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The Development of Prospective Secondary Biology Teachers PCK

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Abstract In order to understand how prospective teachers develop knowledge for teaching, researchers must identify the types of knowledge that are integral to effective science teaching. This case study investigated how 4 prospective secondary biology teachers' science teaching orientations, knowledge of science learners, and knowledge of instructional sequence, developed during a post-baccalaureate teacher education program. Data sources included a lesson planning task and two interview-observation cycles during the participants' year-long internship. Over the course of a year, the participants' science teaching orientations were based primarily on their K-16 learning experiences, and were robust and highly resistant to change. The prospective teachers became more aware of student learning difficulties, and therefore, developed more elaborated knowledge of the requirements of learning. They consistently sequenced instruction in ways that gave priority to transmitting information to students. Prospective teachers' development of knowledge of student understanding of science and instructional sequence were congruent with their science teaching orientations. Implications are given for teacher education and future research.

Keywords Instructional sequence · Knowledge of learners · Learning cycle · Pedagogical content knowledge · Teacher knowledge

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Introduction

One of the difficulties teachers face in learning how to teach in reform-oriented ways is that this new practice is very different from what teachers experienced as science learners (Adams and Krockover 1997; Davis et al. 2006). Researchers have identified that learning to teach science is a complex process where prior knowledge and experiences shape the development of new knowledge (Russell and Martin 2007). For example, Lortie (1975) argued that experiences in K-16 science courses (what he called the apprenticeship of observation) ground prospective teachers' beliefs about teaching and learning at the onset of a teacher preparation program. Schön (1983) proposed that prospective teachers build valuable knowledge by focusing on their practice, their current and past experiences, and identifying what works and does not work in the classroom to improve student learning. Thus, one goal of teacher preparation is developing teacher knowledge that is grounded in close observation of their experiences, students, and understanding of educational research versus training prospective teachers to be technicians, who acquire basic, mechanical, teaching skills (Zeichner 1993). In order to understand how teachers develop knowledge during teacher preparation, researchers must identify the types of knowledge that are integral to effective science teaching. The purpose of this study is to describe and understand prospective science teachers' knowledge development.

Theoretical Framework

In 1986, Lee Shulman advanced thinking about teacher knowledge by proposing a model that emphasized that teaching requires more than just subject matter knowledge. Shulman claimed that effective teachers use both content and pedagogical knowledge, transforming this knowledge into knowledge for teaching specific topics and referred to this knowledge as pedagogical content knowledge (PCK). A number of science teacher education researchers have used PCK as a theoretical framework to understand science teacher knowledge for teaching (Friedrichsen et al. 2009; Friedrichsen and Dana 2005; Loughran et al. 2004; Magnusson et al. 1999; Van Driel et al. 1998, 2002). Shulman (1986) proposed that in order to investigate teacher knowledge, 'scholars must necessarily narrow their scope, focus their view, and formulate a question far less complex then the form in which the world presents itself in practice' (p. 6). This study aim to investigate prospective science teachers' knowledge development at the subject specific level (see Veal and MaKinster 1999) for three knowledge components emphasized in the Magnusson et al., PCK model (orientations, knowledge of learners, and knowledge of instructional sequence).

Conceptual Framework for Knowledge of Instructional Sequence: 5E Instructional Model

In our teacher preparation program, reform-oriented science teaching is promoted through the use of an exploration before explanation sequence of instruction as advocated by the learning cycle and 5E model of instruction. The learning cycle sequence of instruction is a robust instructional approach supported by extensive research that consistently shows the sequence of instruction impacts student learning (Abraham and Renner 1986; Johnson and Lawson 1998; Marek and Methven 1991; Purser and Renner 1983; Renner et al. 1988; Schneider and Renner 1980). The 5E model of instruction is a student-centered approach designed to help teachers improve their instructional practices (Bybee et al. 2006; Bybee 1997) and originated from the *Science Curriculum Improvement Study* (SCIS) curriculum (Karplus and Thier 1967). The 5E Instructional Model includes the following phases: engage, explore, explain, elaborate and evaluate (Bybee 1997). The middle three phases of the model, explore, explain, and elaborate, parallel the three stages of the SCIS learning cycle: exploration, concept introduction, and application. The engage phase focuses on motivating students to learn the science concept and assessing students' preconceptions. The evaluation phase is the culminating experience for the learner and is an opportunity for the student to reflect on his or her own learning. Thus, the 5E instructional model retains the essence of the original learning cycle—exploration before concept introduction, allowing students to experience the phenomenon before constructing explanations with the teacher's support.

Literature Review

The literature review is organized in the following sequence: (a) prospective teachers' science teaching orientations (b) prospective secondary science teachers' knowledge of students' understanding of science, and (c) prospective teachers' PCK for instructional sequence.

Science Teacher Orientations

In the Magnusson et al., PCK model, science teaching orientations are defined as 'a teacher's knowledge and beliefs about the purposes for teaching science at a particular grade level' (Magnusson et al. 1999, p. 97). Researching science teaching orientations was catalyzed, in part, by the broader literature on prospective teachers' beliefs about teaching and learning (Calderhead 1986; Da-Silva et al. 2006; Kagan 1992; Lortie 1975; Nespor 1987; Pajares 1992). Borko and Putnam (1996) proposed teacher beliefs act as a 'conceptual map' that guides instructional decisions and practice. Bryan and Atwater (2002) identified that a significant relationships exists among teacher beliefs and teaching practices. Indeed, a substantial body of research suggests that teachers' knowledge and beliefs have a profound impact on all aspects of their teaching (Ball 1991; Carlsen 1991; Davis et al. 2006; Nespor 1987).

In studying the factors that contribute to the development of teachers' science teaching orientations, researchers have investigated background experiences, teacher preparation, and teaching experience. A few researchers have investigated the influence of a teacher preparation program on the development of prospective secondary science teachers' orientations (Koballa et al. 2005; Lemberger et al. 1999; Marion et al. 1999). Lemberger, et al. (1999) studied prospective secondary science teachers' conceptions of science and science teaching. The teacher preparation program did little to change these conceptions (orientations) of teaching and learning. Koballa et al. (2005) identified five 'conceptions' about science teaching held by prospective secondary science teachers in an alternative certification program. Similar to Lemberger et al., Koballa et al. reported that teachers were reluctant to change their conceptions of teaching science during the teacher preparation program. In the literature the construct of science teaching orientations is messy (Friedrichsen and Dana 2005) and further research is needed to bring clarity to this construct. Friedrichsen et al. (2011) reviewed the literature on teacher beliefs and science teaching orientations, and recommended that science teacher orientations focus on beliefs about the role of the teacher, the role of the student, views about science, and goals or purposes for teaching science.

Prospective Teachers' PCK for Students' Understanding of Science

This component of the Magnusson et al. (1999) PCK model refers to the knowledge teachers have about the requirements for learning science, approaches to learning science, and areas that students find difficult. Magnusson et al. (1999) described the knowledge of requirements for learning refers to teachers' knowledge of 'variations to students' approaches to learning' (Magnusson et al. 1999, p. 104).

Some research suggests that prospective secondary science teachers are focused on themselves (i.e., their knowledge, experiences, and teaching) when preparing lessons and do not think deeply about student learning or the difficulties students face learning new content. De Jong (2000) and De Jong and Van Driel (2001) investigated prospective chemistry teachers concerns about student learning when planning and teaching lessons. De Jong (2000) reported that prospective teachers were concerned about their own knowledge and how they would teach the relationship between concepts of bond-energy and temperature change. Very few of the prospective secondary science teachers voiced a concern with student learning. In another study, De Jong and Van Driel (2001) investigated prospective chemistry teachers' knowledge of the difficulties students would face with the lesson they had planned before and after teaching the lesson. Before the lesson, less than half (3 of 8) students mentioned concerns about student difficulties with the lesson. Research by Geddis and Roberts (1998) found that their participants' strong commitment to transmitting the content to students through lectures left little room for the consideration of student learning. In a study of 12 prospective Malaysian physics teachers' PCK, Halim and Meerah (2002)reported that many participants were unable to identify misconceptions students might have learning physics concepts and thought students would have few difficulties with the lesson they had planned.

Researchers have found that teaching experience and teacher preparation courses can influence prospective secondary science teachers' PCK for learners (Davis et al. 2006; Russell and Martin 2007; Tabachnick and Zeichner 1999; van Driel et al. 1998, 2002). Tabachnick and Zeichner (1999) investigated how an action research seminar influenced prospective science teachers' knowledge of students' prior conceptions. They found that, over time, prospective teachers were able to elicit students' prior knowledge, but the teachers struggled to use this information to plan their instruction. Two studies by Van Driel et al. (1998, 2002) indicated that prospective secondary science teachers predict few learning difficulties when initially designing science lessons but develop PCK for learners when they teach their lessons.

Beginning Teachers' PCK for Sequence of Instruction

Magnusson et al. (1999) conceptualized knowledge of instructional strategies as being comprised of two different sub-components: 'knowledge of subject-specific strategies' and 'knowledge of topic-specific strategies.' Magnusson et al. (1999) described subject-specific strategies as 'broadly applicable; they are specific to teaching *science* (italics in original) as opposed to other subjects' and knowledge of topic-specific strategies as 'much narrower in scope; they apply to teaching particular *topics* (italics in original) within the domain of science (p. 110).'

Research on beginning teachers' knowledge of the learning cycle and the 5E instructional model is limited to studies at the elementary and middle school level. Odom and Settlage (1996) assessed prospective elementary teachers' understanding of the three phases of the learning cycle using a two-tiered test, the Learning Cycle Test (LCT). The researchers concluded that despite students learning about the learning cycle in methods classes, they lacked an understanding of the purposes and activities used in each of the phases of the learning cycle. In a follow-up study, Settlage (2000) investigated prospective elementary teachers' confidence toward using the learning cycle approach using a pre/post Self Efficacy Test and the LCT. The prospective teachers experienced the learning cycle as learners, observed learning cycle lessons being taught, and taught lessons using the learning cycle. As a result, Settlage reported prospective teachers' self-efficacy toward using the learning cycle increased and their anxiety about teaching science decreased. Additionally, he found a positive relationship between prospective teachers' performance on the LCT and their beliefs about their abilities to influence their future students' learning.

Duran et al. (2004) investigated 25 middle level prospective teachers' perceptions of a newly designed, reform-oriented physics course. The authors reported students struggled with the constructivist nature of the course as the instructors sequenced instruction in a way that differed from the students' prior science learning experiences. Students thought the workload was much greater than in traditional courses. The students resisted learning science concepts through the 5E instructional model and inquiry, and preferred to have the instructors give them the correct answers. Additionally, the participants believed they would not be able to design lessons based on the 5E instructional model from this experience alone. The students thought they needed additional specialized courses that blended content with pedagogy in order to design and implement lessons using the 5E instructional model. These findings suggest the shift from traditional lectures to the 5E instructional model takes time and commitment on behalf of both prospective teachers and science educators. Research, particularly at the secondary level, is needed to understand how to foster the transition from traditional transmission of content via lectures to the use of inquiry-based instructional strategies (e.g., the 5E instructional model).

Research Questions

The research questions that guided this study are: (1) What are prospective teachers' science teaching orientations, knowledge of students' understandings of science, and knowledge of instructional sequencing, throughout a teacher certification program?; and (2) In what ways do prospective secondary teachers' science teaching orientations, knowledge of students' understandings of science, and knowledge of sequencing of science instruction interact over time?

Research Design

This is a longitudinal, multiple case study of four prospective biology teachers' PCK development during a post-baccalaureate teacher education program, with each teacher representing a single case of PCK development. To better understand these teachers' development of knowledge, we describe the unique contextual settings of the program, participants, data collection, and data analysis.

Context

The participants enrolled in a post-baccalaureate science teacher preparation program, STEP, (Demir 2006) designed for individuals who desired a science-specific teacher preparation program in an accelerated time frame. All participants had undergraduate degrees in biology. The prospective teachers attended a concentrated, 8-week summer block of introductory education courses. During the school year, they were teaching interns at partner high schools (20 h per week), and enrolled in additional campus-based coursework, including a sequence of three Secondary Science Methods courses. Although the courses also emphasize inquiry-based (see Demir 2006) and a conceptual change approach to science teaching and learning and the nature of science, each of the three science methods course instructors emphasized the use of the 5E instructional model, having specific course goals and activities related to its use (Bybee 1997). (see Table 1).

Participants

In case studies, researchers often use a purposeful sampling approach to identify cases they view to be 'information-rich' (Patton 2002). Four prospective secondary biology teachers participated in this case study, three females and one male. The participants' pseudonyms are Mary, Amy, Lilly and Jason. We purposefully selected these individuals for several reasons. First, they represent the majority of our STEP students in being recent graduates with baccalaureate degrees in biology. Second, these four individuals agreed to participate in the study and were reflective of their teaching practice. Third, the first two authors are former high school biology teachers and could draw on their background experiences during data collection and analysis. Therefore, these four participants were purposefully selected as

Table 1 Secondary science methods instructors course goals and activities related to the 5E instructional model

Course (semester, year)	Course goals related to the 5E	Course activities related to the 5E
Secondary science methods I course (summer, 2007)	Students will become familiar with the phases of the 5E instructional model	Introduced to the phases of the 5E Experienced three 5E units as science learners (i.e., nature of science, parachutes, and NIH inquiry module) Read and reflected on science learning through a 5E instructional model (Bybee 1997)
Secondary science methods II course (fall, 2007)	Students will develop a working understanding of the design and rationale of the 5E instructional model	Experienced two 5E science units as learners (i.e., Bernouilli's principle, osmosis) Designed and taught science lessons for the engage, explore, and explain phases of the 5E Engaged in discussions about the purposes of the 5E phases
Secondary science methods III (spring, 2008)	Students will design a curriculum unit using the 5E instructional model. The design of the unit will be informed by current learning theory, the National Science Inquiry Standards, and the State Science Education Standards	Experienced one 5E unit as science learners (i.e., Moon Unit) Designed and taught a 1-week science unit based on the 5E instructional model in their internships

'information rich' cases because they could provide insight for understanding the development of biology teachers' PCK.

Data Collection

We collected data during the first three semesters of the post-baccalaureate science teacher certification program, STEP. To document incoming PCK, we administered a lesson-planning task based on the van der Valk and Broekman (1999)lesson preparation method, a data collection method that numerous researchers have used to investigate teachers' knowledge about teaching science content at a specific grade level (Friedrichsen et al.2009; De Jong et al. 1999; Frederik et al. 1999). Participants designed two 50-min lessons that could be used to teach 8th graders addressing the following standard from our state's science standards, 'There is heritable variation within every species of organism.' Following the lesson planning task, we conducted a semi-structured interview (Patton 2002; Seidman 1998) with each participant. In the larger research project investigating teacher knowledge using the Magnusson et al. model, we designed the interview protocol to elicit prospective teachers' knowledge of each of the PCK components. For this study, we report only the data related to their science teaching orientations, knowledge of learners, and knowledge of instructional sequence. At the end of the first summer of the STEP program, we conducted a second semi-structured interview to allow the prospective teachers to review, reflect on, and change their initial lesson plan based on what they learning during their summer coursework.

We carried out two interview-observation cycles during the participants' internships in local schools, one in each of the fall and spring semesters. Each cycle included a pre-observation interview, 2 consecutive days of field observations that were video-recorded, and two stimulated-recall interviews using video clips of the prospective teachers teaching (Friedrichsen et al. 2009). For the larger research project, the interviews were designed to elicit teacher knowledge and promote reflection in each of the PCK components. For this study, we report the interview data related to science teaching orientations, knowledge of learners, and knowledge of instructional sequences, much like the first summer interview. During the two stimulated-recall interviews, short video-clips from the teaching observation were viewed to promote discussion and reflection about the participant's teaching and their PCK development. Researchers drew upon the classroom observations to probe more deeply during the semi-structured interviews. In Table 2 we provide a timeline of data collection, including the instrument used to collect data, and representative questions and topics used to elicit prospective teachers' science teaching orientations, knowledge of learners, and knowledge of instructional sequence.

In case studies, researchers use multiple data sources to construct a holistic and meaningful representation of personal experiences (Denzin and Lincoln 2005). The primary data sources for this case study were interviews transcripts, and the secondary data included field notes, lesson plans, and classroom documents.

Data Analysis

In this study, we define a case as one prospective teacher's development of knowledge for teaching over time. We constructed the cases in two steps. All of the authors read the interview transcripts and the first author coded the interview transcripts using qualitative data analysis software, NVivo 7. The coding scheme consisted of three major categories based on the Magnusson et al. (1999) PCK model: (a) science teaching orientations, (b) knowledge of learners, and (c) knowledge of instructional sequences. Within each major category, sub-codes were created as follows: for orientations by drawing on Friedrichsen et al. (2011); for knowledge of learners by using Magnusson et al.'s (1999) definitions; and for knowledge of instructional sequence by using the 5E sequence of instruction (Bybee 1997) and Abraham's (1992) categories for types of instruction (e.g., verify, inform, practice) (see Table 3) .

The process of constructing cases occurred in multiple steps. After the initial coding, the first author wrote a summary profile (within case analysis) for each participant. The profiles were written as a narrative and included evidence from multiple data sources (e.g., interview transcripts and lesson plans) and multiple verbatim quotes fundamental to describing the four prospective teachers' knowledge at each point in time. The other two authors checked the profiles to help triangulate data sources. Thus, we achieved triangulation through multiple data sources (Yin 1994), as well as through multiple researchers (Denzin and Lincoln

Table 2 Representative semi-structured interview questions

Time	Instrument	Examples of questions and topics
Entry	Lesson preparation task	What do you want students to learn?
		What will occur during the beginning, middle, and end of each class?
		What are the teacher and student roles?
		What the materials you will need?
		Include any handouts or slides you plan to use.
	Entry task interview	What do you think students will already know about this topic?
		Do you expect students to have difficulty with anything that you have planned (why)?
		From your plan, it appears that you chose to organize the class as (i.e., lecture, experiment, investigation). Talk to me about making that decision.
		Where did you learn about how to teach this way?
		Did you consider organizing the classes in a different way (why/why not)?
End of summer	End of summer interview	Would you make changes to the purpose of the lesson? why/why not?
		Would you make changes to the instructional style of the lesson (e.g. more exploratory, more teacher-directed?)? why/why not?
Fall/spring semester	Post-observation interview	How do you think this particular group of students learn math/science best (why do you think that)?
		How have your experiences with these students influenced the way you teach?
		From your plan, it appears that you chose to organize the class as (i.e., lecture, experiment, investigation). Talk to me about making that decision.
		Where did you learn about how to teach this way?
		Did you consider organizing the classes in a different way (why/why not)?
	Stimulated recall interview	In general, how would you describe your teaching style?
		To what degree, did your instruction reflect your preferred teaching style? Explain
		What do you think is the teacher's role in a typical lesson?
		What do you think is the students' role in a typical lesson?

2005). In the second phase of data analysis, we conducted a cross-cases analysis of the four participants, examining the data set for patterns and themes. In case study research, the process of generating assertions and drawing conclusions from evidence is facilitated by identifying common themes and patterns (Miles and Huberman 1994). The first author generated tentative assertions for each of the three selected PCK categories: teaching orientations, knowledge of students' understandings of science, and knowledge of instructional sequences. We tested these tentative assertions during group research meetings, with all authors checking the data for confirming and conflicting evidence.

Table 3 Coding categories for teachers orientations, knowledge of learners, and instructional sequence

Categories	Codes	Descriptions
Orientations	Goals	The participant's intentions, aims, and purposes related to math, science, teaching, and learning
	Teacher's role	The participant's views of his/her role in the classroom
	Students' role	The participant's views of the students' roles in the classroom
	Views of teaching and learning	The participant's views of "how they expect to teach"
Knowledge of learners	Requirements for learning specific science	The participants views of how students learn science
	Areas that students find difficult	The participant's views of topics, strategies, and activities students find troublesome for learning
Sequence of instruction	Inform	Transmit content to students
	Practice	Rehearse content presented during lectures and teacher-led discussions and apply new knowledge in other contexts
	Review	Remind students of content covered during previous classes
	Focus	Introduce topics that will be covered during class
	Investigate	Collect data about content covered in subsequent lessons
	Elaborate	Use prior experiences and knowledge to manipulate a variable during lab
	Evaluate	Assess student understanding of science content based on experiences collecting data and knowledge from class

Interpretations

In this section we present four cross-case assertions describing the major themes common across the four cases.

Assertion 1: The prospective teachers' science teaching orientations were based on their K-16 learning experiences and other background experiences. Incoming science teaching orientations were robust and highly resistant to change during the teacher preparation program.

All four teachers held teaching orientations shaped by their background experiences as K-16 students and youth mentors. The prospective teachers entered the secondary teacher preparation program with science teaching orientations primarily influenced by their experiences as students. For example, at the beginning of the program, Mary explained that she always been taught science in a traditional, 'delivery' mode. She said, 'The majority of my classes it was a lecture for x amount of time, and usually it was, at minimal, for 15 min of lecture' (Mary, Entry Task Interview). In describing her views of teacher and student roles, Mary believed she should focus on transmitting knowledge through lectures. She said, 'I'm most comfortable with lectures because when they come back here [laboratory] you may lose control of them' (Mary, End of Summer Interview). Based on Amy's K-16 experiences, she also thought her role as a teacher was to deliver content to students.

Amy commented, 'I would be satisfied if I was able to cover all of the material on the lesson plan for the day and had time for discussion at the end' (Amy, Entry Task Interview). Lilly also focused on her responsibilities during instruction, and believed that students have a passive role in the classroom as she explained; she must 'maintain the fact that you are the one who's in charge.' (Lilly, End of the Summer Interview). These three prospective teachers (Mary, Amy, and Lilly) were similar in that they were highly committed to the view that science teaching is transmitting knowledge to students based on their past K-16 experiences learning science that were largely teacher-centered.

At the beginning of the STEP program Jason held an orientation to science teaching that was largely based on his experiences mentoring youth in Young Life, a Christian ministry, and from his K-16 school experiences. Jason was successful using discussions in Young Life to help students discover life lessons. However, he experienced delivery modes of instruction as a K-16 student. Jason held competing conceptions based on these background experiences. Ideally, he hoped he could guide students, through discussions, to discover scientific concepts on their own. At the beginning of the program, Jason said: 'My facilitation of classroom discussion and questioning would lead my students to learn ideas on their own in hope that it would become real and that their discovery is what is leading their learning' (Jason, Entry Task Interview). From watching his K-16 science teachers, Jason believed he needed to use teacher-led discussions to provide students with new terms and concepts. Because of his experiences in Young Life and his contrasting experiences as a student, Jason held competing conceptions of teaching and learning. Although the participants gained additional goals and views of the teacher's role, their science teaching orientations were robust and did not change significantly throughout the science teacher preparation program (see Table 4).

Mary, Amy, and Lilly were similar in that they consistently believed that teaching is telling and learning is listening. For example, during the fall semester Amy described her views: 'The role of the teacher is to provide guidance for the daily class activities and to make sure the students are staying on task. You are giving them the materials that they need in order to understand the objective' (Amy, Pre-observation Interview, Fall). During the fall semester Lilly continued to think that science teaching is mostly telling and learning is listening. However, she also learned from her mentor teacher that teachers should help guide students to learn some of the content on their own. For example, Lilly explained how teachers should be both leaders and guides, 'I guess guiding them through the lesson, and they obviously don't have control. I do, giving them material but not just directing the whole time because they are involved as well' (Lilly, Stimulated Recall, Fall Day 1). Near the end of the guided internship, Mary's science teaching orientation had not changed significantly. She strongly held onto the belief that teaching is telling and learning is listening. When she talked about the lessons she had planned for teaching blood circulation, she focused on using lectures to help students learn the new content. Mary commented, 'I was just going to kind of go straight to the meat and start talking about the different parts of the heart…to make sure we are all on the same page' (Mary, Pre-observation Interview, Spring). These three individuals

Table 4 Development of Mary's, Amy's, Lilly's and Jason's orientations to science teaching

Dimensions		Entry	Fall Semester	Spring Semester
Goals	Prepare for future courses (Mary/Amy/Lilly)	→	→	→
	Apply science to their lives (Mary/Amy/Lilly)	→	→	→
	Apply science, discover science knowledge, and prepare students for future classes (Jason)	→	→	→
Views of Teaching and Learning	Teaching is telling, learning is listening (Mary/Amy/Lilly)	→	→	→
	Helping students discover science knowledge to apply to their lives (Jason)	→	→	→
	Providing content through teacher-led discussions and learning is participating in discussions (Jason)	→	→	→
Teacher Roles	Leader (Mary/Amy/Lilly)	→	→	→
	Guide (Lilly)		→	→
	Leader/Guide (Jason)	→	→	→
Student Roles	Follower (Mary/Amy/Lilly)	→	→	→
	Discoverers (Jason)	→	→	→

(Mary, Amy, and Lilly) consistently believed the teacher's role was to lead students who have a passive role (i.e., 'followers') in learning science (see Table 4).

Jason's orientation also did not change significantly. During the secondary teacher preparation program, Jason held two views of teaching and learning: (a) learning is a process of discovering knowledge so students can apply science to life, (b) teaching is providing content through teacher-led discussions and learning is participating in discussions. For example, during the spring semester, Jason explained that his role was to help students be self-directed learners by guiding them to discover science content on their own. When describing his role, Jason said, 'to create that scaffolding that a student needs to learn on their own. I think I have to give them the tools so they can discover and build some background knowledge for them, but hopefully my role is a supporter and guider' (Jason, Stimulated Recall, Spring Day 2). According to these views he believed that the students' role is be open-minded and inquisitive so they discover some science content on their own (see Table 4). For these four prospective secondary science teachers, their strongly held orientations to science teaching were based on their K-16 experiences as students and persisted throughout the yearlong teacher preparation program.

Assertion 2: Over time, prospective teachers became more aware of student learning difficulties, and therefore, developed more elaborated knowledge of the requirements of learning.

At the beginning of the STEP program, the participants were unsure of 8th grade students' prior knowledge of genetics (the topic of the entry lesson planning task); yet, they all believed they could help students learn science by relating new content to students' life experiences through lectures and teacher-led discussions. These were strategies they observed their high school and college professors use to help students learn science. For example, Mary thought students might be familiar with the term 'DNA' and she planned to teach heredity by using teacher-led discussions to relate to students' experiences with crime solving television shows. Amy thought students had been exposed to heredity in previous science courses, and she planned to help students learn genetics by showing them how to construct a family tree. Lilly believed students did not have much experience learning biology. She planned to help students learn heredity by: (1) using an analogy that video game codes are like alleles and traits, and (2) showing how mixing different colors of paint is similar to the inheritance of dominant and recessive alleles. (Lilly's paint representation is problematic because it supports a misconception that genetic traits are blended.) Based on his experiences mentoring youth in Young Life and his own K-16 experiences, Jason entered the STEP program with an understanding that learning is dependent on a number of factors and believed he could help students learn science by using 'discussions' which encouraged student participation. He planned on using 'discussions' to go back and forth between asking questions, eliciting student ideas based on their experiences, and introducing new terminology and concepts. Each of these participants thought they could help students learn science by relating to students' experiences either through lectures or discussions.

After 11 weeks in the STEP program, Mary, Amy, and Lilly realized that relating the content to students' life experiences would not be enough to help students learn science. Their ideas expanded as a result of their experiences in the secondary science methods courses. For example, Mary still believed that learners need lectures, but she learned from the secondary science methods courses that students also needed to 'discover' content on their own and 'engage in group work.' In the Secondary Science Methods courses, Amy learned that students need to make observations of phenomena, investigate scientific questions by collecting data, and have collaborative opportunities to teach each other. Lilly believed that, regardless of students' prior knowledge, she could help them learn by lecturing and by having students manipulate variables during confirmatory-type laboratories that occurred after the lectures. Jason found that the ideas proposed about learners in the Secondary Science Methods courses strongly reinforced his initial conceptions about students 'discovering' science on their own and making evidence-based explanations about science phenomena.

Over time, the prospective teachers developed a growing awareness of student difficulties and broadened their knowledge of the requirements for science learning. Each participant added to his/her knowledge of learners while retaining prior conceptions of students' needs. Mary, for example, believed lectures are fundamental for learning, but that teachers frequently need to provide multiple exposures to the material as well as group work to help students commit new terms to memory. When Mary developed her unit on the heart, she provided students with multiple opportunities to practice tracing blood flow through the heart. Likewise, prior to developing her cloning unit, Amy realized her students had trouble comprehending all of the information presented in her lectures. During the fall semester Amy thought that learning begins when the teacher tells students information that connects the content to students' prior experiences. She commented:

> Most of this biology stuff is new to them so I feel like we have to start from the beginning …. But once we start giving them information, they pick it up really quickly and they're able to apply new knowledge to the old knowledge. (Amy, Pre-observation Interview, Fall)

Like Mary and Amy, Lilly primarily used lectures to teach science content. She knew from working with students and her mentor teacher that students needed multiple exposures to material to commit terms and concepts to memory. In Lilly's spring semester lessons on the biochemical evidence for evolution, she used PowerPoint slides to lecture, and then provided students with multiple opportunities to compare and contrast different organisms' amino acid sequences. Lilly described the importance of providing multiple exposures and repetition so students could commit vocabulary to memory:

> I think that helps because any time you're trying to learn something, hearing about it over and over; reading about it; doing activities; working with it; you're naturally just gonna understand it better. (Lilly, Stimulated Recall, Spring Day 1)

During the study, Jason also developed additional ideas about learners. Similar to the other participants, Jason learned from his mentor teacher that students need multiple opportunities to practice new terms in order to commit them to memory. During the spring semester Jason designed a lesson with independent student investigations as a way for students to 'discover' science content on their own. Jason was able to combine his ideas about discovery learning and evidence-based explanations to create a more sophisticated idea about how students can learn science content on their own. In this regard Jason commented, 'Students have a much better understanding when they have to make claims based on evidence … they learn more about the scientific method and discovery' (Jason, Stimulated Recall, Spring Day 2). Jason believed that students could discover some science content own their own if they had experiences making scientific claims based on data and evidence they have collected.

As the participants gained teaching experience, they developed a growing awareness of students' difficulties and consistently focused on students needing lectures and teacher-led discussions to learn science. Table 5 indicates what prospective teachers focused on across time.

Assertion 3: Prospective teachers consistently sequenced instruction in ways that gave priority to transmitting information to students.

At the beginning of the STEP program, all four participants planned to use an instructional sequence aimed at providing new information to students using 'inform' types of instruction. The participants believed science learning begins when the teacher transmits knowledge to students. The other activities they planned were dependent on the knowledge provided during 'inform' types of instruction and included: (1) 'review' types of instruction to remind students of content previously

Table 5 Development of prospective teachers' knowledge of students requirements for learning science

Participant	Entry	End of summer	Fall/spring semester
Mary	Lectures	Lectures	Lectures
	Connections to life	Connections to life	Not mentioned
		Discover new ideas on their own	Not mentioned
			Not mentioned
		Group work	Hands-on
			Multiple exposures to new content
			Collaborative experiences
Amy	Teacher-led discussions	Teacher-led discussions	Teacher-led discussions/lectures
	Connections to life	Connections to life	Connections to life
		Hands-on experiences	Hands-on experiences
		Making observations of phenomena	Not mentioned
			"Peer teaching" experiences
Lilly	Teacher-led discussions	Teacher-led discussions	Teacher-led discussions
	Connections to life	Connections to life	Connections to life
		Repetition	Not Mentioned
		Make scientific decisions	Making scientific decisions
			Multiple exposures
			Evidence-based experiences
			Hands-on experiences
			Connections to previous course content
Jason	Teacher-led discussions	Teacher-led discussions	Teacher-led discussions
	Connections to life	Connections to life	Connections to life
	Discover new ideas on their own	Discover new ideas on their own	Discover new ideas on their own
	Evidence-based experiences	Evidence-based experiences	Not Mentioned
	Connections to previous content	Not mentioned	Connections to previous content
	Collaborative experiences to build knowledge	Not mentioned	Collaborative experiences to build knowledge
			Multiple exposures
			Discover new ideas through evidence-based experiences

covered; (2) 'focus' types of instruction to provide an opportunity for the teacher to motivate and focus students; and (3) 'practice' types of instruction to have students use and rehearse ideas from 'inform' types of instruction through interactions with peers, texts, the teacher, and worksheets. Mary's lesson plans are representative of the participants' entry lesson plans (see Table 6). During the End of the Summer interviews, the participants continued to focus on presenting information to students during 'inform' types of instruction because they believed that learning begins when the teacher lectures or 'discusses' new content.

All four participants' knowledge of instructional strategies developed during the fall and spring semesters. Even though the participants developed additional

Table 6 Mary's lesson plan, day 1 & 2, beginning of summer

Sequence	Activity	Description
Day 1		
Inform	Lecture	Teacher lectures on genetics, DNA, and heritability, dominant versus recessive traits, natural selection, and Punnett squares
Practice	Independent practice	Students practice doing Punnett squares
Inform	Lecture	Teacher lectures and provides more detailed examples of Punnett squares
Practice	Homework	Students do Punnett squares as homework
Day 2		
Review	Review homework	Teacher reviews homework on heritability
Practice	Students collect data	Students count the number of different traits that are prevalent in the class and the number of people who have those traits
Inform	Discussion	Teacher leads a discussion on natural selection and survival of the fittest

instructional strategies, all four participants continued to believe that teaching and learning begin when the teacher tells students new content through 'inform' types of instruction. For example, during the spring semester, Amy included a laboratory investigation in her photosynthesis unit. Prior to the investigation, Amy modeled the lab procedure step-by-step, telling students what data to collect and what results to expect. Amy felt the students would not be successful gathering data unless she told them the results beforehand. On the second day, Amy had students share their lab results, but she did not help students construct their own understanding of photosynthesis based upon their lab data; instead, Amy lectured on photosynthesis without making connecting to the laboratory experience.

In Lilly's diffusion and osmosis unit in the fall semester, she had students manipulate variables in an independent investigation that was part of the 'elaborate' phase of her instruction. However, the placement of the 'elaborate' was based on students' prior knowledge and experiences that included: (1) lectures and teacher-led discussions on diffusion and osmosis, and (2) an 'investigation' where students collected data to verify what Lilly had told students in her previous lectures. Lilly believed that students needed knowledge provided during 'inform' types of instruction to be successful in the 'elaboration.'

During the spring semester, Jason drew on the secondary science methods courses and the 5E instructional model to design his lessons on DNA. However, prior to the interview-observation cycle, Jason used lectures and teacher-led discussions to teach DNA structure and function. Jason believed the order of the 5E phases was unimportant and students needed knowledge about DNA before they could have experiences to formulate their own explanations from experiences.

All four participants consistently placed 'inform' types of instruction near the beginning of lessons so they could transmit new terms and concepts to students. They consistently believed that science learning begins when the teacher introduces

Table 7 Summary of prospective teachers' knowledge of instructional sequences

<table>
<tr><th rowspan="2">Participant</th><th colspan="2">Entry</th><th colspan="2">End of summer</th><th colspan="2">Fall</th><th colspan="2">Spring</th></tr>
<tr><th>Day 1</th><th>Day 2</th><th>Day 1</th><th>Day 2</th><th>Day 1</th><th>Day 2</th><th>Day 1</th><th>Day 2</th></tr>
<tr><td>Mary</td><td>Inform
Practice
Inform
Practice</td><td>Review
Practice
Inform</td><td>Review
Practice
Inform
Practice</td><td>Review
Practice
Inform</td><td>Review
Inform
Inform</td><td>Review
Inform
Practice</td><td>Review
Focus
Inform</td><td>Practice
Practice
Practice</td></tr>
<tr><td>Amy</td><td>Inform
Practice
Inform
Practice</td><td>Review
Practice</td><td>Inform
Practice
Inform
Practice</td><td>Review
Practice</td><td>Review
Inform
Practice
Inform</td><td>Review
Inform
Practice</td><td>Focus
Inform
Investigate</td><td>Focus
Inform
Investigate</td></tr>
<tr><td>Lilly</td><td>Focus
Inform
Practice</td><td>Focus
Inform
Practice
Inform</td><td>Focus
Inform
Practice</td><td>Focus
Inform
Practice
Inform</td><td>Inform
Focus
Elaborate
Extend</td><td>Focus
Inform
Practice</td><td>Focus
Inform
Practice</td><td>Focus
Practice</td></tr>
<tr><td>Jason</td><td>Focus
Inform</td><td>Review
Inform
Inform</td><td>Focus
Elaborate</td><td>Inform
Inform</td><td>Review
Inform
Practice</td><td>Inform
Practice</td><td>Inform
Focus
Explore
Inform
Elaborate-Part I</td><td>Review
Elaborate-Part II
Evaluate</td></tr>
</table>

new terms and concepts. Although the four participants increased their knowledge of instructional strategies, they did not sequence instruction so students could first formulate an explanation of science phenomena in their own words. Table 7 summarizes the participants' instructional sequences over time.

Assertion 4: The development of prospective secondary science teachers' knowledge of students' understanding of science and instructional sequence was congruent with their science teaching orientations.

During the 9 months of the STEP program, the prospective teachers developed knowledge of learners and instructional sequence based on the STEP program; however, their incoming science teaching orientations were robust and resistant to change. Throughout the STEP program, the participants' developing knowledge of student understanding of science and instructional sequences closely aligned with their science teaching orientations.

For example, Mary learned in the Secondary Science Methods courses that she needed to build on students' prior knowledge. Based on her science teaching orientation, Mary interpreted this to mean she needed to begin each lecture by reviewing material from the previous lecture and she needed to provide students multiple exposures and group work to learn the content. Consistent with this view, after her lectures she used a number of different 'practice' types of activities so students could have multiple exposures to help students overcome their difficulties learning new content. Amy believed students need a combination of lectures, 'peer teaching' experiences, and teacher-led hands-on experiences. Because of the cloning unit she was teaching in the fall semester, Amy wanted to prepare students to make educated decisions. To meet her goal, she led discussions with students about the positive and negative aspects of therapeutic and reproductive cloning. After she led students in a discussion, she purposefully provided 'practice' types of activities so students could rehearse the material. From the STEP courses in the first summer, Lilly learned that teachers should let students have some choices in their learning and that students need multiple opportunities to develop and test their explanations of phenomena (e.g., elaborate phase of 5E). Lilly's science teaching orientation was dominated by the view that teaching as telling and learning as listening. In the fall semester, Lilly did allow students to manipulate variables in an osmosis laboratory. However, before the lab, Lily lectured on osmosis, demonstrated the procedure and outcome of a cookbook osmosis lab, had students complete the cookbook lab, and had students practice new terms and concepts through worksheets.

Even though Mary, Amy, and Lilly developed new ideas about teaching, their view that teaching and learning is mostly a teacher-centered process, facilitated through lectures and teacher-led discussions, persisted throughout the STEP program (see Table 4). The prospective teachers' expanded views of the teacher/student role were congruent with their views that teaching is telling and learning is listening. Mary, Amy, and Lilly's science teaching orientations acted as a barrier to developing more sophisticated PCK. They never became dissatisfied with their view of teaching as transmitting information and learning is practicing new content by having multiple exposures to new terms and concepts. As a result, these three teachers struggled to embrace reform-oriented views of teaching and learning because these views did not fit with their science teaching orientations and their experiences working with their mentors.

Jason's orientation also influenced how he made sense of his experiences in the STEP program. He drew on multiple experiences during the STEP program to try and resolve tensions in his views of teaching and learning. Jason drew on his Young Life experiences because he was dissatisfied with his K-16 experiences that were mostly traditional and teacher-centered. He was eager to find new ways to think about science teaching that mirrored his knowledge of learners from Young Life. As a result, he embraced some of the strategies presented in the Science Methods courses because they provided intelligible ways to make teaching and learning more student-centered. For example, he tried to design a lesson in a 5E instructional sequence during the spring semester (see Table 4). Although he had students make scientific claims based on evidence from student investigations, he thought he needed to begin the lesson with a lecture over cellular structure and function. Thus, his view that teaching and learning is primarily facilitated through teacher-led discussions influenced his knowledge of sequencing science instruction in a 5E sequence.

Jason entered the STEP program with more student-centered views of teaching than the other three participants. Jason's conflict was a result of the interactions taking place between his competing views of teaching and learning. At the end of

9 months in the STEP program, Jason was in the process of restructuring his knowledge of teaching and learning. Implementing the 5E instructional model and replacing views of discovery learning may require a more radical re-structuring of Jason's science teaching orientation. Ultimately, Jason was unable to completely abandon his beliefs about using traditional instructional strategies focused on explaining content to students.

In each of these cases, teacher integration of knowledge of learners and instructional sequences was directly influenced by their science teaching orientations, influencing how they interpreted their experiences in the STEP program and their internship. Although this illustrates a shift in their source of knowledge away from their K-12 learning experiences to sequencing science instruction to meet perceived students' needs, it emphasizes the pivotal role that science teaching orientations play in the development of prospective secondary science teachers' PCK.

Discussion

Although the 5E model is a prominent reform-oriented instructional sequence in the USA (Bybee 1997), prospective secondary science teachers had difficulty implementing the 5Es in their teaching. We learned that although prospective secondary science teachers learned about, experienced, and designed 5E instructional sequences in science methods courses during their year-long teacher preparation program, they did not use the 5Es in their internship classrooms. Researchers have raised the issue that many prospective teachers are unable to implement the reform-minded practices they learn in science methods courses (Adams and Krockover 1997). Hewson et al. found that although prospective teachers learned about conceptual change approaches in methods courses, they were unable to use them in practice (Lemberger et al. 1999; Marion et al. 1999).

The Magnusson et al. PCK model is a conceptual tool that identifies important knowledge domains that are needed to be an effective teacher. The findings of this study provide an empirical test of the Magnusson PCK model and its usefulness for examining PCK development. One significant finding from this study is a more thorough, conceptually-based understanding of the interaction among components of the PCK model. We learned that as prospective teachers gained more knowledge and experience, the interaction that develops between teachers' knowledge of learners and their knowledge of instructional sequences becomes more integrated. This is evidenced by the teachers adding 'practice' types of activities to their instruction based on what they learned about their students' difficulties learning new content. This study emphasized the interconnectedness that exists among components of the Magnusson et al. PCK model and that multiple components (knowledge of science learners and instructional sequences) develop simultaneously. In addition, the findings demonstrate a strong relationship exists between science teaching orientations and knowledge of learners and instructional sequences. For these prospective teachers, developing a more sophisticated science teaching orientation was also a prerequisite to developing knowledge of learners and instructional sequences. The orientations that the prospective secondary science teachers brought to teacher preparation were robust and resistant to change and played a pivotal role in the development of prospective secondary science teachers PCK.

Implications and Conclusions

The findings of this study indicate that teacher educators must elicit and challenge prospective teachers' science teaching orientations. As a result of their K-16 science learning and other background experiences, the prospective teachers in this study entered the teacher education program with strongly held views of teaching as telling. Thus, teacher educators need to elicit prospective teachers' science teaching orientations at the beginning of a teacher preparation program. Teacher educators should be explicit about views of science teaching and help prospective teachers examine their own views in light of reform-oriented practice. Russell and Martin (2007) suggest that teacher preparation might be better viewed as a process of conceptual change. Using this perspective, science methods courses and field experiences should help prospective teachers become dissatisfied with traditional, teacher-centered science teaching orientations while providing intelligible, alternative views. Creating conditions for cognitive conflict and providing opportunities for reflection on views and practice could help prospective teachers re-consider their views of teaching.

This study also presents implications for studying teacher knowledge. The findings have caused us to reconsider using the Magnusson et al. (1999) PCK model and knowledge development. More elaborate PCK models are needed to that account for the integration of knowledge components in order to better understand how teachers learn to teach science. A developmental PCK model must be flexible and fluid, not treating knowledge as fragmented components. We learned from data analysis that as prospective secondary science teachers gain more experience, the interaction that develops between teachers' knowledge of learners and their knowledge of instructional sequences becomes more integrated. More studies are needed that look at these PCK components and others included in the Magnusson et al. PCK model to provide a more complete view of how secondary science teacher knowledge (orientations, knowledge of learners, and knowledge of instructional sequence) is integrated.

In conclusion, research on the nature of PCK development has the potential to inform the design of teacher preparation programs. Prospective secondary teachers enter teacher education programs with robust orientations to science teaching that are primarily based on their K-16 experiences. The prospective teachers' science teaching orientations significantly shaped how they made sense of experiences in methods courses and field experiences. While science teaching orientations could be a powerful support for future learning, it can also act as a barrier to knowledge development. To develop reform-minded knowledge of teaching and learning, prospective teachers must become dissatisfied with teacher-centered views as they explore more reformed-oriented beliefs about teaching and learning.

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