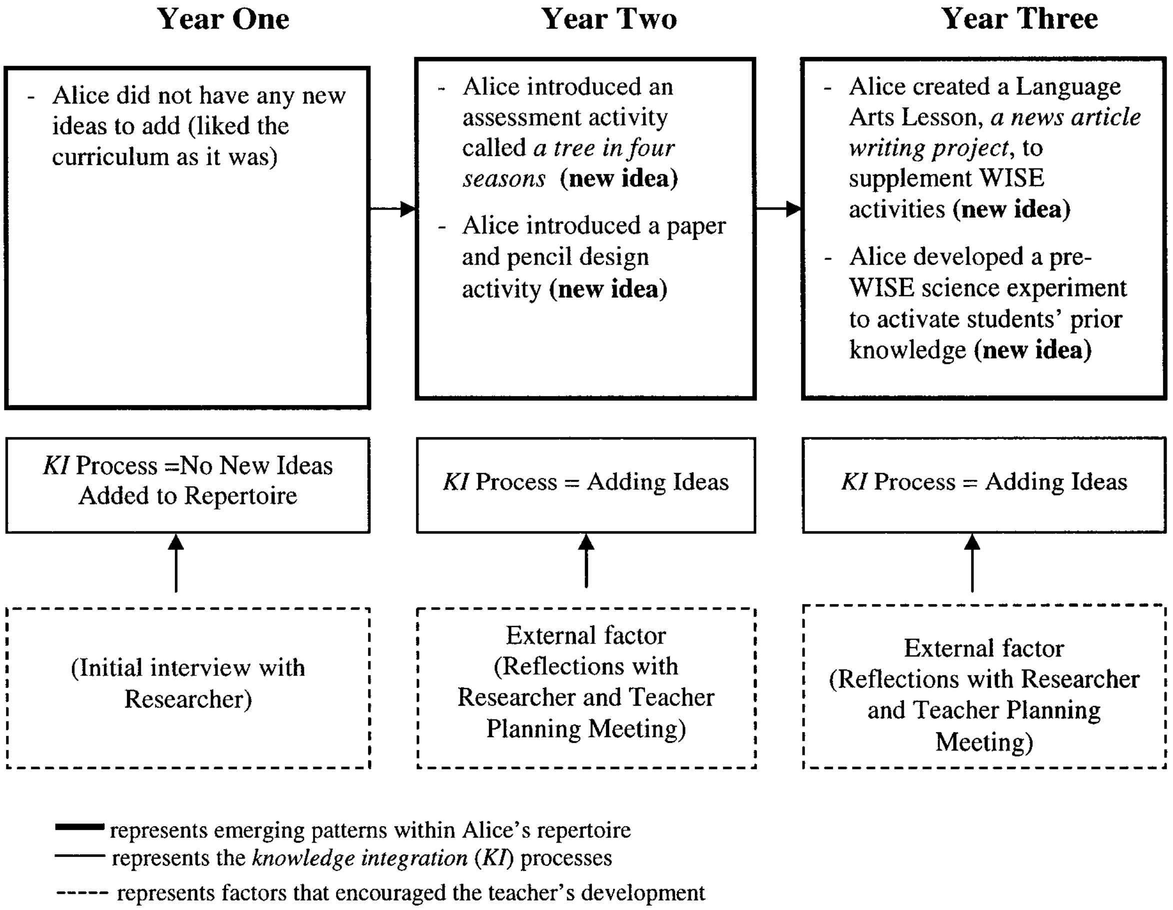


Figure 6.9. Alice's Knowledge of the Science Curriculum for *Plants in Space*.

As shown in Figure 6.9, in year two, Alice discussed the implementation of two new curriculum ideas, the *Tree in four season's activity* and the *paper-pencil design activity of a plant growth chamber for space*. During year two, I conducted retrospective interviews with Alice, soliciting her accounts of changes in her pedagogical conceptions and instructional practices. She indicated on numerous occasions in year two (i.e., prior to the implementation of WISE, during the WISE project run) that these changes in her practice could be attributed to her growing familiarity with the curriculum and what it means to support students' scientific inquiry. For example, in year two prior to implementation of WISE, Alice described the challenges she faced with online inquiry and the science content:

> *[In the first year, my goals were] to reinforce the scientific method, just to give kids good concepts about the plants and to have them problem-solve, and figure out which one was the space plant and which one was the earth plant. I thought it went ok. I thought it was really hard because I felt like I was learning with them and I did not know the unit online. But I did have a helper [visiting scholar], which totally made a big difference. She had a science background, and I don't. So a lot of the concepts, the kids would ask questions, she was able to answer them in-depth.*

I then asked Alice what she had learned through this experience of running WISE for the first time in year one. Alice responded with:

> *Well, I learned about the program, for one, which was good. And I learned a lot about plants—photosynthesis, I mean the whole process of a plant [making its food], and what it needs such as nutrients...And then just how the program worked, the experiments. Timing, what can you do for timing [referencing how to pace the WISE activities]. I feel like I'm better able to prepare for this unit, and the timing of it, and what is expected in the very end. My goals [referring to year two] are to help the kids to have a better understanding of the science concepts…they need to know not only what plants need to grow, but why it's important and how it affects them. And I would think the other one would be to get students to think about how plants…if they can grow in space. It's asking them a question, and having them problem-solve it, using the evidence. And that's really important to have them to try to figure it out on their own.*

During the WISE curriculum run, Alice stated:

> *I think one of the goals I'd like to see for them [referring to year two class] is to use the knowledge that they know and apply it. And just to learn about the big picture of the world, and how there's different ways to do things, like growing [plants] hydroponicly and what are the benefits and what are the disadvantages, and what would work best in a certain situation?.*

Alice indicated that she had a better idea of what to teach, including an understanding of the science concepts: *This year I knew the first thing that I was going to* *focus on, photosynthesis and the roots, and chlorophyll. And for me, I understood the information a little more, whereas last year I didn't really have the [knowledge].*

In year three, prior to the WISE implementation, Alice continued to add new curriculum ideas to her repertoire (see Figure 6.9). For example, during a teacher planning meeting, Alice indicated that she would like for her students to do a final class project related to the WISE project activities. She came up with the idea of a *school newspaper*. Alice said, *We [referring to her and the students] could even talk about the different parts of a newspaper [i.e., an opinion column, your main headlines, the cartoon section]…* She pointed out that her class do current events (i.e., they subscribe to *Time Magazine* for kids), and as a result they could brainstorm other headings. Alice indicated that her goals this year is *to guide them [students] through the WISE program. I want them to be able to draw conclusions and base it on evidence.* She felt like the newspaper project was a great way to contribute to this process.

Professional development activities. The analysis of Alice's curriculum knowledge shows her engaging in the knowledge integration process of adding ideas to her repertoire. Thus, providing Alice with repeated opportunities to reflect on her pedagogical conceptions and practice (i.e., opportunities to participate in retrospective interviews) contributed to her development in pedagogical content knowledge.

Teachers' Knowledge of Students' Science Conceptions

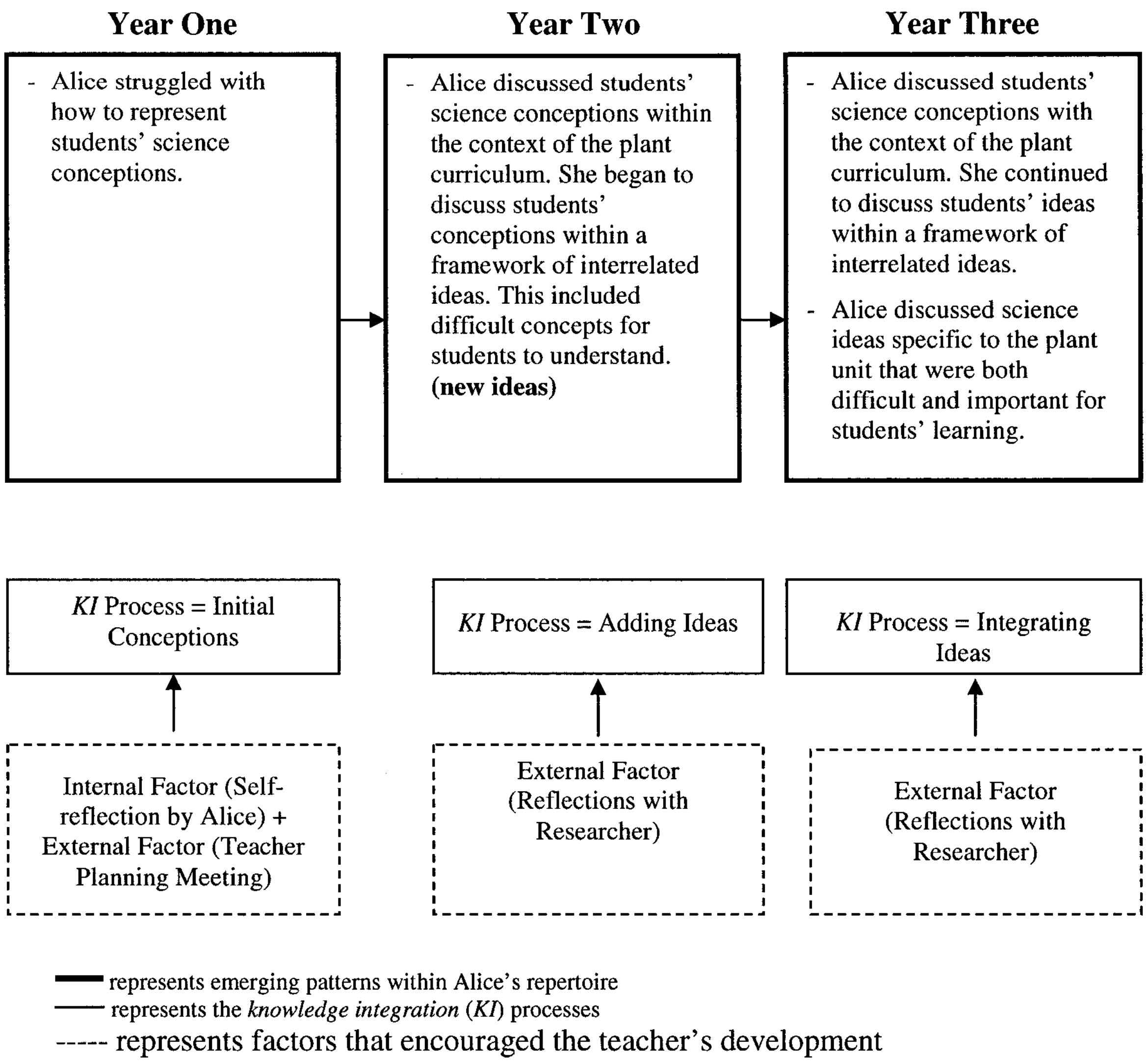
Figure 6.10 below illustrates Alice's knowledge integration processes with respect to students' science ideas specific to the plant unit. The first year consisted of me scaffolding Alice's interpretations of student conceptions. I provided scaffolding as a result of Alice's emerging science content knowledge. As shown in Figure 6.10, Alice struggled with how to represent students' science conceptions. For example, at the beginning the plant run, Alice emphasized in a meeting with me and her colleagues that she had spent an entire Friday afternoon teaching science, which entailed students reflecting on the board and Alice rotating back and forth between the reading center and the computer center in the classroom. Alice indicated that she had reviewed the students' online notes the preceding day (referring to a Thursday) and had written down the main trends observed. Alice further explained, *We reflected and we wrote the questions, the first two questions on the board, and then the kids gave information.* I asked Alice to clarify what things had she written on the board. Alice said:

> *That was the first two questions [referring to questions in the students' online WISE note]. It says, 'What do plants need in order to grow?' And then they wrote all the different things. And we talked a little about photosynthesis...Mostly, the kids had some really, really, good questions. They had so many great questions. And so she [referring to the visiting scholar who was in the classroom during this reflection lessons] was just answering them.*

I then asked, *What type of questions were they [the students] asking?* Alice said,

> *Let me think of some of the questions they were asking. She [visiting scholar] was talking about the light the sun gives off and how it gives red light. And then the students were asking, 'Well, how come it doesn't turn the plant red?' They were going into things like that. They [students] were asking some more...I'm trying to think of what they were. Some were really good questions.*

Although I guided Alice in interpreting students' conceptions, she still struggled with how to represent students' science ideas.



- Alice struggled with how to represent students' science conceptions.

- Alice discussed students' science conceptions within the context of the plant curriculum. She began to discuss students' conceptions within a framework of interrelated ideas. This included difficult concepts for students to understand. **(new ideas)**

- Alice discussed students' science conceptions with the context of the plant curriculum. She continued to discuss students' ideas within a framework of interrelated ideas.
- Alice discussed science ideas specific to the plant unit that were both difficult and important for students' learning.

▬ represents emerging patterns within Alice's repertoire
── represents the *knowledge integration* (*KI*) processes
----- represents factors that encouraged the teacher's development

Figure 6.10. Alice's Knowledge of Students' Science Conceptions.

Moreover, during the mid-phase of the WISE project in year one, Alice sought help from others including me and a visiting scholar in her classroom, and she felt these interactions contributed to positive changes in her practice and her thinking about student learning of the science content. For example, during a whole class reflection lesson on *light/photosynthesis*, *hydroponics*, and *growing plants in space*, Alice invited the visiting scholar and myself on several occasions to answer student questions posed that she was uncertain how to answer. For example, during the lesson, student Gabe asked, *I just have a question. What is a living organism?* Another student (Dan) responded with, *Something that moves and breathes.* Alice said, *Ms. Roberts [referring to the visiting scholar] do you want to answer that?* Ms. Roberts' response to Gabe included, *That's close. Movement is one thing and respirations and using energy is something else. Respiration is a part of breathing…And that's part of using energy. And another thing is [referring to a living organism] that it has to reproduce because, otherwise, the whole thing will die.*

At a subsequent point in time during the same lesson, a student asked Alice if it was possible for a plant to get 'too much minerals.' Alice asked, *Michelle, Can a plant get too much minerals?* I indicated that plants could get too much of the required nutrients as well as insufficient amounts of the required nutrients, thus in both cases causing the plants to be unhealthy (e.g., affecting their coloration). I encouraged the student to think about how the human body might respond to excess nutrients such as calcium. Both of these examples are compelling in that they illustrate how a teacher seeks help for her students when necessary.

In an interview, during the WISE plant run in year two, I asked Alice if she thought her first year students got to where she wanted them to be with respect to understanding the big ideas in the plant project (i.e., during and at the end of the plant unit), and how that compared to her current student body. Alice responded with:

> *Yeah. I think they [referring to year 1 class] got a lot out of the project, definitely, without a doubt. I think they understood what photosynthesis was. I don't think they made the connection with the whole life cycle and which plant is space and which plant is earth. I don't think that they did that. You know, or even with the light conditions, the different light conditions, I don't think they got that. But, I definitely think they got [something]. I mean, you always get something out of it. But I think this class [referring to year 2 class] is getting a whole lot more out of it. I think they really understand the different [lighting conditions]. I think they*

> *understand why things are happening. The 24-hour, like too much light, I don't think they're making any kind of connection with that. But tomorrow I'm going to do that, [ask] what their observations are with each, and [have the students] write them down and see if they can come to some conclusions. So this year's class, I would definitely say is getting there. I think they're just making connections; I think they're getting more out of it.*

I continued by asking Alice why she thought her second year class was developing a deeper understanding of how the various lighting conditions were affecting plants growth and development. Alice stated, *I knew what's going on in the project [referring to year two]. [In year 1,] I was learning along with the kids—I felt like I was a student going through WISE myself.* I later asked Alice during that same interview, *How are you going to connect the whole class review chart of plants growing under various lighting conditions during your lesson tomorrow with the concept of the plants' life cycles?*

Alice said:

> *Well, this is my idea, and feel free to jump in and suggest anything because I'm kind of really not sure. What I was going to do is to kind of have three charts, and I was going to have them all get their plants, and just write, '12-hour,' '24-hour,' 'no light.' And then I was going to have them look at their plants, and maybe split it [into] A and B. And then they can tell me some observations that they're having for each one…And then I was going to say, 'Okay, now let's make some conclusions based on these observations. What do you know about A-24? What do you know about B-24?' Or, you know, whatever, you know. And have them kind of come up with some conclusions. And then, maybe say, 'Okay, why do you think this is happening? I mean, what do you think is going on here?'*

The aforementioned example illustrates that not only was Alice becoming aware of her students' science conceptions within a framework of interrelated concepts and processes in year two, but also illustrates her thinking process with respect to the design of science activities to address students' lack of understanding in a particular area.

As shown in Figure 6.10, in year three, Alice integrates more ideas in her repertoire. For example, Alice not only discussed science ideas that were difficult for students to understand, but also she discussed ideas that were important for student learning. Prior to implementing WISE in year three, Alice stated, *I think the function of the plant's leaves and each part of the plant are important concepts for student learning. I think the photosynthesis [process] is important and how it relates to a plant making food internally.* She further emphasized the importance of understanding the role of chlorophyll and how it is related to plants' leaves changing colors in different seasons. Alice followed-up by saying, *I think connecting how chlorophyll relates to photosynthesis is important. I mean, they understand about chlorophyll, but I don't think they understand how it's related to photosynthesis [including plants stop making their food].*

Professional development activities. In year two, my role shifted toward encouraging Alice to reflect more on her own thinking about students' conceptualizations of the science content. For example, prior to the WISE implementation in year two, I asked Alice what particular concept or concepts in the plant unit did she think was difficult for students to understand. She responded with,

> *I think the challenging part would be the whole concept of growing plants in space. A lot of them [referring to her first year class] were thinking 'Oh, the dirt is going to float up...' Like when we were talking about it [space] before, that was one of the questions that was brought up. Five kids started yelling and screaming, 'Oh, it will never happen [referring to growing plants in space]! The dirt is going to be flying all over the place because of gravity. And where are they [plant] going to get the light from? It's dark in space.*

She further indicated that her current students (year two class) had some prior knowledge of the concept 'growing plants in space.' As a result, they were less likely to experience difficulty with the concept. This example also illustrates the relationship between Alice's *knowledge of students' science conceptions* and her *knowledge of instructional strategies*. For example, the role of communication in assessing students' learning (i.e., listening) continued to permeate in Alice's repertoire even as she discussed students' science ideas.

Based on the above analysis, another factor that supported Alice's development in *knowledge of students' science conceptions* includes the mentoring (referring to my participating in class discourse) I provided during her first year of teaching WISE by her request.

A Summary of Alice's Learning Trajectory

In conclusion, findings show that Alice's questioning patterns became more conceptually oriented in years two and three, and she engaged in more science dialogues with small groups of students in her second and third year of teaching WISE *Plants in Space*. Alice also developed in pedagogical content knowledge from years one through three. Findings further show integration of the knowledge integration processes by Alice's third year of teaching the WISE plant curriculum unit. Similar to Lee, factors such as the social supports provided by the researcher contributed to her development in practice and knowledge. The social supports provided by the researcher included: (a) scaffolding Alice in reflecting on her practice and knowledge, (b) assisting her with WISE plant curriculum customizations, and (c) providing mentoring during her first year of teaching WISE by her request. Evidence presented in this chapter supports my conclusion in chapter 5 that a trajectory constitutes changes in the teachers' practices and knowledge as they are influenced by external and internal professional development supports. As in the case of both a novice teacher (Alice) and an experienced teacher

(Lee), implementing a technology-enhanced curriculum for the first time allows further development in both knowledge and practice.

WISE supports teachers by giving detailed accounts of student learning (applies to both Alice and Lee). As shown in this chapter and chapter 5, teachers contribute to students' knowledge integration process by asking them to reflect on scientific evidence in the projects, make links between scientific ideas, explain their reasoning, and provide evidence to support claims. Additionally, the *Plants in Space* unit afforded students in Alice's classroom to connect science class ideas to personally relevant problems and prior knowledge through conducting the plant observations and online investigations.

CHAPTER 7

COMPARISON OF TEACHERS' TRAJECTORIES

Introduction

In chapters 5 and 6, I discussed how the experienced teacher (Lee) and the novice teacher (Alice) learned to teach inquiry science in a technology-based environment, WISE, over time. The findings displayed in chapters 5 and 6 show that Lee and Alice developed in their teaching practices and pedagogical content knowledge across the three year time span. Results also revealed that the social supports provided by the researcher and self-reflections by the teachers contributed to their development. In this chapter, I compare and contrast the trajectories of change in the novice and experienced teacher's practice and knowledge.

Trajectories of Change in Teachers' Practices

At the onset of the study, both Lee and Alice started with goals consistent with an inquiry-oriented approach. Lee's teaching strategies became more inquiry oriented across time as he had repeated opportunities to implement this new technological innovation, WISE. In contrast, Alice's practice did not match her pedagogical conceptions in her first year of teaching WISE *Plants in Space*. Her teaching approach became more inquiry oriented in years two and three. It took Alice a year of classroom experience, with a lot of professional support, for her to begin asking inquiry questions. She gained deeper understandings of the science content from using the curriculum and relying on the researcher plus WISE in year one.

There were several key differences and similarities in Lee's trajectory versus Alice's trajectory in regards to their teaching practice over the three year time period. First, Lee elicited students' science ideas primarily through conceptual questioning as he taught the *Light/photosynthesis* lessons in years one through three. Similar patterns were not seen in Alice's teaching until years two and three. Second, as discussed in chapter 5, Lee designed the Language Arts Lesson called *Why do leaves change colors in the Fall?* This curriculum customization was taught in years one through three. However, Alice did not integrate science (referring to the *Plants in Space* unit) as part of the domain of Language Arts until year three, when she implemented the news article writing project. Finally, findings show that whenever Lee and Alice taught the key science topics during the WISE online investigations across time, they taught the topics in small group settings.

For both Alice and Lee, use of technology accompanied an increase in science dialogue with small groups in successive years. More specifically, WISE features supported students' knowledge integration through requiring them to critique scientific evidence, construct explanations, and make predictions. As a result of WISE capturing students' ideas (referring to students' responses to WISE online note questions) and giving the teachers detailed accounts of these student ideas, Lee and Alice were able to make students' scientific thinking visible around the focal science topics through conceptual questioning and by engaging them in more science dialogues across time. This involved the teachers encouraging their students to (a) reflect on the science content in *Plants in Space*, (b) challenge each other's perspectives, (c) connect new and prior science ideas, (d) make predictions, and (e)support claims with evidence.

Trajectories of Change in Teachers' Pedagogical Content Knowledge

Lee and Alice came into the project with both similar and differing preconceptions. In this section, I compare and contrast similarities and differences in Lee and Alice's pedagogical content knowledge across the three year time period. As discussed in chapter 5, teachers' pedagogical content knowledge includes three components: (a) *knowledge of instructional strategies,* (b) *knowledge of students' science conceptions, and* (c) *knowledge of the science curriculum.*

Chapters 5 and 6 reveal a few key similarities and differences in Alice's and Lee's trajectory of *knowledge of instructional strategies*[1]. Prior to the implementation of WISE in year one, both Alice and Lee emphasized the use of questioning as a strategy to help students learn in general. By year two, the teachers revised this initial conception specific to the WISE content. In this case, they took a similar path and ended up at the same place. As a case in point, in year one, Lee and Alice's initial conception of questioning did not focus on the use of questioning as a strategy to enhance students' understanding around specific science content in the plant unit. After they revised this conception specific to the WISE content in year two, it remained in their repertoire in year three as well. Other common conceptions that Lee and Alice had in year one and year three regarding ways to help students learn science included: (a) the value of equity in the classroom, and (b) the importance of student collaboration. However the way they

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[1] Recall that this component of pedagogical content knowledge, *teachers' knowledge of instructional strategies*, consists of two sub-categories: teachers' knowledge of strategies to help students understand specific content in the WISE plant curriculum unit, and teachers' knowledge of methods for assessing student learning specific to the plant unit.

represented these ideas were different. For example, in year one, it was challenging for Alice to express what equity and student collaboration really meant, whereas Lee's thinking process around these two ideas was quite sophisticated. By year three, both teachers discussed the notion of equity and collaboration in very sophisticated ways.

Differences in knowledge of strategies to help students understand specific content in *Plants in Space* included: (a) Lee added a new idea to his repertoire in year three, which included providing his students with online feedback in WISE for reflection purposes, and (b) Alice used *labeling* when referring to students' perceived achievement levels. However, by year three, Alice began to think deeply about how to better assist all students regardless of their achievement level (i.e., second language learners and students with language disabilities).

With respect to the teachers' knowledge of methods for assessing student learning in the plant curriculum unit, they had very similar pedagogical conceptions. In year one, the teachers continuously emphasized the importance of listening to students in general as a way to determine if they understand science. In year two, both Lee and Alice added a new idea to their repertoire regarding assessing students' science learning—use of a more formal method of assessment. At the same time, this informal method of assessment (listening) continued to resonate in Alice's repertoire in years two and three. She revised this idea to be more specific to the WISE content as well. It was not until year three, that this informal method of assessment—listening reappeared in Lee's repertoire. Additionally, Lee and Alice added new ideas to their repertoire in year three regarding specific informal and formal assessment measures.

Moreover, as both teachers developed in pedagogical content knowledge, their teaching practices became more reflective of their pedagogical conceptions. It is important to point out that Lee unlike Alice began in year two (i.e. year three) thinking at a metacognitive level when discussing effective ways to help students understand the specific science content in the WISE plant unit. This also applies to how Lee represented his knowledge of specific methods for assessing student understanding. Observations of Lee's teaching in years two and three reflected both metacognitive processes.

Chapters 5 and 6 also reveal similar and different patterns in Alice and Lee's *curriculum knowledge* for *Plants in Space* across the three year time span. First, unlike Alice, Lee was a co-developer of the WISE plant curriculum (referring to the Pre-WISE time frame in Figure 5.9). Second, in year one, both Alice and Lee were happy with the current version of *Plants in Space*. They did not have any new curriculum ideas to add. However, they both ended up designing a supplementary classroom lesson—i.e., a WISE offline introduction activity that solicited students' prior knowledge about plants. Third, in year two, they both were innovative in creating new curriculum customizations. Lee developed an online quiz for WISE and suggested ideas for improving content and revising sentences in WISE evidence to help students make connections. In year three, Alice added new curriculum ideas to her repertoire such as creating a Language Arts lesson, whereas, Lee integrated ideas within his repertoire, which included reflecting on his past WISE plant curriculum goals and determining his next steps. Lee also articulated his reasons for making repeated curriculum customizations (e.g., Language Art Lesson called *Why do leaves change colors in the Fall?*) to the plant unit. Alice did not integrate science (referring to the *Plants in Space* unit) as part of the domain of Language Arts until year three, when she implemented the news article writing project.

Both Lee and Alice developed in their *knowledge of students' science conceptions* over the three year time span. Results show in chapters 5 and 6 similar and different patterns in the teachers' pedagogical conceptions. In year one, Lee provided examples of students' science conceptions not within the scope of the plant curriculum. At the same time, Alice struggled with how to represent students' science conceptions. In year two, both Alice and Lee discussed students' science conceptions within the context of the plant curriculum, including difficult science concepts. Similar to Lee, the role of communication in assessing students' learning (i.e., listening) continued to permeate in Alice's repertoire even as she discussed students' science ideas. However, in year two, Alice began discussing students' science conceptions within a framework of interrelated ideas. Finally, although in year three Alice continued to discuss students' science conceptions within a framework of interrelated ideas, Lee shows more integrated understanding of these ideas.

In conclusion, the novice and experienced teacher improved in their teaching practices and pedagogical content knowledge from years one through three. The results show integration of the knowledge integration processes by Alice and Lee's third year of teaching the WISE plant curriculum unit. Moreover, evidence further show that the experience teacher (Lee) had a stronger knowledge base to develop his techniques in dealing with WISE.

CHAPTER 8

CONCLUSION

Introduction

This dissertation investigated teachers' development in practice and knowledge. I created case studies of two elementary school teachers—a novice called Alice and an experienced teacher called Lee—who learned to teach inquiry science within a technology-based curriculum across a three year span. The overarching question for this dissertation was:

> *What are the trajectories of elementary school teachers' learning to teach a science curriculum unit using an inquiry approach in a Web-based Inquiry Science Environment (WISE)?*

To answer, I focused on the following sub-questions: (a) What is the interplay between teachers' practice and their pedagogical content knowledge as they implement a technology-based curriculum? (b) How did more effective practices emerge as a result of using technology, and what were they? (c) What supported the teachers' development? In the first chapter, I defined a trajectory very generally as a pathway that teachers take over time when they implement the inquiry science curriculum, WISE. I pointed out that Shulman (1986a, 1986b, & 1987) defines pedagogical content knowledge as:

(a) teachers' knowledge of ways of representing or formulating particular content to make it understandable to students to promote student learning, and (b) teachers' knowledge of students' ideas, including students' conceptions and preconceptions about the content area, as well as what makes specific content difficult or easy for students to understand.

The teachers in this study were committed to the view that using an inquiry approach to science teaching promotes deep understanding in students. They worked over three years to enact this inquiry approach, a process that is complex and demanding for teachers.

As Ball (2000) points out, inquiry teaching is challenging for many elementary teachers of mathematics or science, because it requires them to integrate and utilize deep understandings of the content and pedagogy. Many elementary school teachers do not have strong backgrounds in science content or technology or in inquiry-oriented instruction (e.g., Alberts, 2000; Becker, Ravitz, & Wong, 1999; Pedersen & Yerrick, 2000; Smith & Neale, 1989).

This study added yet another dimension—technology. Inquiry teaching in a technology-based learning environment is complex and demanding for teachers because it requires: (a) exploration of open and complex questions, (b) use of new representations of science content such as graphs, (c) new logistical practices such as managing small groups of students, and (d) understanding of technological and network related issues (Fishman, Marx, Best, & Tal, 2003; Ladewski, Krajcik, & Harvey, 1994; Li, 2002; Marx, Blumenfeld, Krajcik, Blunk, Crawford, Kelly, & Meyer, 1994; Slotta, 2004).

Consistent with the science education literature, the experiences of these two teachers revealed the complexities and demands of inquiry teaching in a technology-based learning environment (e.g., Polman & Pea, 2001). For example, in the case of Alice, the novice teacher, asking inquiry questions was difficult at first. And for Alice, engaging small groups of students in science dialogue, and meeting the challenge of new science content when implementing WISE was also both unfamiliar and demanding. Lee, the experienced teacher, was more adept at inquiry questions from the start, reflecting his knowledge of the content in WISE *Plants in Space*. He was also enthusiastic about the integrated use of technology. Lee capitalized on the capacity of WISE to capture students' results and reflections and provide teachers with detailed accounts of student learning (i.e., students' responses to WISE online note questions) early in his use of the technology. Both Lee and Alice were increasingly able to help students to make their scientific thinking visible in dialogues and in the interactions with science content in the WISE evidence.

My study revealed that both teachers, the novice and the experienced schoolteacher, increased their success in meeting the challenges of inquiry teaching. They learned from ongoing professional support from the investigator, repeated opportunities to implement an inquiry-based curriculum, and their own efforts to customize instruction and learn the science content.

Specifically, I developed methods for documenting ways that elementary teachers came to make students' scientific thinking visible through the use of technology over time by analyzing two dimensions of teaching practice—Questioning Patterns and Science Dialogue. Eliciting students' prior knowledge about a scientific topic and encouraging them to connect existing and new ideas can promote conceptual understanding (Linn & Hsi, 2000; van Zee, Iwasky, Kurose, Simpson, & Wild, 2001). As Black and Wiliam (1998) emphasize, "*The dialogue between pupils and a teacher should be thoughtful, reflective, focused to evoke and explore understanding, and conducted so that all pupils have and opportunity to think and express their ideas*" (p. 144). My study directly reinforces the validity of Black and Wiliam's view. My results demonstrated that science dialogues did provide opportunities for teachers and students to sort out their science ideas, resolve miscommunications, and achieve common understandings.

In addition, I documented changes in Lee and Alice's pedagogical content knowledge across the three year time span as a way of understanding the changes in their practice. I looked at teacher knowledge in a variety of topic areas to capture pedagogical content knowledge—*knowledge of instructional strategies*, *knowledge of the science curriculum*, and *knowledge of students' science conceptions* to understand development in Lee's and Alice's pedagogical content knowledge. I traced changes in each category of pedagogical content knowledge by looking for evidence of the following knowledge integration processes for teachers (Linn & Hsi, 2000): (a) adding new ideas to their repertoire, (b) sorting ideas, (c) reconciling ideas that appear contradictory, and (d) integrating preexisting and new ideas. In the Scaffolded Knowledge Integration framework—SKI, learners are viewed as adding ideas to their repertoire of models and reorganizing their knowledge (Linn, 1995; Linn, Eylon, & Davis, 2004; Linn & Hsi, 2000). The SKI framework features four tenets to promote knowledge integration: (a) making thinking visible for learners, (b) providing social supports to learners, (c) making science accessible for learners, and (d) promoting autonomy for lifelong science learning.

To place these findings in perspective I discuss: (a) the effective practices that emerged as a result of Lee and Alice using the WISE technology for three years, (b) the interplay between the teachers' practices and their pedagogical content knowledge, and

(c) the factors that supported the teachers' development. I also describe the possible benefits for others springing from this research.

Teaching Practices Arising from Using WISE

Many researchers agree that teachers benefit from repeated opportunities to teach the same science curriculum from one year to the next (e.g., Fishman et al., 2003; Polman and Pea, 2001; and Slotta, 2004). With effective and transparent materials, teachers can draw on evidence from student work, learn the science, and try out new approaches (Linn & Hsi, 2000). Teachers develop in pedagogical content knowledge—the ideas and practices necessary to teach a specific topic and to promote specific activities when the materials support this effort. In this study, I explored how the teachers used questioning in the context of WISE evidence and students' online notes to elicit students' science ideas on key concepts in the plant curriculum unit. I found that studying teachers' questioning patterns provided a window on teacher understanding of the science. Studying the social context for the questions—the interactions between the teacher and students and the questions—provided intriguing data on how understanding of student ideas develops. For example, in the case of Lee and Alice, studying dialogue enabled me to trace how they learned to teach for depth versus coverage and how they provided students with ample time to reflect on their science ideas. Also, unique elaborations by Lee and Alice created opportunities for both the teachers and the students to sort out their science ideas and achieve common understandings.

At the onset of the WISE *Plants in Space* project, the experienced teacher (Lee) started with goals consistent with an inquiry-oriented approach. His teaching methods became more inquiry-oriented across time as he had repeated opportunities to implement this new technological innovation. Additionally, my ongoing professional support contributed to Lee's development in practice over the three year period.

As discussed in chapter 5, Lee elicited students' science ideas primarily through conceptual questioning as he taught the *Light/photosynthesis* lessons. His teaching strategies became even more conceptually oriented in years two and three. This change can be attributed to: (a) Lee taught the topic for a longer period of time in years two and three, (b) Lee had repeated opportunities to implement an inquiry-based curriculum, (c) Lee had opportunities to reflect on his teaching practice and pedagogical conceptions over the three year time span, and (d) the feedback inherent in WISE enabled Lee to help students make their scientific thinking visible across time. Because some logistical questions are appropriate, Lee asked a small percentage of logistical questions over the three year span to monitor students' progress and to encourage them to stay on task. Lee also integrated technology more deeply over time. For example, in year one, Lee taught the focal topic, *Light/photosynthesis*, as part of whole class and small group reflection, offline only. During the second and third enactment of *Plants in Space*, (i.e., the other key science topic), Lee taught all the science topics in small group online settings during WISE investigations.

On the other hand, Alice, the novice teacher, started with goals consistent with an inquiry-oriented approach, but it still took a year of classroom experience, with substantial professional support, for her to begin asking inquiry questions. In the first year, Alice:

- Learned the "logistical ropes" of using the technology, both procedurally and conceptually

- Gained deeper understandings of the science content from using the curriculum and relying on the researcher plus WISE
- Developed a deeper understanding of the curriculum goals, and of students' goals in relations to the curriculum, by reflecting on her teaching

During the second and third year, Alice trusted WISE to take care of most of the logistical issues, and built on her science knowledge to help students reflect on their ideas. Changes over time in Alice's understanding of how students were conceptualizing the content helped to explain shifts in her pedagogy.

Capitalizing on the capacity of WISE to capture students' results and reflections and provide teachers with detailed accounts of student learning (i.e., students' responses to WISE online note questions), Lee and Alice were increasingly able to help students to make their scientific thinking visible across time through reflecting on science content in WISE evidence.

Interplay between Teachers' Practices and Pedagogical Content Knowledge

As discussed in chapters 5 and 6, as Lee and Alice developed in pedagogical content knowledge, i.e., (a) *knowledge of instructional strategies*, (b) *knowledge of science curriculum*, and (c) *knowledge of students' science conceptions*, their teaching practices became more reflective of their pedagogical conceptions.

The analysis of Lee's and Alice's *knowledge of instructional strategies* showed that they held similar pedagogical conceptions in their first year of teaching WISE. For example, their initial conceptions about strategies to help students understand specific science content and how to assess students' science knowledge in *Plants in Space* were both very general. However, there was one key difference—Alice used *labeling* when referring to her students' perceived achievement levels, while Lee thought deeply about how to assist all students regardless of their achievement level. After their first year of teaching WISE, both Lee and Alice engaged in the knowledge integration process of using questioning as a strategy to help students learn content in *Plants in Space*.

As described in chapters 5 and 6, there were also some differences in their repertoire of ideas. By year three, Alice began to think deeply about how to better assist all students regardless of their achievement level. Lee, being more experienced than Alice, added a new idea to his repertoire in year three, which included taking advantage of another way to give feedback in WISE for reflection purposes. This conclusion was validated by my direct observations of Lee's teaching in the classroom coupled with a review of Lee's online comments to his students in year three.

Findings in chapters 5 and 6 also revealed that Lee and Alice started at very different places in their trajectories of *knowledge of the science curriculum*, but ended up in equivalent places after only three years. Alice began at the implementation phase, whereas Lee was both implementer and co-developer of the WISE *Plants in Space* curriculum. The teachers were most similar in their thinking process in years one and three. Neither Lee nor Alice had any new curriculum ideas to add in year one. They were happy with the current version of *Plants in Space*. However, during the WISE run in year one, Lee ended up designing supplementary classroom activities such as a Language Arts lesson. In their second year of teaching WISE, both teachers made customizations to particular curriculum activities to meet the needs of their classes. Lee implemented the same Language Arts lesson, but also made enhancements (e.g., online assessment) to the WISE software. Alice designed an assessment activity and introduced it offline. In year three, Alice continued to add new curriculum ideas to her repertoire such as creating a Language Arts lesson to supplement a WISE activity. In contrast, Lee integrated ideas within his repertoire, which included reflecting on his past WISE plant curriculum goals and determining his next steps. For example, Lee articulated his reasons for making repeated customizations (i.e., the Language Arts lesson) to the plant unit. It was not until year three that Alice integrated science (referring to the *Plants in Space* unit) as part of the domain of Language Arts.

Lee and Alice increased their *knowledge of students' science conceptions*. However, they conceptualized students' understandings differently in the first year of teaching WISE. Lee articulated examples of students' science conceptions but not within the scope of the *Plants in Space* curriculum. On the other hand, Alice struggled with how to represent students' science ideas in the curriculum. In the second year of implementing WISE, Lee and Alice discussed students' science conceptions within the context of the plant curriculum, including difficult science concepts. Similar to Lee, the role of communication in assessing students' learning (i.e., listening) continued to permeate in Alice's repertoire even as she discussed students' science ideas. However, in year two, Alice began discussing students' science conceptions within a framework of interrelated ideas. Although in year three Alice continued to discuss students' science conceptions with a framework of interrelated ideas, Lee shows more integrated understanding of these ideas.

Factors Supporting Teachers' Development

The evidence presented in chapters 5 and 6 suggests factors that contributed to Lee and Alice's development in knowledge and practice. The teachers' practices and knowledge were influenced by external and internal professional supports. The external factors I consider are the support I provided to the teachers, the opportunities for professional collaboration, and detailed accounts of student learning on WISE. Internal factors emerged as a result of the teachers analyzing their own action (e.g., self-reflection).

Over the course of the three year period, I provided the following social supports to Lee and Alice:

- Scaffolding Lee and Alice in reflecting on their practices and knowledge
- Assisting them with curriculum customizations
- Participating in class discourse during the novice teacher's (Alice) first year of teaching WISE by her request
- Assisting Lee with putting other scaffolds in place to support his learning such as interactions with scientists via the Internet
- Providing technical support—i.e., training the teachers to use the authoring environment and curriculum software in WISE
- Providing technology support—i.e., assisted the teachers in writing a successful grant proposal that provided more networked computers in their classrooms

Collaborative learning situations such as these can provide teachers as well as students with opportunities to offer explanations, interpretations and resolutions supported by a researcher, peer or scientist (e.g., Brown & Campione, 1996; Brown & Palincsar, 1989; Linn & Hsi, 2000).

WISE also provided support to the teachers in this study by providing them with detailed accounts of their students' work and making available to them the capability to respond electronically to students' online work. WISE *Plants in Space* enabled the teachers to interact with their students in small groups about the science content. Therefore, the teachers were able to help students to make their scientific thinking visible across time through reflecting on the science content in the WISE evidence.

Internal professional supports such as self-reflection enabled the fifth grade teachers to reflect on how their students were conceptualizing the science content in WISE across time, which in turn also helped them to make students' scientific thinking more visible.

As the teachers improved in their teaching and understanding, so did their students. Prior to the enactment of the *Plants in Space* curriculum unit in years one through three, evidence showed that students in Lee and Alice's science class held numerous alternative conceptions about the core science topic—*Light/photosynthesis*. Student groups in both teachers' classes performed significantly better in year three, compared to year one, on the WISE online assessment items. For example, students made more links between scientific ideas. The improvement in student understanding across successive years can be attributed to the following changes in the curriculum implementation: (a) the frequency with which the core topic occurred in years two and three in both teachers' science classroom, (b) the increased integrated use of technology by both teachers during the WISE enactment in years two and three, and (c) the increase in science dialogues in years two and three in Lee and Alice's classroom.

Next Steps

Changes in teaching occur sometimes rapidly and sometimes slowly. This case study shows that repeated practice with the same curriculum can improve individual teachers' performance. Teachers need varied forms of support. Professional developers can have the best impact of progress when professional development last for a minimum of 2 years with regular follow-up and reviews of student work to effect change.

A leverage point for professional developers, involves helping elementary school teachers within their classrooms improve their pedagogical content knowledge through (a) adding new ideas to the repertoire, (b) integrating ideas, and (c) reconciling contradictory ideas in the repertoire (Davis, 2004; Linn et al., 2004).

Additionally, through understanding the experiences (including struggles) practicing teachers face across time, and by analyzing their common trajectories as they implement scientific inquiry, the science professional development community can create more systematic initiatives for supporting classroom teachers' professional growth. These learning trajectories can shed light on how teachers make sense of new practices and how their pedagogical conceptions evolve across time.

This study compared and contrasted these two teachers' pathways towards developing new pedagogical practices. A small sample allows analysis of the context in which teachers work, and the way their practices change gradually over time. Generalizing from these cases to the broader teaching community means carefully analyzing new contexts.

The results suggest a number of strategies for supporting improvement in the strategies teachers use when implementing WISE inquiry units. Teachers appear to learn better strategies when a mentor: (a) scaffolds them in reflecting on their practice and knowledge, (b) assists them with WISE curriculum customizations, (c) provides mentoring during a novice teacher's first year of teaching WISE, and (d) assists the teachers with putting other scaffolds in place to support their learning such as interactions with scientists via the Internet. WISE offers the teachers the opportunity to integrate technology (i.e., the World Wide Web) into their classroom practice in a meaningful way.

Finally, the process of change in teachers' practices and pedagogical conceptions begins to emerge only in the second year. Presenting teachers with opportunities to add ideas to their repertoire and to sort out their preexisting ideas requires sustained professional development.

These findings are consistent with the recommendations of other researchers who focus on the role of professional development in instructional improvement (e.g., Ball, 1996). Teachers are increasingly faced with great pressures from the standards and assessments movement, administrative pressures, parents, and so on daily in addition to being responsible for educating approximately 20 to 30 students per classroom. As Wilson and Berne (1999) point out, not only do the standards movements (e.g., the National Science Education Standards) call for higher standards for teachers, but new measures of performance for students at the K-12 grade level. Therefore, professional development opportunities for teachers are essential for such reform-oriented initiatives. Science teachers need professional development that (NRC, 1996): (a) provides them with the opportunity to learn science content through inquiry, (b) introduces them to technology, (c) enables them to develop in pedagogical content knowledge, (d) provides them with opportunities to align curriculum and assessment, (e) provides them with opportunities to collaborate with other teachers to evaluate student work, and (f) encourages them to reflect on their practice and knowledge.

The knowledge gained from this kind of research can enable the professional development community in science education to create more systematic initiatives for supporting teachers as they learn inquiry teaching.

REFERENCES

Akerson, V. L., & Abd-El-Khalick, F. (2003). Teaching elements of nature of science: A yearlong case study of a fourth-grade teacher. *Journal of Research in Science Teaching, 40* (10), 1025-1049.

Alberts, B. (2000). Some thoughts of a scientist on inquiry. In J. Minstrell & E. H. van Zee (Eds.), *Inquiring into inquiry learning and teaching in science,* (pp. 3-13). Washington, DC: American Association for the Advancement of Science.

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy.* New York: Oxford University Press.

Ammon, P., & Black, A. (1998). Development psychology as a guide for teaching and teacher preparation. In N. M. Lambert & B. L. McCombs (Eds.), *How students learn: Reforming schools through learner-centered education*, (pp. 409-448). Washington, DC: American Psychological Association.

Ammon, P., & Hutcheson, B. P. (1989). Promoting the development of teachers' pedagogical conceptions. *Genetic Epistemologist, 17*(4), 23-29.

Anderson, C.W., Sheldon, T. S., & Dubay, J. (1990). The effects of instruction on college majors' conceptions of respiration and photosynthesis. *Journal of Research in Science Teaching, 27*, 761-776.

Ball, D. L. (1996). Teacher learning and the mathematics reforms: What we think we know and what we need to learn. *Phi Delta Kappan, 77*(7), 500-508.

Ball, D. L. (2000). Bridging practices: Intertwining content and pedagogy in teaching and learning to teach. *Journal of Teacher Education, 51*(3), 241-247.

Becker, H., Ravitz, J., & Wong, Y. (1999). *Teacher and teacher-directed student use of computers and software.* (No. 3. Teaching Learning and Computing: 1998 National Survey). Irvine: University of California at Irvine, Center for Research in Information Technology in Organization.

Black, P., & Wiliam, D. (1998). Inside the black box. *Phi Delta Kappan, 80*(2), 139-148.

Blumer, H. (1969). *Symbolic interactionism.* Englewood Cliffs, NJ: Prince-Hall.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (1999). *How people learn: Brain, mind, experience, and school.* Washington, DC: National Academy Press.

Brown, A. L., & Campione, J. C. (1996). Psychological theory and the design of innovative learning environments: On procedures, principles, and systems. In L. Schauble & R. Glaser (Eds.), *Innovations in learning: New environments for education*, (pp. 289-325). Mahwah, NJ: Erlbaum.

Brown, A. L., & Palincsar, A. S. (1989). Guided, cooperative learning and individual knowledge acquisition. In L. B. Resnick (Ed.), *Knowing, learning, and instruction*, (pp. 393-451). Mahwah, NJ: Erlbaum.

California Department of Education. (2003).). *Science framework for California public schools: Kindergarten through grade twelve.* Sacramento, CA: California Department of Education Press.

Champagne, A. B., Klopfer, L. E., & Gunstone, R. F. (1982). Cognitive research and the design of science instruction. *Educational Psychologist, 17*(1), 31-53.

Clark, D., & Linn, M. C. (2003). Designing for knowledge integration: The impact of instructional time. *The Journal of the Learning Sciences, 12*(4), 1-23.

Cobb, P., Yackel, E., & Wood, T. (1993). Theoretical orientation. In T. Wood, P. Cobb, & D. Dillon (Eds.), *Rethinking elementary school mathematics: Insights and issues* (*Journal for Research in Mathematics Educations,* Monograph No. 6, pp. 21-32). Reston, VA: National Council of Teachers of Mathematics.

Cognition and Technology Group at Vanderbilt. (2002). Connecting learning theory and instructional practice: Leveraging some powerful affordances of technology. In H. O'Neill & R. Perez (Eds.), *Technology application in education: A learning view*, (pp. 173-209). Mahwah, NJ: Erlbaum.

Cole, M. (1996). *Cultural psychology: A once and future discipline.* Cambridge, MA: Harvard University Press.

Davis, E. A. (2004). Knowledge integration in science teaching: Analyzing teachers' knowledge development. *Research in Science Education, 34*(1), 21-53.

Denzin, N. K. (1978). *The research act: A Theoretical introduction to sociological methods.* New York: McGraw-Hill.

Emerson, R. M., Fretz, R. I., & Shaw, L. L. (1995). *Writing ethnographic fieldnotes.* Chicago: The University of Chicago Press.

Fishman, B. J., Marx, R. W., Best, S., & Tal, R. T. (2003). Linking teacher and student learning to improve professional development in systemic reform. *Teaching and Teacher Education, 19*(6), 643-658.

Grossman, P. (1990). *The making of a teacher: Teacher knowledge and teacher education.* New York: Teachers College Press.

Grossman, P., Valencia, S. W., Evans, K., Thompson, C., Martin, S., & Place, N. (2000). Transitions into teaching: Learning to teach writing in teacher education and beyond. *Journal of Literacy Research, 32*(4), 631-662.

Ladewski, B. G., Krajcik, J. S., & Harvey, C. L. (1994). A middle grade science teacher's emerging understanding of project-based instruction. *Elementary School Journal, 94*(5), 499-515.

Lampert, M. (2001). *Teaching problems and the problems of teaching*. New Haven, CT: Yale University Press.

Leinhardt, G. (1992). What research on learning tells us about teaching. *Educational Leadership, 49*(7), 20-25.

Levin, B. B., & Ammon, P. (1996). A longitudinal study of the development of teachers' pedagogical conceptions: The case of Ron. *Teacher Education Quarterly, 23*(4), 5-25.

Li, A. L. (2002). *Emerging patterns of technology affordances in teacher discourse.* (Report No. IR-021-422). Washington DC: Office of Educational Research and Improvement (ED). (ERIC Document Reproduction Service No. ED 467501).

Linn, M. C. (1995). Designing computer learning environments for engineering and computer science: The scaffolded knowledge integration framework. *Journal of Science Education and Technology, 4*(2), 103-126.

Linn, M. C., Clark, D., & Slotta, J. D. (2003). WISE Design for Knowledge Integration. *Science Education*, *87*, 517-538.

Linn, M. C., diSessa, A., Pea, R. D., & Songer, N. B. (1994). Can research on science learning and instruction inform standards for science education? *Journal of Science Education and Technology, 3*(1), 7-15.

Linn, M. C., & Eylon, B.-S. (1996). Lifelong science learning: A longitudinal case study. *Proceedings of Cognitive Science Society, 1996*, (pp, 597-602). Mahwah, NJ: Lawrence Erlbaum Associates.

Linn, M. C., Eylon, B.-S., & Davis, E. A. (2004). The knowledge integration perspective on learning. In M. C. Linn, E.A. Davis, & P. Bell (Eds.), *Internet environments for science education*, (pp. 29-46). Mahwah, NJ: Lawrence Erlbaum Associates.

Linn, M. C., & Hsi, S. (2000). *Computers, teachers, peers: Science learning partners.* Mahwah, NJ: Lawrence Erlbaum Associates.

Linn, M. C., Shear, L., Bell, P., & Slotta, J. D. (1999). Organizing principles for science education partnerships: Case studies of students' learning about 'rats in space' and 'deformed frogs'. *Educational Technology Research and Development, 47*(2), 61-85.

Linn, M. C., & Slotta, J. D. (2000). WISE science. *Educational Leadership, 58*(2): 29-32.

Loucks-Horsley, S., Hewson, P. W., Love, N., & Stiles, K. E. (1998). Designing professional development for teachers of science and mathematics. Thousand Oaks, CA: Corwin Press, Inc.

Loughran, J., Mulhall, P., & Berry, A. (2004). In search of pedagogical content knowledge in science: Developing ways of articulating and documenting professional practice. *Journal of Research in Science Teaching, 41*(4), 370-391.

Lumpe, A. T., & Staver, J. R. (1995). Peer collaboration and concept development: Learning about photosynthesis. *Journal of Research in Science Teaching, 32*(1), 71-98.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources and development of pedagogical content knowledge for science teaching. In N. Lederman, & J. Guess-Newsome (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education*, (pp. 55-132). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Marx, R., Blumenfeld, P., Krajcik, J., Blunk, M., Crawford, B., Kelly, B., & Meyer, K. (1994). Enacting project-based science: Experiences of four middle grade teachers. *The Elementary School Journal, 94*(5), 517-538.

Myerhoff, B. G. (1980). *Number our days.* New York: Simon and Schuster.

Merriam, S. B. (1988). *Case study research in education: A qualitative approach.* San Francisco: Jossey-Bass.

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

Palincsar, A. S., & Brown, A. L. (1984). Reciprocal teaching of comprehension-fostering and monitoring activities. *Cognition and Instruction, 1*(2), 117-175.

Patton, M. Q. (2002). Qualitative Research & Evaluation Methods. (34d ed.). Thousand Oaks, CA: Sage Publications.

Pedersen, J. E., & Yerrick, R. K. (2000). Technology in science teacher education: Survey of current uses and desired knowledge among science educators. *Journal of Science Teacher Education, 11*(2), 131-153.

Piaget, J. (1970). *Genetic epistemology*. New York: Columbia Press.

Piaget, J. (1980). *Adaptation and intelligence: Organic selection and phenocopy.* Chicago: The University of Chicago Press.

Polman, J. L., & Pea, R. D. (2001). Transformative communication as a cultural tool for guiding inquiry science. *Science Education, 85*, 223-238.

Putnam, R. T., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning? *Educational Researcher, 29*(1), 4-15.

Ragin, C. C. (1987). *The comparative method.* Berkeley, CA: University of California Press.

Roth, J. J. (1989). *Conceptual understanding and higher level thinking in the elementary science curriculum: Three perspectives.* Report No. SE-051-184. Washington DC: Office of Educational Research and Improvement (ED). (ERIC Document Reproduction Service No. ED 315 303).

Schoenfeld, A. H. (1992). Learning to think mathematically: Problem solving, metacognition, and sense-making in mathematics. In D. Grouws (Ed.), *Handbook for Research on Mathematics Teaching and Learning* (pp. 334-370). New York: MacMillan.

Sherin, M. G. (2002). When teaching becomes learning. *Cognition and Instruction, 20*(2), 119-150.

Shulman, L. S. (1986a). Those who understand: A conception of teacher knowledge. *American Educator, 10*(1), 9-15, 43-44.

Shulman, L. S. (1986b). Those who understand: knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review 57*(1), 1-22.

Slotta, J. D. (2004). The Web-Based Inquiry Science Environment (WISE): Scaffolding knowledge integration in the science classroom. In M. C. Linn, E.A. Davis, & P. Bell (Eds.), *Internet environments for science education*, (pp. 203-232). Mahwah, NJ: Lawrence Erlbaum Associates.

Smith, D. C., & Neale, D. C. (1989). The construction of subject matter knowledge in primary science teaching. *Teaching and Teacher Education, 5*(1), 1-20.

Smith, M. S. (2000). Balancing old and new: An experienced middle school teacher's learning in the context of mathematics instructional reform. *The Elementary School Journal, 100*(4), 351-375.

Strauss, A. L., & Corbin, J. (1990). Basics of qualitative research: Grounded theory procedures and techniques. Newbury Park, CA: Sage Publications.

Tharp, R. G., & Gallimore, R. (1988). *Rousing minds to life: Teaching, learning and schooling in social context.* New York: Cambridge University Press.

Weiss, R. S. (1994). *Learning from strangers: The art and method of qualitative interview studies.* New York: The Free Press.

Wertsch, J. V., & Kanner, B. G. (1992). A sociocultural approach to intellectual development. In R. J. Sternberg, & C. A. Berg (Eds.), *Intellectual Development*, (pp. 328-349). New York: Cambridge University Press.

White, B. Y., & Frederiksen, J. R. (2000). Metacognitive facilitation: An approach to making scientific inquiry accessible to all. In J. Minstrell & E. H. van Zee (Eds.), *Inquiring into inquiry learning and teaching in science.* (pp. 331-370). Washington, DC: American Association for the Advancement of Science.

Williams, M., & Linn, M.C. (2002). WISE inquiry in fifth grade biology. *Research in Science Education, 32*(4), 415-436.

Williams, M., & Linn, M. C. (2003). Collaborating with WISE scientists. *Science & Children, 41*(1), 31-35.

Wilson, S. M., & Berne, J. (1999). Teacher learning and the acquisition of professional knowledge: An examination of research on contemporary professional development. *Review of Research in Education, 24,* 173-209.

Wood, T., Cobb, P., & Yackel, E. (1991). Change in teaching mathematics: A case Study. *American Educational Research Journal, 28*(3), 587-616.

Van Zee, E. H., Iwasyk, M., Kurose, A., Simpson, D., & Wild, J. (2001). Student and teacher questioning during conversations about science. *Journal of Research in Science Teaching. 38*(2), 159-190.

APPENDIX

Lesson Plans for the WISE *Plants in Space* Curriculum Unit.

Module I: What Makes Plants Grow?

Introduction

The WISE module—*What Makes Plants Grow?* is a part of a series of plant projects.

This project focuses on the necessary conditions for plants to live and grow in general. The main idea is to explore factors needed to sustain plant life on earth such as light, water, and nutrients.

Curricular Context

We designed this project for upper elementary school. Our learning goals correlate with the state and national standards.

Getting Started With WISE

Allow approximately 1-2 days for setting up student accounts and having a brief discussion around the importance of computers and the Internet, in addition to walking students through the WISE interface.

If this is the first WISE project that your students have every run, there are some initial goals that you might want to implement in early classroom discussions. We suggest the following initial student registration procedures:

- Ask students why we may want to use computers and the Internet for learning about science

- Possibly have a brief discussion about the Internet and how some sites are not as trustworthy as others (i.e., information may be somewhat distorted)

-Help your students register in WISE (can be some what time consuming)

-Walk them through the interface

Note: We recommend that students be assigned in groups of two. After each student has registered in WISE, they can then sign up within their group in the *What Makes Plants Grow?* module. The computer will automatically recall the members of each group, therefore, any student within a group can log into the project.

Activity 1

Classroom Practice

This activity can take approximately 1-2 hours depending on how much time is allocated to project overview and group discussion.

Curriculum Notes

Begin the project by providing your students with an overview of the project and allow them to participate in a "hands-on" demo of the activity structure. When the students first enter the project, they will be provided with a brief overview. Encourage the students to read it carefully for reinforcement purposes.

"Introduction" is the first WISE activity. It introduces the students to the project. Ask your students to think about what plants might need in order to live and why.

"What do you think about plants?" Ask them to click on this step and a note screen will appear for the students to make their predictions.

"Plants are fascinating organisms" is the last step in activity 1. Instruct your students to read the evidence carefully. They will then be asked to write an evidence note.

Activity 2

Curriculum Notes

This activity can be done within 1 hour or less. This is an excellent time to have the students to begin consulting with an expert either before or after the **"Soil for Supper"** activity.

In the **"Soil for Supper"** activity, students will predict what they think plants use to grow and see if they will change their minds by the end of the activity. There are five inquiry elements in the **"Soil for Supper"** activity. Assist the students in focusing on the *"Brain Warm-up"* element. As students critique the Van Helmont evidence, walk around and talk to them about it. At the end of the story, the students are provided with a brief synopsis of the story in today's language. Have your students take an evidence note when they finish reading and critiquing the evidence (Van Helmont Story) with their partners.

Bring the class together as a whole group and have a discussion on the **"Soil for Supper"** activity.

Activity 3

Classroom Practice

In this activity, we suggest that you allow the students to critique one to two pieces of evidence per day (for approximately 1 hour), which includes taking notes on the evidence, taking part in whole class discussions, participating in the online discussion, and getting hints from Amanda the Panda.

Curriculum Notes

The **"So What Does a Plant Need in order to Grow?"** activity requires students to explore factors needed to sustain plant life on earth such as nutrients, sunlight, and water. Students will also survey evidence that provide information on plants ability to grow in water alone, which is referred to as hydroponics.

Each piece of evidence introduces a new factor that will inform the assembly of their hydroponic garden. After each evidence page, students are asked to take notes about important ideas in the evidence.

Evidence include:

- Fascinating photosynthesis
- Do plants need nutrients?
- What do roots do for plants?
- Is there different ways to grow plants?
- More Photosynthesis

Allow for whole and small group discussion time on the various pieces of evidence. Encourage students to discuss with their partners how the needs of plants are similar to what their own bodies require in order to grow.

Special Notes

Below is a list of optional questions for you to discuss with your students regarding the above evidence critiqued:

- What are the benefits of growing plants hydroponicly?
- Since soil provides plants with nutrients and support for their roots, how could one account for this when using a hydroponic system?
- Why do you think plants having the correct balance of nutrients are important?
- What could happen to humans if they do not have light?
- Why is water necessary for plant growth and development?

Activity 4

Classroom Practice

This activity called **"Sharing What We Know"** is an optional activity to enable you to assess your students' progress before preceding to the science WISE project, *How do Earth and Space Plants Grow?* Allocate approximately 30 minutes for students to complete the "Assessment" activity.

Curriculum Notes

The assessment questions consist of multiple choice questions and a short essay. Please encourage students to provide as much detail as possible when answering the essay questions.

Activity 5

Classroom Practice

You can introduce this activity at any point during the course of the project. It is optional whether you allow your students to visit the online discussion on an ongoing basis or participate in it at the end of the project. Allow students to ask questions, raise issues, and solicit comments during and online discussion forum.

Curriculum Notes

During this activity, students can consult with the teacher, another class, a scientist or even fellow classmates.

Instruct your students to begin the online discussion by clicking on the discussion icon. Remind the students that the discussion topic is called **"Plants Are All Around Us"**.

Students are presented with the following questions:

- Can plants where you live grow in the desert?
- Why or why not?"

Module II: How Do Earth and Space Plants Grow?

Introduction

This is the second project in the *Plants in Space* Curriculum unit.

In this project, students will investigate different conditions for growing plants in space and growing plants on the earth. They will perform hands-on activities that involve creating an indoor garden, and sprouting two kinds of plants--regular earth plants (radishes) and AstroPlants (a type of Wisconsin Fast Plant™).

Students will be asked to predict which of their plants are Fast Plants and which of their plants are earth plants after thinking about the differences between the two species of plants. This will involve observing plant growth and development daily, and collecting and analyzing the data.

The main goal for this project is for students to design a plant growth chamber to simulate the space environment. In order to design a plant habitat, students have to determine which crop (earth plants or AstroPlants) is best suited for accompanying NASA scientists on an imaginary space flight mission.

Curricular Context

We designed this project for upper elementary school. Our learning goals correlate with the state and national standards.

Getting Started With WISE

Allow approximately 1-2 days for setting up student accounts and having a brief discussion around the importance of computers and the Internet, in addition to walking students through the WISE interface.

If this is the first WISE project that your students have every run, there are some initial goals that you might want to implement in early classroom discussions. We suggest the following initial student registration procedures:

-Ask students why we may want to use computers and the Internet for learning about science

-Possibly have a brief discussion about the Internet and how some sites aren't as trustworthy as others (i.e., information may be somewhat distorted)

-Help your students register in WISE (can be some what time consuming)

-Walk them through the interface

Note: We recommend that students are assigned in groups of two. After each student has registered in WISE, they can then sign up within their group in the "How do Earth and Space Plants Grow" module. The computer will automatically recall the members of each group, therefore, any student within a group can log into the project.

Activity 1

Classroom Practice

Allow approximately 10-15 minutes to discuss the project goal with your students. Then allow another 15-30 minutes or so for students to complete the remaining steps within this activity.

Curriculum Notes

Begin the project by providing your students with an overview of the project and allow them to participate in a "hands-on" demo of the activity structure. When the students first enter the project, they will be provided with a brief overview. Encourage your students to read the introductory text carefully.

Also in this activity, students will be exploring the life cycle of AstroPlants and earth plants.

"Comparing life cycles" is the first WISE activity. It introduces the students to the project. In this activity, students will explore the life cycle of AstroPlants and earth plants.

"A little about plants" Ask your students to click on this step and discuss with each other how AstroPlants differ from earth plants.

"Growing earth plants" is the third step in activity 1. Instruct your students to read the evidence carefully. They will then be asked to participate in a discussion with their partners.

The following questions are presented to students:

- Have you ever grown an earth plant (i.e. flowers, lettuce, beans, etc.)?
- What kind of plant did you grow?
- How long did it take for the seed to begin to grow?
- Have you ever noticed that some earth plants sprout faster than others?
- What kind of plants were they?

"What to do" is the last step in activity 1. This step reminds your students that they will be receiving instructions from their teacher on how to set up a hydroponic garden.

Special Notes

You might want to spread this activity out over a two day period. During the first set up day, reemphasize the goal of the project. Allow approximately 30 minutes or more for getting the materials sorted and organized.

Allow approximately 1 1/2 hours during day two for students to construct their experiments. Pairs of students can be combined in larger groups when constructing the three plant growth chambers for the purpose of sharing the responsibilities. Please note that each pair will have two types of plants growing under two conditions (details discussed below).

Directions for setting up a plant growth chamber in your classroom:

- You will need three boxes. Line the interior of each box with foil. Tape the foil down to the boxes (including the inside of the two flaps and the top of the box). Do not place a light fixture in the dark environment. If possible, use a box with a top (line it with foil) for the no light environment (to see how a box can be set up in a dark environment, refer to the last plant growth chamber image at the bottom of the lesson plan page).
- Cut a 1 inch or more diameter hole in the top of the two large boxes that will consist of 12 and 24 hours of light.
- Cut off two of the flaps on one side of the two boxes. The remaining two flaps can be used as a door to open and close the box.
- Use a drop lamp with a 30-watt fluorescent circular light (which can be purchased at stores such as ACE hardware, etc). Insert the light fixture base through the hole in the top of the two boxes that will contain light.
- Masking tape can be used to close the flaps (door) of the boxes.
- Make sure the box that contain 24 hours of light have small holes at the top and around the sides.

Additional instructions for setting up the experiments:

- Give both the earth plants and the AstroPlants a variable (i.e. "A" & "B"- like in the science journal below). Instruct the pairs of students to write the variable for the plant type on the plastic planting labels. Students should put their names and the planting dates on the planting labels, too.
- Fast Plants (i.e. AstroPlants) have extremely fast life cycles. Over time, students will be able to notice substantial differences between the two types of plants. Students are asked to predict which plants are NASA space plants and which plants are earth plants in the "How do Earth and Space Plants Grow" project.

- Ask 1/2 of the pairs of students to plant two AstroPlants seeds in one cell of a quad (refer to picture at the top of the lesson plans page to see what a quad looks like), and two earth plant seeds (e.g. radishes) in one cell of a quad in the no light or 24 hours of light environment.
- Ask all pairs of students to plant two AstroPlants seeds in one cell of a quad, and two earth plants seeds in one cell of a quad in the 12 hours of light environment.

Options for ordering supplies:

Order the "Growing Instructions" manual by Wisconsin Fast Plants for instructions to setting up your hydroponic garden. "Growing Instructions" can be order through Carolina Biological Supply Company. The phone number is 1-800-334-5551. The catalog number is 15-8952.

The following supplies can be order from Carolina Biological Supply Company by phone: quads, AstroPlants seeds, fertilizer pellets, reservoirs, wicks, water mats, plant labels, anti-algal squares, dried honeybees (extension activity on pollination), and piplets. The manual explains how to set up your hydroponic garden. Vermiculite can be used as a medium to support the roots instead of top/potting soil. You can purchase radish seeds or another type of earth plant seed from a local store.

Please note that many of the above supplies might also be purchased locally. You may also have access to some of these materials at your school. Reservoirs (plastic containers similar to shoe boxes) can be purchased at stores like ACE Hardware.

Activity 2

Classroom Practice

This is an optional activity. Allow approximately 5-10 minutes for the students to read about the plant growth chamber experiment.

Curriculum Notes

This activity **"Collecting your data"** reminds students that as they collect their data, remember what they read about light/photosynthesis and other factors that affect plant growth in the first WISE module.

- What do you expect to find with the plants growing without any light?
- Can you tell which is the AstroPlant and which is the earth plant?
- Think about how you are going to create your own journal. Perhaps your teacher will help.

Special Notes

The amount of time students spend conducting observations and recording data in their journals daily is teacher specific.

Remind your students that they will observe their AstroPlants and earth plants daily and record the data in their science journal. This also entails illustrating what the plants look like under different conditions.

It might be most effective to rotate a few groups of students at a time to conduct observations during science instruction time.

Ask your students to click on the step called "Sample journal sheet and questions to think about" step. They can view a sample journal. It might be a good idea to have your students to direct their attention to the online sample journal as you introduce them to the printed journal version.

Click the following link to print out a copy of "My Science Journal". My Science Journal...

This journal is an optional feature.

Activity 3

Classroom Practice

We suggest that you allow students to critique one evidence per day (for approximately 15-20 minutes), which includes taking notes on the evidence, taking part in whole class discussion, participating in the online discussion (optional), and getting hints from Amanda the Panda.

Curriculum Notes

In this activity, students will be critiquing two pieces of evidence pertaining to the conditions of space. They will also be asked to take notes on each piece of evidence. The computer will not allow the students to take notes on a particular piece of evidence until they have read it first.

The following are the "Conditions of Space" evidence list:

- Space in Space...
- Energy is Limited on a Space Shuttle...

Students are asked to critique the **"Space in Space"** evidence and speculate on whether they think the NASA scientists have a lot of space or a small amount of space around them on the shuttle. They are then asked to take an evidence note on the evidence and consider questions such as: (a) Which of your plants do you think would be bigger, the space plants or the earth plants? and (b) If one plant is bigger than the other, does that mean it is growing faster?

The **"Energy is Limited on a Space Shuttle"** evidence page provides information on the type of lighting system astronauts use aboard NASA space shuttles when growing plants. Students are asked: "So, which plants, earth plants or NASA space plants, do you think will grow faster with the fluorescent lights? Why?"

Special Notes

Extending the "Energy is Limited on a Space Shuttle" Activity:

We suggest that you ask your students to revisit the type of lighting system they are growing their plants under (i.e. fluorescent lights) in the classroom. Ask students to explain why a household lighting system (60 watt bulbs) might not be an appropriate type of light source for growing their plants in the classroom and on a space shuttle. You might consider allowing your students to place their hands underneath a classroom lamp and place their hands underneath one of the fluorescent (24 hr or 12 hr lighting environments) lights in their classroom growth chamber. They should be able to feel a difference in temperature. The suggested activities can help students visualize the LED (light-emitting diodes) technology used on NASA space shuttles.

Activity 4

Classroom Practice

We suggest that you demo the **"Graphing data"** activity to the students when first introducing it. Students will revisit this activity on a regular basis (frequency is determined by an individual teacher).

Curriculum Notes

In this activity students will be graphing their data set. Students will be using a special graphing tool that helps them to graph the average plant height each week. Specifically, they will make two graphs, one for each of their plant growth chambers.

Students are provided with the following simple instructions:

> First, you and your classmates should record the height of each plant EVERY DAY in your class science journal.

At the end of the week, we recommend that you ask your students to calculate the average height of each plant type. The special graphing tool (provided in the next two steps) will allow students to graph the height of their plants using rubber stamps that represent different stages of growth—i.e., sprouts, stems, and blooms.

Students are presented with simple instructions for using the graphing tool.

Activity 5

Classroom Practice

This is an optional activity.

Curriculum Notes

This is the final activity in the project, which is called **"My design"**. In this activity, students can create a final presentation using a feature called **"Show and Tell"**. This feature allows students to create a presentation of selective pieces of work completed throughout this project to present to their classmates online. Students can add titles to particular slides if they choose.