Biology Faculty at Large Research Institutions:

The Nature of their Pedagogical Content Knowledge

by

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ABSTRACT

To address the need of scientists and engineers in the United States workforce and ensure that students in higher education become scientifically literate, research and policy has called for improvements in undergraduate education in the sciences. One particular pathway for improving undergraduate education in the science fields is to reform undergraduate teaching. Only a limited number of studies have explored the pedagogical content knowledge of postsecondary level teachers. This study was conducted to characterize the PCK of biology faculty and explore the factors influencing their PCK. Data included semi-structured interviews, classroom observations, documents, and instructional artifacts. A qualitative inquiry was designed to conduct an in-depth investigation focusing on the PCK of six biology instructors, particularly the types of knowledge they used for teaching biology, their perceptions of teaching, and the social interactions and experiences that influenced their PCK. The findings of this study reveal that the PCK of the biology faculty included eight domains of knowledge: (1) content, (2) context, (3) learners and learning, (4) curriculum, (5) instructional strategies, (6) representations of biology, (7) assessment, and (8) building rapport with students. Three categories of faculty PCK emerged: (1) PCK as an expert explainer, (2) PCK as an instructional architect, and (3) a transitional PCK, which fell between the two prior categories. Based on the interpretations of the data, four social interactions and experiences were found to influence biology faculty PCK: (1) teaching experience, (2) models and mentors, (3) collaborations about teaching, and (4) science education research. The varying teaching perspectives of the faculty also influenced their PCK. This study shows that the PCK of biology faculty for teaching large introductory courses at

large research institutions is heavily influenced by factors beyond simply years of teaching experience and expert content knowledge. Social interactions and experiences created by the institution play a significant role in developing the PCK of biology faculty.

DEDICATION

I dedicate my dissertation to my family. Thank you for all of the love and support you have given me as I pursued this life goal.

To my husband, Dan, and our sons, Eric and Thomas: thank you for all of the patience and understanding you've given me as we embarked on this journey together.

To my parents, George and Janet, and my sister, Suzanne: thank you for the long distance support, which sustained me and oriented me to remain focused on the bigger picture through all of this work.

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I wish to recognize the faculty and colleagues at Arizona State University who played very important roles in my completing this dissertation. Through the support and guidance of my committee members, I grew as an educational researcher and scholarly writer, and these experiences will certainly influence my future professional work. As my advisor, Dr. Julie Luft maintained high expectations for my doctoral work while providing critical feedback and well-timed confidence-building discussions. She was steadfast in her belief that I would succeed in this endeavor, even when I had doubts. Over the past three years, she dedicated countless hours discussing research, reading and editing my writing, and listening to conference presentations. As many know, Dr. Luft is an exceptional researcher, professor and scholar, and I feel very fortunate to have her as a mentor through graduate school and throughout my career.

I would also like to recognize the invaluable support of Dr. Dale Baker. Through our intimate discussions during the seminar courses and individual impromptu office meetings, she supported my transition from being a teacher of science to being a science teacher educator. On many occasions, she allowed me to benefit from her tremendous experience and insight about educating science teachers as well as the challenges of being a female faculty member. Dr. Baker also provided important guidance for my doctoral research in examining science teaching at the postsecondary level. Given her "open door policy", I visited her office often for advice and support. I hope to serve my future students by passing on her words of wisdom and encouragement.

Additionally, I would like to recognize Dr. Miles Orchinik. He played a significant role in my developing as a teacher educator by providing me with the

opportunity to support his Innovative Graduate Teaching Assistant program in the ASU School of Life Sciences. Through my teaching the graduate TAs and our numerous discussions about teaching and learning, I learned a great deal about the challenges of effecting change in higher education. With his endless passion for improving undergraduate biology education, Dr. Orchinik served as an important role model for maintaining resolve in the face of great resistance.

Finally, I would like to thank the contributions of my colleagues in the science education graduate program. In particular, my fantastic writing group – Heather Pacheco, Kaatje Kraft, and Lorelei Wood – was instrumental in my science education research endeavors. We spent innumerable hours reading, discussing, and critiquing each others' work along with sharing tons of laughter, tears, food and fun. It has been a privilege to be amongst a strong group of women who conduct high quality research in their fields. I will always cherish these professional relationships and friendships.

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U.S. occupational employment projections report that of the 30 fastest growing occupations, with growth rates at 27% or greater, many are science and technology-related (Bureau of Labor Statistics, 2007). Policy makers reason that by improving undergraduate education, more science and engineering students will persist in these fields and fill the future science and engineering positions in the United States (National Research Council [NRC], 2006; NRC, 2012). Additionally, improving undergraduate education in the sciences will ensure that all students in higher education become scientifically literate (NRC, 2006; Brewer & Smith, 2011). That is, they will be able to make better health-related decisions and reason through scientific claims that are shared in the media (e.g., personalized medicine, genetics).

One particular pathway for improving undergraduate education in the science fields is to reform undergraduate teaching. Publications from the National Academy Press conclude that undergraduate education should embrace (a) active learning environments, (b) fewer key concepts, and (c) cooperative learning groups (NRC, 1998, 2000, 2003). These methods give undergraduates an opportunity to build deep knowledge in certain areas, and it allows them to learn how to create learning communities. While it is important that these strategies are implemented in science classrooms of postsecondary institutions of all sizes, colleges and universities with large student enrollment are teaching science to significant numbers of science and non-science majors.

The National Center for Education Statistics collects and disseminates data regarding higher education through the Integrated Postsecondary Education Data System (IPEDS). Based upon the Carnegie Foundation's classification system (McCormick &

Zhao, 2005), this database identified 184 colleges and universities as large, research institutions offering doctoral degrees (IPDES, 2012). A large research/doctoral institution is a postsecondary school with total full-time student population exceeding 10,000 that awards doctoral degrees and has a “heavy-emphasis on research” (McCormick & Zhao, 2005). The percentages of science-related (biological and biomedical sciences and physical sciences) and non-science-related university graduates in the 2008-09 academic year are illustrated in Figure 1. Of the over 124,000 science-related (biological and biomedical sciences and physical sciences) baccalaureate and graduate-level degrees awarded by all four-year institutions in 2008-09, approximately 57 percent were earned by students at large, doctoral/research institutions (IPDES, 2012). Most undergraduate

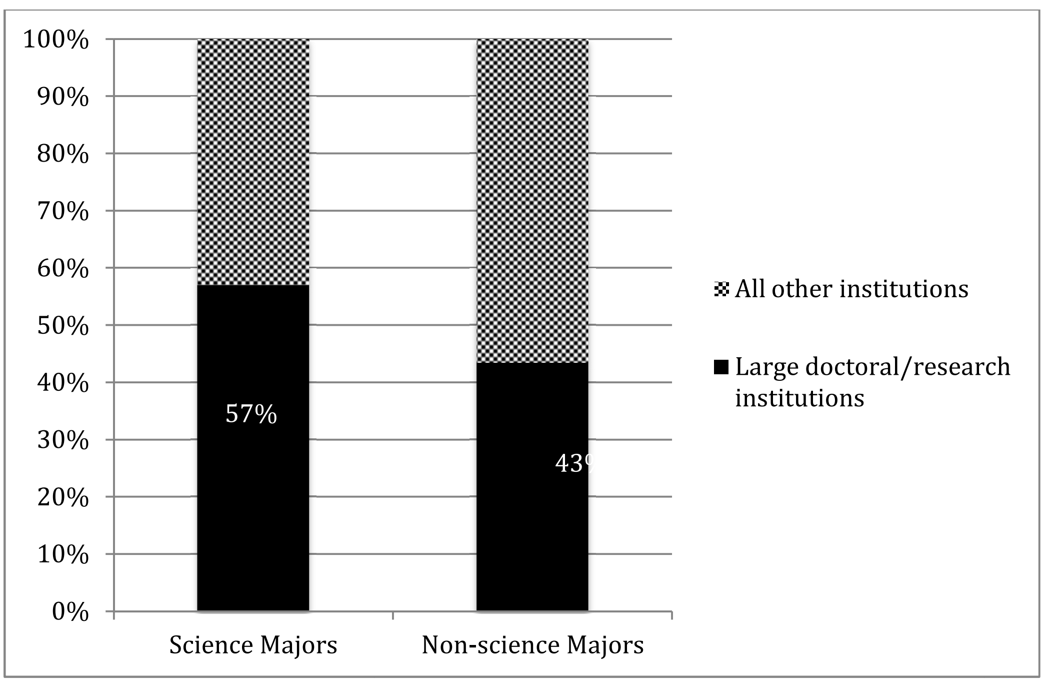


Figure 1. National Center for Education Statistics (NCES) (2012) data on the percentage of science-related (biological and biomedical sciences and physical sciences) and non-science-related university graduates in the 2008-09 academic year.

programs for non-science majors require students to take introductory-level science courses, which serve to be their last formal learning opportunities in science. During the 2008-09 academic year, approximately 43 percent of these non-science majors earning a baccalaureate degree or higher graduated from a large, doctoral/research institution (IPDES, 2012). Given these statistics, improving the quality of undergraduate science teaching at large, research/doctoral institutions can potentially increase the science learning of considerable numbers of postsecondary students.

Efforts have been made to reform undergraduate science teaching, and numerous studies have been performed to evaluate the success of these reform efforts. Through these efforts, various barriers to reform have been identified, such as time constraints, lack of support from administration, reward and tenure policies toward teaching, and student limitations (Ebert-May, 2011). Other research in higher education has emphasized the role of teachers' beliefs in influencing their teaching practices. Across multiple disciplines, interview data revealed that Australian university teachers' "intentions" were consistent with their stated approaches to teaching (Trigwell & Prosser, 1996; Trigwell, Prosser, Martin, & Ramsden, 2005; Trigwell, Prosser, & Taylor, 1994). In a critical review, Kane (2002) reported that a preponderance of the research in postsecondary teaching was limited to examining what teachers say without examining their actual teaching practices; they claimed that the research only told "half of the story". In the context of a professional development workshop, one important study revealed that the biology faculty's self-reported use of innovative teaching strategies was not consistent with observed classroom practices (Ebert-May, 2011). Although these teachers perceived themselves as making use of more learner-centered strategies, they primarily engaged in the transmission model of teaching.

In contrast with secondary-level educational research, very few studies have investigated faculty knowledge for teaching. "Planning and teaching any subject is a highly complex cognitive activity in which the teacher must apply knowledge from multiple domains" (Magnusson, 1999, p. 95). In 1986, Shulman put forth a framework to explore the types of knowledge that teachers use and integrate to form a unique knowledge base for teaching that he called pedagogical content knowledge (PCK). The seven domains of teacher knowledge presented by Shulman (1987) are listed below:

- *Content knowledge;*
- *General pedagogical knowledge*, with special reference to those broad principles and strategies of classroom management and organization that appear to transcend subject matter;
- *Curriculum knowledge*, with particular grasp of the materials and programs that serve as "tools of the trade" for teachers;
- *Pedagogical content knowledge*, that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding;
- *Knowledge of learners and their characteristics*;
- *Knowledge of educational contexts*, ranging from the workings of the group or classroom, the governance and financing of school districts, to the character of communities and cultures; and
- *Knowledge of educational ends, purposes, and values*, and their philosophical and historical grounds.

This framework has been used extensively in research performed at the kindergarten through 12th grade (K-12) levels of schooling. However, only a limited number of studies of teachers' PCK have been performed in higher education. These studies investigated teachers' PCK across multiple disciplines in which the majority of the teachers were employed at small liberal arts colleges (Lenze, 1994; Fernandez-Balboa, 1995; Major, 2002; 2006). Given that university faculty are considered to be content specialists, these studies focused primarily on the teachers' knowledge of students and instructional strategies. Two of the studies found that faculty's knowledge of students was predominantly in the areas of motivation levels (Fernandez-Balboa, 1995) and issues with academic processes (Lenze, 1994) rather than difficulties that students experience in learning content. Major (2002; 2006) reported that faculty in an elective campus-wide professional development project were knowledgeable about students' learning difficulties, however, the teachers did not mention modifying their teaching based upon this knowledge. Based upon interview responses, faculty were found to have knowledge of a wide array of instructional strategies (Fernandez-Balboa, 1995; Major 2002; 2006). The findings of these studies reveal that faculty knowledge for teaching is less developed in particular areas, which may be adversely affecting their PCK development.

Statement of the Problem

The previous studies of postsecondary teachers' PCK were limited to investigating teachers' general PCK across disciplines. Discipline-specific PCK for teaching undergraduate science has yet to be investigated. In addition, given the contextual differences, it is likely that the PCK of faculty at large doctoral/research institutions differs from that of teachers at liberal arts colleges. For this reason, the nature of PCK specific to biology faculty teaching large introductory-level courses remains to be explored.

The purpose of this study is to investigate the nature of the PCK of biology faculty who are teaching at large doctoral/ research institutions. The study seeks to identify the types of knowledge used by biology faculty in teaching large introductory-level courses. In addition, the experiences, interactions and teaching perspectives influencing the PCK of biology faculty will be explored.

Research Questions

The overarching research question for this study is: What is the nature of the PCK of biology faculty at large doctoral/research institutions? The study focused on characterizing the teachers' PCK for teaching about genetics within the context of an introductory biology course. Sub-questions for the research include:

- What are the types of knowledge that biology faculty use for teaching?
- What social interactions influence the PCK of biology faculty?
- How do the teaching perspectives of biology faculty influence their PCK?

To address these research questions, I focused on biology faculty from three large doctoral/research institutions. The study involved data collection at or near the time that the faculty are actively engaged in teaching an introductory-level course. This investigation analyzed data in order to better understand the nature of the PCK of biology faculty.

Significance of the Study

Conducted in the setting of large doctoral/research institutions, this study of biology faculty PCK and the factors influencing their PCK will serve to inform faculty, researchers, and administrators about how postsecondary teachers develop knowledge to teach science. We will better understand the knowledge base influencing teaching practices, which ultimately impact student science learning at the postsecondary level. As teachers of both science-majors and non-science majors, biology faculty at large, doctoral/research institutions impact the science learning of significant numbers of undergraduate students. By characterizing the PCK of biology faculty, instructional reform efforts could be designed and implemented to target identified knowledge domains that may require strengthening in postsecondary science teaching. Furthermore, the findings of this study may aid in administrators developing policies and/or incentive structures for faculty to promote improved undergraduate science teaching and learning.

Overview of the Study

The second chapter includes a review of the research literature relevant to this study of biology faculty PCK. The first section of Chapter 2 provides a historical perspective of educational research at the time of Shulman's introduction of the PCK framework. The second section includes a discussion of the various models of PCK presented in the literature. The third section reviews the research on what is currently known about the PCK of science teachers at the secondary and postsecondary levels. In the last section, the gaps within the literature are discussed.

Chapter 3 details the qualitative research design proposed for conducting this study of biology faculty PCK. The epistemological view and theoretical perspective guiding the study are presented along with the research design. The discussion includes a description of the selected methodology of case study. Details regarding the study setting and participants are provided. The chapter also includes a description of the proposed data sources and analysis procedures to be utilized for addressing the research questions. Issues of validity and reliability are discussed with a description of proposed strategies to minimize potential problems. Finally, the limitations of the study are presented.

Chapter 4 presents the individual faculty profiles developed for each of the six participants included in the study. These profiles were created by analyzing and synthesizing the various data collected.

Chapter 5 includes the discussion of the findings, conclusions, implications of the study, and directions for future research.

Chapter 2: Literature Review

A heated debate that took place in the 1980's revolved around two views of teaching: teaching as a profession and teaching as a skilled labor position. Some argued for teacher evaluations to be based upon disciplinary skills for maintaining an orderly classroom. Others argued for greater emphasis to be placed on teachers' knowledge of the subject matter. This debate catapulted educational research in a direction of exploring and characterizing the knowledge and beliefs of teachers. During the course of their investigations, researchers interviewed teachers and observed classrooms in an attempt to capture, describe, and define the tacit knowledge of exceptional educators.

Much of the research was driven by the question: what do teachers need to know in order to be an effective teacher? In 1986, Shulman put forth a paper discussing the lack of studies emphasizing the knowledge needed for proficient teaching. In support of future educational research, he proposed a model that included a knowledge domain, which he asserted was unique to teachers: pedagogical content knowledge (PCK). From the time that it was presented, Shulman's model has undergone many modifications and refinements by numerous education researchers. Some assert that the field is currently in the midst of a Kuhnian paradigmatic shift (Kuhn, 1970) in which a change in the kinds of questions has lead to new methods and novel discoveries.

Over the past 25 years, PCK models have been used to investigate the knowledge of science teachers at all levels of education. The purpose of this review is to survey the body of literature in the area of PCK as it relates to secondary science teachers and science faculty who teach undergraduates. Various PCK models are presented and discussed along with the findings of relevant studies. Additionally, recommendations for future research in the area of undergraduate science teaching are provided.

What is Pedagogical Content Knowledge?

The concept of pedagogical content knowledge was first introduced by Lee Shulman (1986, 1987) through a series of professional publications. Motivated to redirect educational research, he put forth a new framework emphasizing the types of knowledge required for teaching subject matter to others. Shulman asserted that,

> The actions of both policymakers and teacher educators in the past have been consistent with the formulation that teaching requires basic skills, content knowledge, and general pedagogical skills. Assessments of teachers in most states consist of some combination of basic-skills tests, an examination of competence in subject matter, and observations in the classroom to ensure that certain kinds of general teaching behavior are present. In this manner, I would argue, teaching is trivialized, its complexities ignored, and its demands diminished. (Shulman, 1986, p. 6)

He contended that an elaborate knowledge base exists for teaching that extends beyond the isolated domains of content and pedagogy.

Shulman (1987) described these types of knowledge as that which distinguish a teacher from a specialist within a particular discipline. He asserted that studies of teachers had revealed that content knowledge and pedagogical knowledge were important for teaching, yet the sum of the two knowledge domains produced an inadequate depiction of the total knowledge for teaching. In 1986, he introduced the term, pedagogical content knowledge (PCK), and provided a rich description of the construct:

> Within the category of pedagogical content knowledge, I include, for the most regularly taught topics in one's subject area, the most useful forms of representations of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations – in a word, the ways of representing and formulating the subject that make it comprehensible to others, [and] pedagogical content knowledge also includes an understanding of what makes the learning of specific topics easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons. (Shulman, 1986, p. 3)

Given the complexity and specificity of PCK, Shulman (1986) compared the knowledge development of teachers to that of doctors and lawyers, who become proficient in skills, cases, and procedures demonstrated in practice. He urged educational researchers and policy-makers to view teachers as 'professionals' rather than 'skilled workers' and provided a conceptual framework for examining teachers' knowledge.

Shulman (1987) presented a comprehensive list of the types of knowledge that teachers use and develop in their profession. The seven knowledge domains and their definitions are included below:

1) content knowledge;
2) general pedagogical knowledge, with special reference to those broad principles and strategies of classroom management and organization that appear to transcend subject matter;

3) curriculum knowledge, with particular grasp of the materials and programs that serve as 'tools of the trade' for teachers;
4) pedagogical content knowledge, that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding;
5) knowledge of learners and their characteristics;
6) knowledge of educational contexts, ranging from the workings of the group or classroom, the governance and financing of school districts, to the character of communities and cultures; and
7) knowledge of educational ends, purposes, and values, and their philosophical and historical grounds. (Shulman, 1987, p. 8)

Shulman theorized PCK to be a unique and discrete knowledge domain that developed as teachers engaged in practice. PCK "represents a blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (Shulman, 1987, p. 8).

Other researchers have expanded upon Shulman's definition of PCK. Geddis (1993) described PCK as the knowledge involved in the "transformation of subject matter knowledge into forms accessible to the students being taught" (p. 675). Researchers have worked toward developing an accepted definition based upon research findings. Lee and Luft (2008) presented a definition based upon the nature of PCK reported in the literature:

> PCK is the experiential knowledge and skills acquired through classroom experience, and PCK is the integrated set of knowledge, concepts, beliefs, and values that teachers develop in the context of the teaching situation. (Lee et al., 2008, p. 1345)

Park and Oliver (2008) developed a comprehensive definition based upon the multitude of definitions found in the literature:

> PCK is teachers' understanding and enactment of how to help a group of students understand specific subject matter using multiple instructional strategies, representations, and assessments while working within the contextual, cultural, and social limitations in the learning environment. (Park et al., 2008, p. 264)

Although many contend that PCK remains an elusive construct, Shulman was successful in redirecting educational research as his conceptual framework of teachers' knowledge has been utilized in studies of educators at all levels and across disciplines. These studies have resulted in the development of various models of PCK.

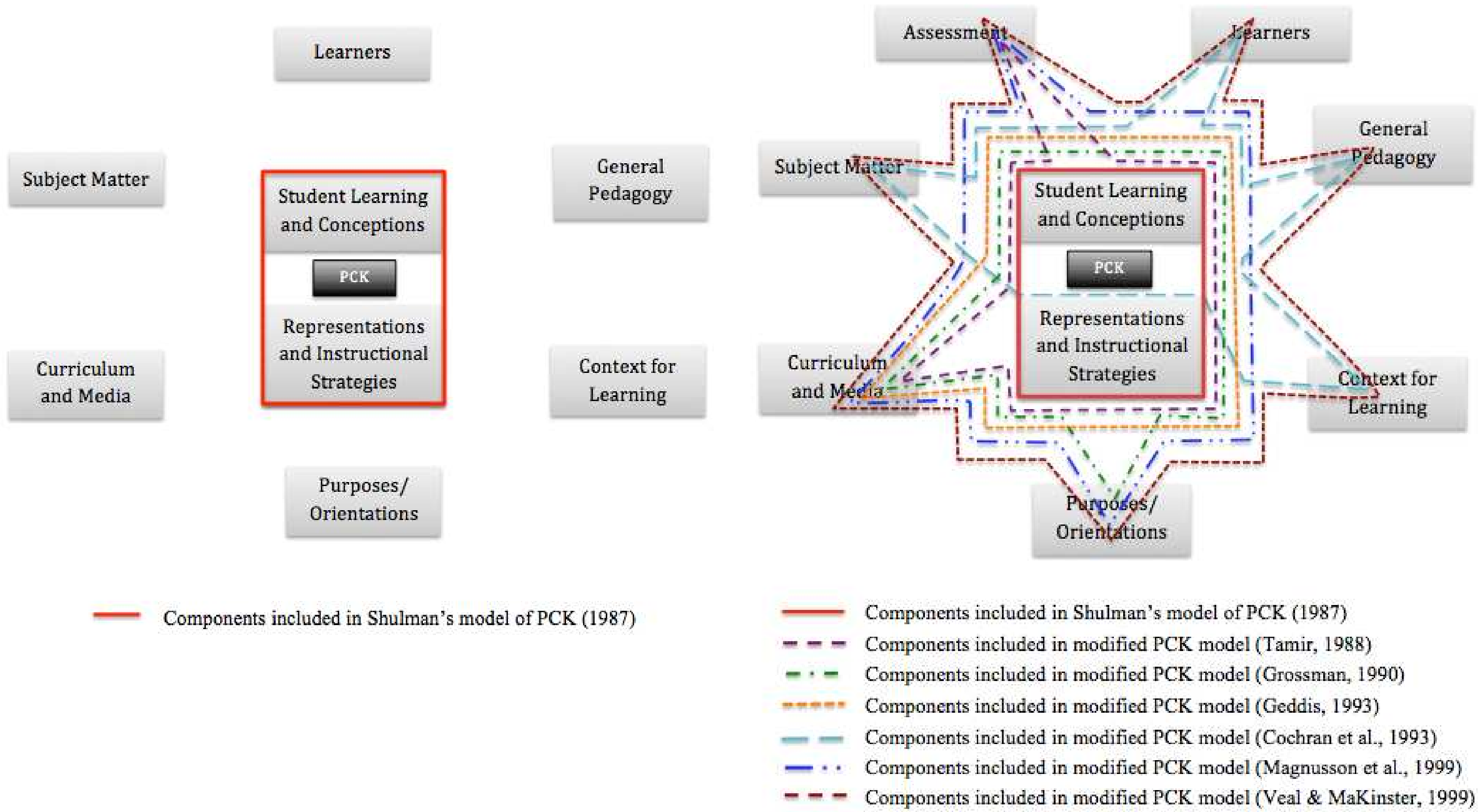
Various Models of PCK

Many educational researchers embraced Shulman's conception of teachers' knowledge domains including PCK. Over the past two decades, alternative models of PCK have been introduced and used in studying the knowledge of teachers. Most of these are theoretical models which are modified versions of Shulman's original framework. In some cases, the obscure concept of teachers' orientations was integrated into the model. Other models of PCK emerged from data collected in the field. These various models of PCK are discussed.

Theoretical models based on Shulman's original conception. Shulman's original model limited PCK as teachers' knowledge of representations and instructional strategies along with knowledge of student learning and conceptions. Several researchers put forth modified theoretical models of the PCK framework based on Shulman's original conception. The differences between the various models based upon the selected components of PCK are illustrated in Figure 2.

Tamir (1988) modified this conception of PCK with the addition of knowledge of assessment and knowledge of curriculum. He reasoned that knowledge of assessment was an essential component of PCK that served to determine the effectiveness of instruction strategies in terms of student learning. Grossman (1990) conceptualized PCK to include the original components along with knowledge of curriculum and knowledge of purposes for teaching. Geddis, Onslow, Beynon, Oesch (1993) also retained Shulman's original components and added knowledge of curriculum, which they referred to as curricular saliency. Magnusson, Krajcik, and Borko (1999) presented a model of PCK that included five components (Figure 3). Four knowledge components (students' understanding of science, instructional strategies in science, assessment in science, science curriculum) are depicted as influencing and being influenced by the teachers' orientation to teaching science.

Cochran, deRuiter, and King (1993) developed a model to emphasize that teachers' PCK is continuously being constructed as they engage in classroom practice. Their PCK components included knowledge of student characteristics, content, pedagogy and the learning context. 'Student characteristics' was defined as students' abilities, learning strategies, ages, development, motivation, and prior conceptions. Cochran et al.



(a) (b)

Figure 2. Models of PCK. (*a*) Representation of Shulman's original model of PCK relative to other knowledge domains; (*b*) Representation of various models of PCK based upon Shulman's original conception.

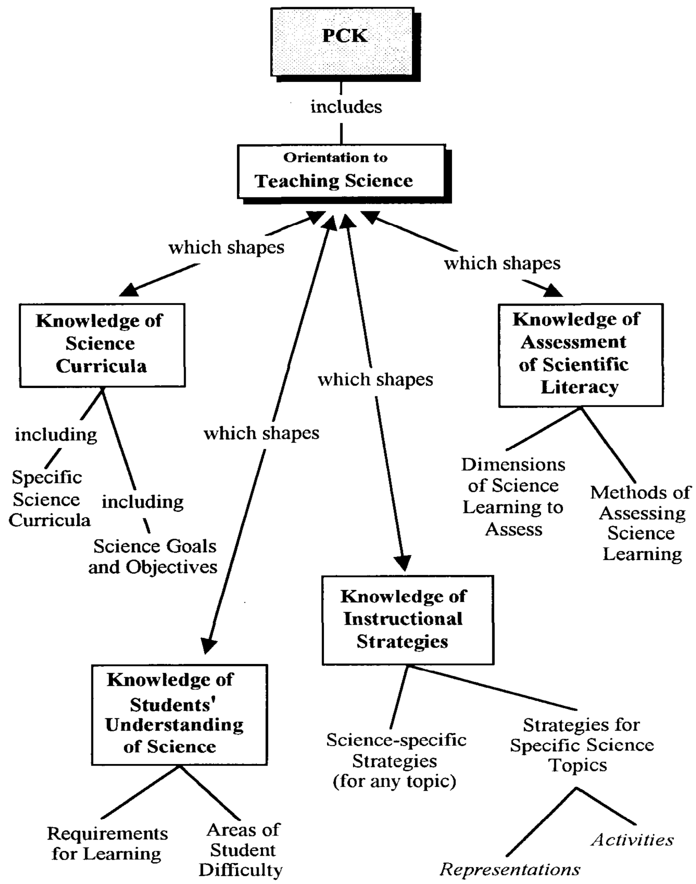
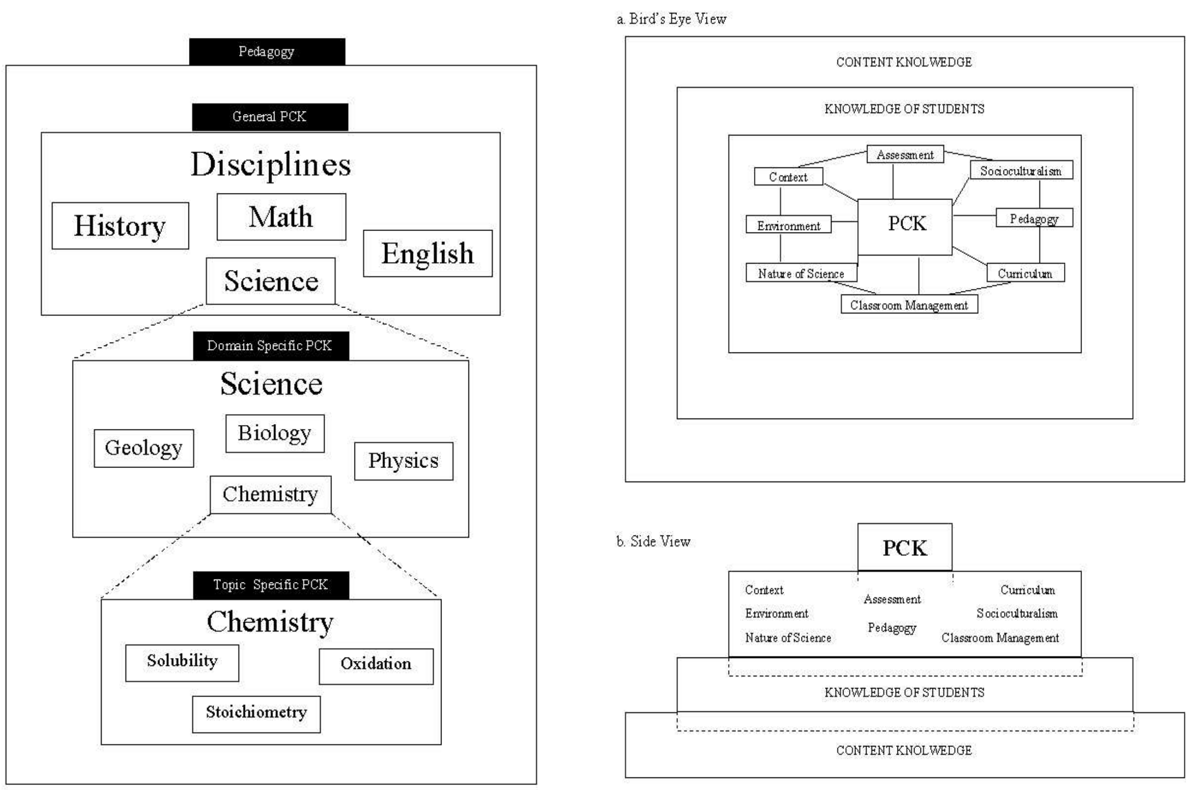


Figure 3. Components of pedagogical content knowledge for science teaching. Adapted from "Nature, sources, and development of pedagogical content knowledge for science teaching," by Magnusson, S., Krajcik, J. and Borko, H., 1999. In J. Gess-Newsome and N. G. Lederman (Eds.), *Examining Pedagogical Content Knowledge: The Construct and Its Implications for Science Education,* p. 99. Copyright 1999 by Kluwer Academic Publishers.

(1993) asserted that teachers' 'PCKg', which denotes the active development of PCK, requires the integration of the four knowledge domains.

Veal and Makinster (1999) introduced a model that depicts PCK as a hierarchial structure they referred to as a 'taxonomy'. Although the authors do not assert that teachers' develop PCK in this manner, they put forth their model as a means to describe the PCK of teachers at different levels. Veal and MaKinster (1999) suggest that teachers develop four levels of PCK: (1) generic, (2) general or subject-specific, (3) domain-specific, and (4) topic-specific (Figure 4). General PCK refers to the knowledge of pedagogy that can be used appropriately across multiple subject areas. Subject-specific PCK includes knowledge of sound pedagogical concepts that are applicable to specific disciplines such as history, math and science. Domain-specific PCK and topic-specific PCK are related directly to the concepts that are being taught (i.e., in the chemistry domain, topics may include solubility, oxidation, and stoichiometry). Veal and MaKinster (1999) included all seven domains of knowledge as components of PCK (Figure 4).



(a) (b)

Figure 4. Veal and MaKinster's general taxonomy of PCK. (*a*) Veal and MaKinster's PCK Taxonomy and (*b*) Model of PCK. Adapted from "Pedagogical content knowledge taxonomies, " by Veal, W. R., & MaKinster, J. G., 1999, *Electronic Journal of Science Education, 3*(4). Copyright 1999 by University of Nevada, Reno.

Grossman (1990), Magnusson et al. (1999), and Veal and Makinster (1999) included teachers' orientations toward teaching science as a component of PCK. However, the definition and use of this construct has varied in science education research.

Models including teachers' orientations. The term "orientation" appears to have multiple meanings in the science education literature. Anderson and Smith (1987) categorized teachers' varying approaches to science teaching (activity-driven, didactic, discovery, and conceptual-change) as "orientations". Grossman (1990) included a domain of teachers' conceptions of the purposes and goals for teaching science as part of her model of PCK. Magnusson, et. al. (1999) retained Grossman's domain and renamed it "orientations". They defined an orientation as a "general way of viewing or conceptualizing science teaching", however, they also provided a list of nine different orientations which appear to be various approaches to teaching: process, academic rigor, didactic, conceptual change, activity- driven, discovery, project-based science, inquiry, and guided inquiry. This duel use of orientations as approaches to teaching and teachers' beliefs remains an unresolved issue in science education research.

In recognizing the complex web of influencing factors, Freidrichsen (2002) referred to orientations as "a messy concept". Friedrichsen, Van Driel, and Abell (2011) put forth a position paper discussing the inconsistent use of orientations in science education research. In an effort to address these issues, the authors provide a more concise definition of orientation as "a set of beliefs with the following dimensions: goals and purposes of science teaching, views of science, and beliefs about science teaching and learning" (Friedrichsen, et al., 2011, p. 1).

The inclusion of orientations as conceptions of science teaching and learning has often lead to studies that include teachers' values and beliefs, not strictly knowledge structures. Friedrichsen and Dana (2003, 2005) defined orientations as teachers' knowledge and beliefs about the purposes and goals for teaching science. Their study found that the teachers' orientations included subject matter, goals related to general schooling (developing reading literacy, skills for success in school and life, a sense of responsibility), and affective components (developing positive attitudes toward science, an environmental ethic, and students' curiosity). In addition, these orientations were strongly influenced by the classroom context, teachers' beliefs about students and learning; other influences included prior work experiences, professional development experiences, and time constraints.

Interestingly, three emergent models include teachers' orientations, presented as teaching purposes, teaching goals, and teachers' beliefs, as components that contribute to teachers' PCK.

Three emergent/semi-emergent PCK models. Three important studies explored the categories of PCK through examination of teachers' ideas and practices using a more grounded approach. Theoretical models are depictions of interactions developed from the perspective of the researcher. In contrast, emergent models are based upon the analysis of collected data yielded from the reporting of teachers and observations of classroom practices. Components of the PCK models developed from the following studies emerged from analysis of the data collected. One of the studies investigated the 'generic' PCK of university faculty across multiple disciplines. Another examined the conceptualization of PCK by secondary science teachers. A third study was initiated with a structured model of PCK, however, major modifications were made to the model based upon emergent themes of topic-specific PCK in chemistry.

In 1995, Fernandez-Balboa and Stiehl conducted a study of 10 experienced university professors from multiple disciplines to explore the 'generic' components of PCK across subjects. The participants were a purposeful sample of faculty that were identified by five college deans as exceptional teachers based upon student evaluations, peer reviews, and teaching awards. Data were collected through in-depth semi-structured interviews during which the participants reflected on their teaching experiences. The authors presented the findings as the faculty's collective PCK rather than the PCK of individual teachers. The results of the study revealed five components of PCK that emerged from the data analysis; these include knowledge of: (1) subject matter, (2) students, (3) instructional strategies, (4) the teaching context, and (5) one's teaching purposes (Figure 5). As one of the first studies of faculty PCK, these findings provided a window into the types of knowledge used by teachers at the tertiary level.

Lee and Luft (2008) conducted research designed to elicit the components of PCK from four experienced secondary teachers. The sample included teachers with more than 10 years of teaching experience and more than three years of mentoring beginning science teachers. Given that the teachers actively taught more than one science discipline, the study explored the general or subject-specific PCK of science teachers. Over a 24-month period, data were collected through three semi-structured interviews, classroom observations, lesson plans and monthly reflective statements from the participants. During an interview, the teachers were asked to develop a conceptualization of PCK for teaching science by constructing a concept map. This particular approach was unique in

Figure 5. Fernandez-Balboa and Stiehl's table of PCK components. Adapted from "The generic nature of pedagogical content knowledge among college professors," by J.M., Fernández-Baboa, and J. Stiehl, 1995, *Teaching and Teacher Education, 11*(3), p. 293-306. Copyright 1995 by Elsevier Limited.

Figure 5. (continued) Fernandez-Balboa and Stiehl's table of PCK components.

that the teachers actively participated in developing and modifying their conceptualizations of PCK.

The secondary science teachers were remarkably consistent in the identification of knowledge domains included in PCK. Results of the analysis revealed seven components of PCK which were identified by all four teachers as important for teaching science: (1) knowledge of science, (2) knowledge of goal, (3) knowledge of students, (4) knowledge of curriculum organization, (5) knowledge of teaching, (6) knowledge of assessment, and (7) knowledge of resources. However, the teachers' conceptions of PCK varied in the interactions between knowledge domains. The four concept maps constructed by teachers in the study are included in Figure 6. Although their models varied, the teachers "demonstrated their ability to access and emphasize the different components individually and simultaneously" (Lee, et al., 2008, p 1360).

Rollnick, Bennett, Rhemtula, Dharsey, and Ndlovu (2008) conducted a study to explore the topic-specific PCK of secondary chemistry teachers in South Africa. The authors utilized the Content Representations and Pedagogical and Professional-experience Repertiores (CoRe and PaP-eRs) methods (Loughran, Berry, & Mulhall, 2004, 2006) to document the teachers' PCK for teaching about the mole and chemical equilibrium. PCK was conceptualized as an amalgam of four knowledge domains that were identified in prior research, however, the data analysis emphasized evidence for knowledge integration in the form of *manifestations*, "any visible products of teaching observable in the classroom" (p. 1380). The study revealed four types of manifestations: (1) representations, (2) curricular saliency, (3) assessment, and (4) topic-specific instructional strategies. Based on these findings, Rollnick et al. (2008) developed a model

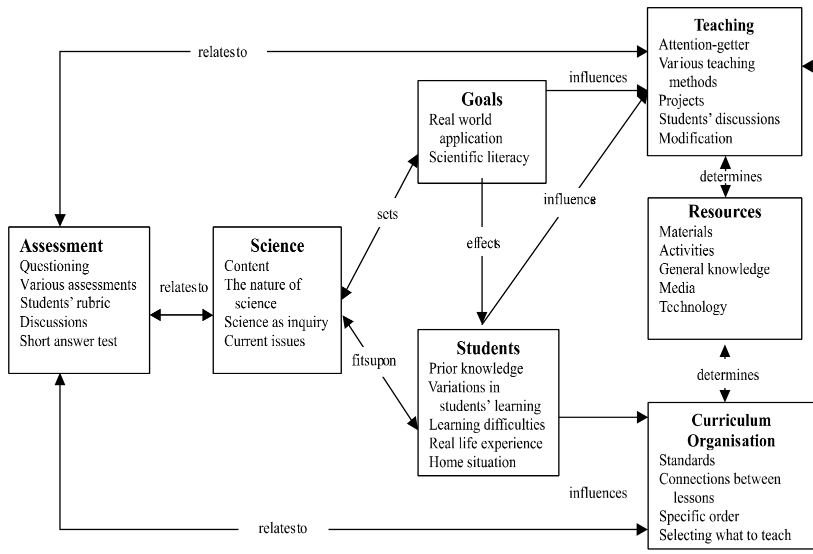


Figure 1. Wendy's conceptualisation of PCK

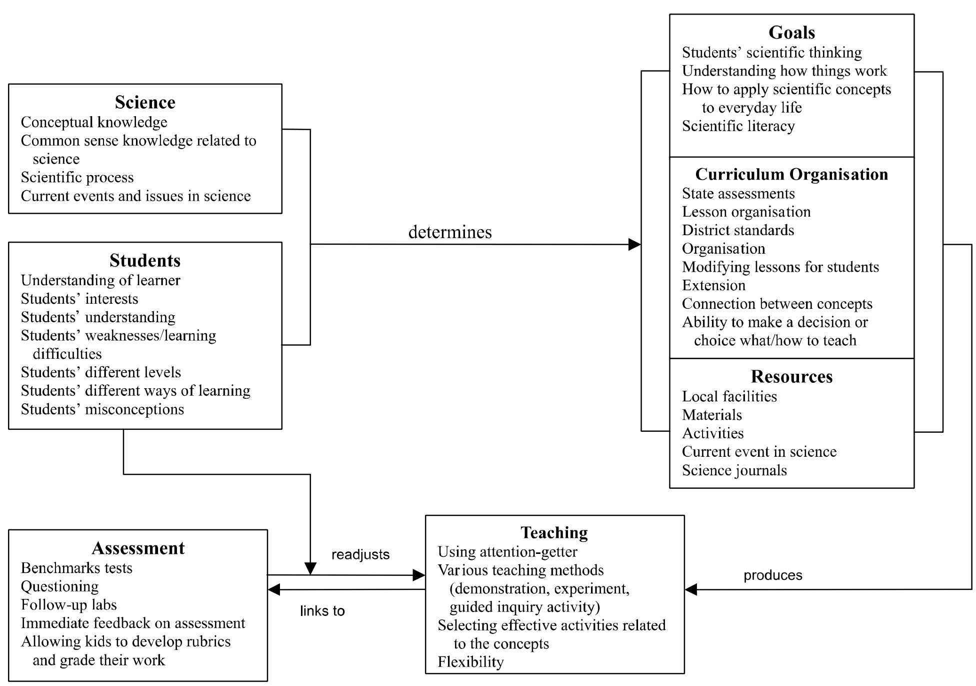


Figure 2. Roger's conceptualisation of PCK

Figure 6. Secondary science teachers Concept Maps of PCK. Adapted from "Experienced secondary science teachers' representation of pedagogical content knowledge," by E. Lee, and J.A. Luft, 2008, *International Journal of Science Education, 30*(10), 1343-1363. Copyright 2008 by Routledge, part of the Taylor & Francis Group.

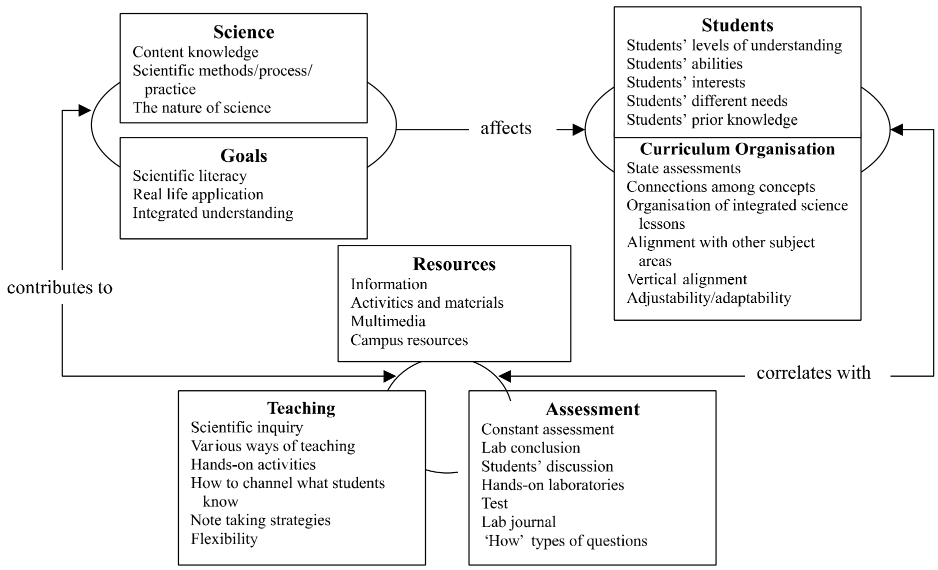


Figure 3. Emily's conceptualisation of PCK

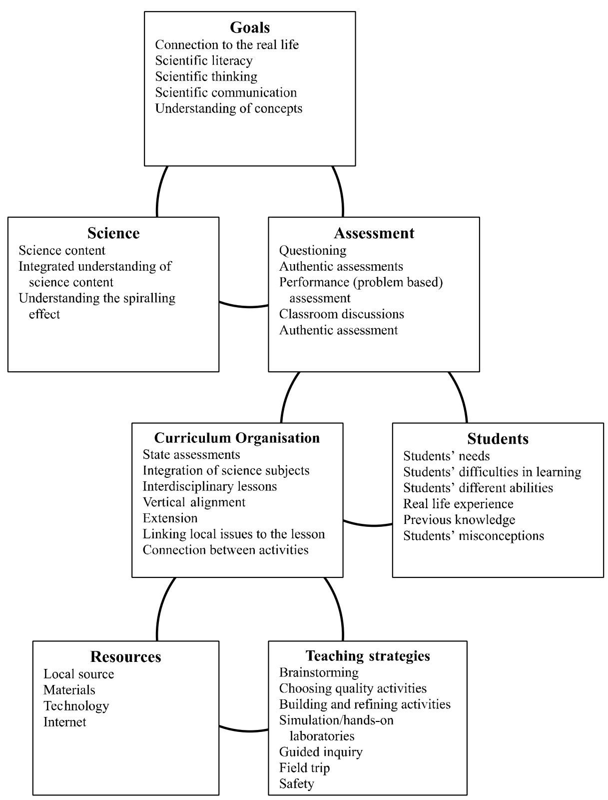


Figure 4. Shawna's conceptualisation of PCK

Figure 6. (continued) Secondary science teachers Concept Maps of PCK .

of knowledge domains that contribute to teachers' PCK and manifestations as products of teachers' PCK (Figure 7).

At the university level, Davidowitz and Rollnick (2011) conducted a similar study of an experienced chemistry instructor teaching a second-semester course of organic chemistry. The authors made use of the same knowledge domains as presented in Rollnick et al. (2008), however, the teacher's beliefs became an influencing factor of PCK. The chemistry instructor strongly emphasized the importance of the curriculum; this idea was identified as a belief tied to his strong background in organic chemistry. Additionally, the emergent manifestations of the chemistry instructor differed from the teachers at the secondary level (Figure 7). The five manifestations included: (1) representations, (2) curricular saliency, (3) explanations, (4) interactions with students, and (5) topic-specific strategies.

Models of PCK have been used to investigate the knowledge of science teachers at all levels of education. The following discussion focuses on the findings of studies at the secondary and postsecondary levels.

What do we know about the PCK of science teachers?

Evidenced by the multitude of PCK models in educational studies, the conceptual framework has been utilized extensively by science education research community. Researchers continue to debate about what defines and contributes to PCK. Nevertheless, many agree that the PCK conceptual framework has lead to the generation of new questions about teaching and new methods of studying the knowledge and skills of the teaching profession (Abell, 2008).

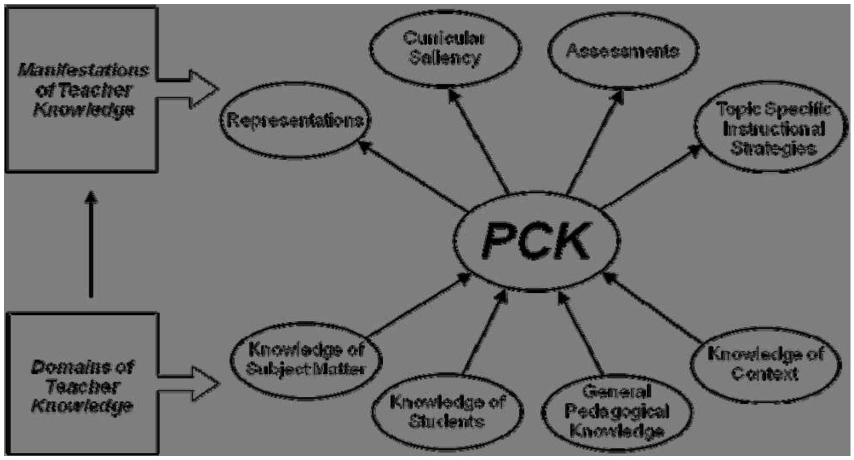


Fig. 1 Model of Rollnick *et al*. (2008).

(a)

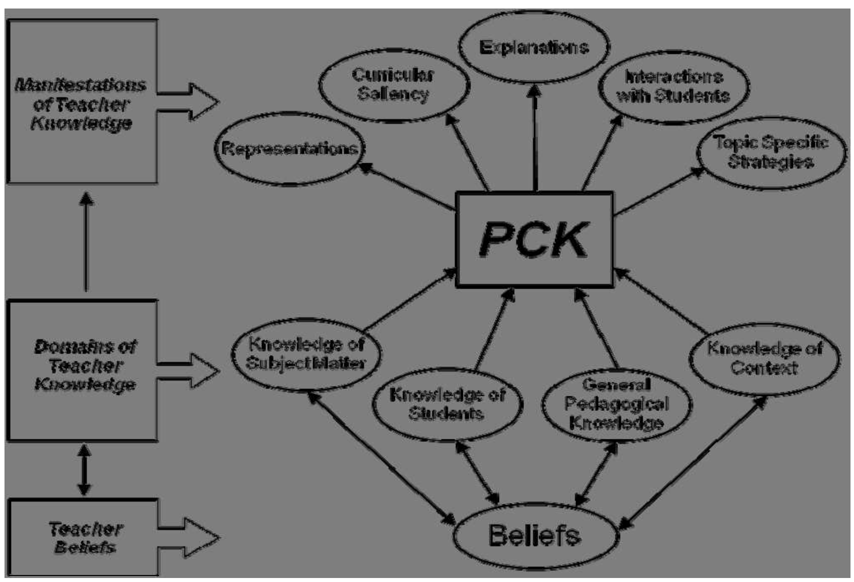


Fig. 4 Modified model for PCK.

(b)

Figure 7. Models of chemistry faculty PCK. (*a*) Secondary science teachers adapted from "The place of subject matter knowledge in pedagogical content knowledge: A case study of south african teachers teaching the amount of substance and chemical equilibrium," by M. Rollnick, J. Bennett, M. Rhemtula, N. Dharsey, and T. Ndlovu, 2008, *International Journal of Science Education, 30*(10), 1365-1387. Copyright 2008 by Routledge, part of the Taylor & Francis Group. (*b*) Undergraduate science teachers adapted from "What lies at the heart of good undergraduate teaching? A case study in organic chemistry," by B. Davidowitz & M. Rollnick, 2011, *Chemistry Education Research and Practice, 12*(3), 355-366. Copyright 2011 by Royal Society of Chemistry.

PCK of secondary science teachers. Studies of science teachers' PCK have been performed primarily at the secondary level with fewer studies conducted in higher education.

1) Teachers require a wide range of knowledge to build effective PCK. Studies employing the PCK framework have revealed that science teachers make use of many different types of knowledge in their profession (Geddis, 1993; Gess-Newsome, 1999; Grossman, 1990; Lee, Brown, Luft, & Roehrig 2007; Lee & Luft, 2008; Magnusson et al., 1999). Secondary science educational researchers have sought to identify the types of knowledge important for effective science teaching. Geddis et al. (1993) found that the strategies employed by an experienced chemistry teacher were supportive of students learning about isotopes. The authors reported that he was able to transform his subject matter knowledge into strategies that provided necessary scaffolding of the content in a way that appealed to student interests. This transformation required knowledge of students and their understandings of science, instructional strategies, alternative representations, and importance of the topic as it related to the overall curriculum.

Lee et al. (2008) elicited the components of PCK from four experienced secondary science teachers. All four teachers identified seven knowledge domains as important for teaching science: (1) knowledge of science, (2) knowledge of goal, (3) knowledge of students, (4) knowledge of curriculum organization, (5) knowledge of teaching, (6) knowledge of assessment, and (7) knowledge of resources. Although their conceptualizations of how the interactions between knowledge domains varied, the teachers "demonstrated their ability to access and emphasize the different components individually and simultaneously"(p. 1360).

2) Teachers require well-developed content knowledge to build effective PCK.

Several studies that investigated the impact of subject matter knowledge on teaching practices found that well-developed content knowledge is imperative for building effective PCK. Rollnick et al., (2008) reported that teachers resorted to more general pedagogical approaches when teaching in an area that they have less-developed content knowledge. This is consistent with studies of secondary science teachers teaching outside of their area of expertise (e.g., Hasweh, 1987; Sanders, Borko, & Lockard,1993). Rollnick et al., (2008) also found that when teachers have well-developed content knowledge, it supported their ability to combine it with other knowledge domains in order to produce innovative teaching strategies. In a study of pre-service teachers, Kapyla, Heikkinen, and Asunta (2009) reported that the student teachers with more content knowledge were better able to detect and respond to students' conceptual difficulties and misconceptions around the topic of photosynthesis than those with less-developed content knowledge.

Deemed as essential for effective science teaching, science content knowledge need for secondary teaching differs from that of scientists. From the teachers' perspective, content knowledge has been identified as the most important knowledge domain for teaching science. Lee et al. (2008) interviewed experienced science teachers with more than 10 years of teaching experience and more than 3 years as a mentor teacher. The teachers reported that a strong science background was essential for teaching science. All described their content knowledge as broader, but shallower than scientists and stated that they had to continually develop their content knowledge. Some educational researchers have sought to differentiate "school subjects" from academic disciplines from multiple fields of study (Ball, et al., 2001; Grossman, 1990; Grossman & Stodolsky, 1995). With only a limited number of studies, others called for further investigation into the differences as they relate specifically to science teaching (Deng, 2007).

Studies of secondary science educators indicate that teachers need a strong understanding of the science content to build effective PCK, however, other research has determined that subject matter knowledge alone is not sufficient for effective teaching (Friedrichsen, Abell, Pareja, Brown, Lankford, & Volkmann, 2009; Lee, et al,, 2005; Lee et al., 2008).

3) Classroom experience is essential to PCK and SMK development. Many researchers agree that PCK is a knowledge domain that develops through teachers' classroom experience (Baxter & Lederman, 1999; De Jong et al., 2004; Geddis et al., 1993; Gess-Newsome, 1999; Grossman, 1990). Beginning with preservice teachers' student-teaching experience, Lederman, Gess-Newsome, and Latz (1994) found that the pedagogical knowledge of the preservice science teachers became more complex over time with a greater emphasis on students' needs as they engaged in their student teaching experience. When interviewed, the preservice teachers pointed to experience with the students as the source of the change.

Studies of prospective chemistry teachers (de Jong and Van Driel, 2004; Van Driel, de Jong, & Verloop, 2002) also found knowledge development during student teaching experiences. The study participants included preservice teachers with master's degrees in chemistry, enrolled in a one-year post-graduate teacher education program. The study focused on the PCK development of the teachers as they engaged in teaching chemistry using the three modes of representation – macroscopic, microscopic, and symbolic. As content specialists, switching between the three representations had become second nature to the participants. “To be conscious of novices’ conceptions is not something that comes easily to experts” (de Jong, Acampo & Verdonk, 1995, p. 1108). After working with students, the participants reported developing an awareness of their transitioning between the three modes of representation while building knowledge of student difficulties in chemistry. The student teachers also began to recognize the inadequacies of the textbooks as a learning tool for students.

Studies of expert and novice teachers have revealed that preservice teachers have less-developed knowledge for teaching than experienced teachers. Geddis et al. (1993) found that preservice chemistry teachers emphasized procedural knowledge of calculating weighted averages when teaching about isotopes. The student teachers did not anticipate that students would encounter difficulties with these calculations. In contrast, the experienced chemistry teacher emphasized conceptual knowledge of the masses of various isotopes. His knowledge of student difficulties in this area enabled him to incorporate appropriate scaffolding and integrate students’ interests to support student learning. Lee et. al. (2005) found that beginning secondary science teachers had limited or basic levels of PCK. Studies involving veteran science teachers have supported the idea that PCK develops with classroom experience as these teachers demonstrated well-developed knowledge across multiple domains (Abd-El-Khalick, 2006; Clermont, Borko, & Krajcik, 1994; Lee & Luft, 2008).

Although it is deemed to be an essential element, studies have indicated that classroom experience alone does not result in PCK development. Friedrichsen et al.

(2009) examined the PCK of secondary biology teachers entering an alternative certification program. The four participants were similar in content training and aptitude (undergraduate biology degrees and high GRE and PRAXIS II scores) with no formal training in education, however, two of the participants had 2 years of prior teaching experience. The authors found that prior teaching experience made little difference as both groups made use of general pedagogy and demonstrated little PCK for teaching about heritable variation. Other studies emphasized that teachers' reflection of classroom experiences plays a critical role in PCK development (De Jong & Van Driel, 2001; Park et al., 2008).

4) Teachers develop different levels of PCK. Studies of secondary science teachers have been performed at discipline, domain, and topic-specific levels. Lee et al.'s (2008) study of secondary science teachers included participants teaching in a variety of domains including general science, biology, chemistry, and earth science). Veal and Kubasko (2003) investigated the differing approaches of biology and geology teachers for teaching about evolution. Findings indicate that the epistemological differences between the two domains influence the transformation of subject matter into teaching practices. Many topic-specific studies have examined teachers' PCK as they teacher specific topics within their domain such as photosynthesis, electrical currents, and chemical equilibrium (Abd-El-Khalick, 2006; Geddis, 1993; Van Driel, Verloop, & De Vos, 1998). Although educational researchers have not asserted a preferred hierarchial level for examining science teachers' PCK, many agree that continuing to perform studies at the various levels is beneficial.

5) Teachers' orientations influence teachers' PCK development. Three emergent models included teachers' orientations as components of PCK. This factor was determined to influence the generic, general or subject-specific, and domain-specific levels of PCK. Orientations defined as goals and purposes for teaching was identified as important at the level of generic and subject-specific (Fernandez-Balboa et al, 1995; Lee et al., 2008). At the domain-specific level, researchers found teachers' orientations as conceptions of teaching and learning to be important.

Studies have also investigated the influence of teachers' orientations as views of science on their PCK development. In a study of secondary chemistry teachers, Veal (2004) found that changes in the teachers' beliefs about content topics facilitated PCK development. Focused on the connection between epistemological views and science teaching, Hashweh (1996a; 1996b) found that teachers that held positivist views expressed more judgment of students' naïve conceptions than teachers with constructivist views. Additionally, teachers with constructivist views had developed a more diverse collection of instructional strategies than the teachers with positivist views of knowledge.

Friedrichsen and Dana (2002) investigated the orientations of four experienced biology science teachers. Based on their findings, the authors developed a complex model of science teaching orientations. The authors also put forth four major findings: (a) the science teachers' orientations shifted based upon the specific course being taught in terms of content and grade level, (b) the teachers' orientations included more than just subject matter goals with the addition of affective components and general schooling goals, (c) prior work experiences influenced their orientations, and (d) the teachers' orientations were heavily influenced by the specific physical and cultural context in which they operated, particularly in the area of beliefs about student learning.

Although described as a ‘messy construct’ (Abell, 2007, p. 1126), orientations are considered to be complex cognitive structures. Friedrichsen et al., (2011) recommended that further studies be performed in the area of orientations and for the development of new instruments in support of future research.

6) The context in which educators teach influences their PCK development. Cochran et al. (1993) and Veal et al. (1999) included teachers’ knowledge of context defined as the contextual, cultural, and social limitations of the learning environment. Barnett and Hodson (2001) provided a broader view of impact of context on teachers’ PCK. They asserted that all of the components of PCK are context-specific and that PCK is experiential knowledge that is developed as a result of teachers’ decisions and experiences in the classroom. Studies involving teachers’ orientations also found that the social and physical context in which teachers operate influences their beliefs (Friedrichsen et al., 2002). While many PCK models and article discussions acknowledge the influence of context on teachers’ PCK development, few studies have specifically examined this interaction with respect to secondary science teachers.

PCK of Postsecondary Science Teachers

Studies in higher education have transitioned from performing and evaluating interventions to studying the impact of teachers’ beliefs on instructional practices. Only a small number of studies have examined teachers’ knowledge structures using the PCK framework. Levinson-Rose and Menges (1981) reviewed over 70 publications directed at improving college teaching. The researchers evaluated each study and assigned a confidence rating regarding the quality of the research. Their findings revealed that the studies were "of lower quality than we hoped" (p. 417). Levinson-Rose et al. remarked that the field of research on improving college teaching was not well defined. As part of a series of recommendations, the authors emphasized the need for collecting data to investigate cognitive, emotional, and developmental experiences of teachers.

Shifting away from evaluating interventions, studies were conducted during the 1990's to investigate post-secondary teachers' beliefs about and orientations toward teaching. Kane, Sandretto, and Heath (2002) published a critical review of research on the teaching beliefs and practices of university professors. Although this line of research parallels studies of teachers' beliefs at the primary and secondary levels, the authors found low levels of cross-referencing by tertiary studies. They also determined that much of the research was confined to examining what teachers say without examining their actual practices. Interestingly, Kane et al. discussed research on teacher knowledge including PCK, however, they recommended continuing research in the area of teacher beliefs in higher education along with the examination of teacher practices through classroom observations. Only a small number of studies of faculty knowledge have been conducted using the PCK framework.

This discussion is intended to situate research in higher education teaching from the teacher's perspective. In comparison to studies at the secondary level, it appears that much of the research at the tertiary level has been in the area of teachers' orientations toward teaching. The findings of the few studies of postsecondary teachers' PCK are discussed.

1) Teachers require a wide range of knowledge to build effective PCK. Our understanding of tertiary science teachers' knowledge needed to build effective PCK is very limited. Most of the studies of faculty knowledge have involved teachers from multiple disciplines. Fernandez-Balboa et al. (1995) designed their study to understand the "generic" nature of tertiary teachers' PCK. The collective PCK of 10 exceptional university teachers from a variety of subject areas was reported to include five knowledge domains: content knowledge, knowledge about students, knowledge of instructional strategies, knowledge of teaching context, and knowledge of the purposes for teaching.

Two studies of faculty PCK examined specific knowledge domains. With a sample of 11 new faculty across multiple disciplines and from various work environments (a research university, a liberal arts college, and a community college), Lenze (1994) studied the teachers' knowledge of student difficulties in learning content. Findings indicated that the faculty were more aware of students' problems regarding academic processes, and the teachers' knowledge of student difficulties were directly linked to content rather than student learning. Major and Palmer (2002, 2006) performed a study of faculty at a small liberal arts college engaged in a campus-wide reform effort of introducing problem-based learning. The research was designed to characterize the PCK development of the teachers who elected to participate in the curriculum change. The authors reported six knowledge domains: goals, context, students, curriculum, pedagogy, and the teachers' role. When combined, the knowledge of teaching goals and the teachers' role consisted of elements consistent with teachers' orientations.

One study sought to capture the topic-specific PCK of faculty teaching quantum chemistry. Padilla and Van Driel (2011) interviewed six university teachers who are specialists in the field of quantum chemistry. The study made use of the Magnusson et al. (1999) model of PCK for data analysis. The authors reported that the teachers had similar orientations (didactic and academic rigor), however, they found variable relationships between the knowledge domains among the faculty. The teachers' knowledge of assessment was less developed than the other domains. Padilla and Van Driel (2011) suggested that the teachers' view of the role of assessment is likely to be an influencing factor.

Based on the findings of a limited number of studies, it is evident that tertiary science teachers require a wide range of knowledge to build their PCK. However, additional studies that allow knowledge structures to emerge from the data are needed. Investigations designed to explore the knowledge of individual science teachers rather than a collection of teachers would lead to a better understanding of science faculty PCK.

2) Teachers require well-developed content knowledge to build effective PCK. Given that university faculty are considered experts in their fields, the research in the area of subject matter knowledge as it relates to teaching is limited. One of the few studies in higher education that employed PCK as a framework (Fernandez-Balboa et. al., 1995) reported that professors' knowledge of subject matter was a 'given', however, all of the university teachers in the study stated that subject matter was important, and several remarked that their subject matter was "not a static body of knowledge". One study provided evidence of the need for strong content knowledge at the postsecondary level. While the study did not attempt to evaluate the teachers' content knowledge, Davidowitz et al. (2011) reported that a chemistry teachers' ability to 'unpack' the content during instruction was supported by a deep understanding of the subject matter.

In the limited number of studies of faculty PCK, most did not investigate the teachers' content knowledge as it was assumed to be sufficient. However, future studies are needed to investigate the specializations of science faculty and how those specializations influence their conceptions of the content and their teaching practices.

3) Classroom experience is essential to PCK and SMK development. The effect of classroom experience on the PCK development of tertiary teachers remains unclear. In an exploratory study of 31 university teachers from multiple disciplines, Trigwell, Prosser, Martin and Ramsden (2005) found that 20 teachers experienced no change in their understanding of their content area. Based upon the interview data, it was determined that these teachers were more likely to experience teaching as a process of information transfer from teacher to student. University teachers from the science and health-related fields (eight individuals) reported little to no change in their subject matter knowledge as a result of teaching experiences. However, other postsecondary teachers reported shifts in their view of the subject matter. Following the implementation of a campus-wide intervention, faculty members of a small, private university reported perceiving their disciplines in new ways as they engaged in the process of transforming their courses (Martin et al., 2006).

The data collection techniques of studies performed at the tertiary level have relied heavily on teacher interviews. The validity of self-reported accounts of classroom practices and interactions has been questioned, and one study revealed that the teachers' descriptions of classroom behaviors did not match those observed during classroom observations (Ebert-May, 2011). Research designs that incorporate multiple data sources including classroom observations would best contribute to our understanding of faculty PCK.

4) Teachers develop different levels of PCK. Studies at the tertiary level have been limited to investigations of generic and topic-specific PCK. Most of the studies of faculty knowledge have involved teachers from multiple disciplines, which limited the findings to include only generic forms of PCK applicable across subject areas (Fernandez-Balboa et al. , 1995; Lenze, 1994; Major et al., 2002, 2006). Two studies of topic-specific faculty PCK were performed in the domain of chemistry: organic chemistry (Davidowitz et al., 2011) and quantum chemistry (Padilla et al., 2011).

With only a limited number of studies focused on science, additional studies are needed at the general, domain-specific, and topic-specific levels.

5) Teachers' orientations influence their PCK development. Studies of tertiary teachers have primarily involved investigations of their orientations toward teaching. Similar to the literature at the secondary level, many terms are used to refer to "orientations" including "paradigms", "intentions", "thinking", "conceptions", and "views". Research at the postsecondary level also appears to face the same duel definition of orientations, approaches to teaching and teachers' beliefs. Most of the literature reports attempts of classifying teachers into various categories of orientations, which are described as approaches to teaching (Kember & Gow, 1994; Mertz & McNeely, 1990; Trigwell, Prosser, and Taylor, 1994; Prosser, Trigwell, and Taylor, 1994; Trigwell and Prosser, 1996)

As orientations continues to be a 'messy construct' at the postsecondary level, Prosser et al., (1994) found that individual university teachers may be categorized into more than one orientation. They reported that five of the 24 university teachers held multiple conceptions, and in three cases, they encountered difficulty in classifying teachers' conceptions due to problems with distinguishing between three categories of conceptions.

Goals and purposes for teaching were identified by tertiary teachers as important factors in three studies of faculty PCK. Faculty from multiple disciplines at a large Australian university expressed the goals of transmitting accurate information to students and for students to form a knowledge base for future learning (Burroughs-Lange, 1996). Ten experienced university faculty in the U.S. described teaching purposes as persuading the students about the importance of the subject matter and enhancing students' lives (Fernandez-Balboa et al., 1995) Other postsecondary teachers reported more general students-centered goals of wanting students to develop a love of learning, develop values and ethics, become responsible members of society, and learn about and become consumers of knowledge (Major et al., 2002).

In a topic-specific study of PCK, chemistry professors' views of science were expressed in their thinking about teaching. Padilla, Ponce-de-Leon, Rembado, and Garritz (2008) interviewed four participants about their teaching of the topic of "amount of substance" using a modified version of Loughran et. al.'s (2004) protocol. The interview responses were classified into one of five 'conceptual profiles', which were categories of the teachers' epistemological views of the subject matter related to student learning. The findings reported that the teachers varied in their views of teaching the about the mole to undergraduate students. One teacher, who had a PhD in inorganic chemistry, held an "empiricist" view as she described teaching the "amount of substance" as obtaining precise measures using empirical scales with an emphasis on the macroscopic view of matter. Another teacher, who had a PhD in biochemistry, held a “formal rationalist” view which linked macroscopic measurements to microscopic entities. The two teachers with bachelor’s degrees in engineering demonstrated a tendency toward the “empiricist” conceptual profile with some indications of “formalist” and “formal rationalist” views. Although the specialization of the individual teachers was not emphasized in the study, the findings support future research in this area.

Research in the area of teachers’ conceptions of teaching and learning were limited to a single study. Burroughs-Lange (1996) studied 20 teachers from multiple disciplines in a large Australian university. The study was designed to determine the types of feedback and interpretations of feedback that interact to develop the teachers’ conceptions of their role as an instructor. The authors found that teachers experienced difficulty expressing their conceptions of the nature of learning, which were limited to descriptions of what the students should be able to do (i.e., transfer learned information from theory into practice); they offered no discussion of the requirements for learning to take place. The teachers’ conceptions of learners referred mainly to the attributes of students (i.e., attitudes, deficits) and the needs of students, which were discussed in the context of students mastering the subject matter rather than the expressed needs of students. These teachers viewed their primary role of instructor as the: (1) designer of learning environments, (2) evaluator of student learning, (3) nurturer, and (4) motivator. Most of the teachers emphasized using the transmission model of teaching with some added features blended into the lecture (i.e., modeling techniques, using technology, sharing their philosophy). Summative assessments were identified as the primary method of assessing students' understanding; diagnostic or formative assessments were not mentioned as evaluative tools.

Davidowitz et al. (2011) modified their original model of PCK to include teachers' orientations as they documented selected teaching practices to specific beliefs. An organic chemistry professors' belief of the importance of motivating students lead him to use instructional strategies and provide explanations that would be encouraging to students. Further studies designed to investigate the influence of teachers' orientations on PCK are needed.

6) The context in which educators teach influences their PCK development. Research of faculty knowledge of context has been limited to the teachers' reporting contextual factors that influence their teaching. Fernandez-Balboa and Stiehl (1995) conducted a study of 10 exceptional university teachers across multiple disciplines. The tertiary teachers identified knowledge of teaching context as an important domain. They reported this knowledge structure as constraints to university teaching such as large class sizes, lack of support, time limitations, scarcity of resources, students' lack of preparedness and poor attitudes about learning, and tenure and promotion standards. Major et al. (2002, 2006) explored faculty knowledge at a small, private, religiously-affiliated liberal arts college in the southeastern U.S. Study participants reported several factors which were categorized as their knowledge of context. The teachers regarded the culture of the region and institution as influencing teaching and learning. With the implementation of a problem-based learning curriculum, teachers encountered issues involving the cultural and religious values of being 'nice and polite'. Students' reluctance to be critical of their peers was considered to be a barrier to student learning.

Similar to secondary science education research, context is often mentioned as an influencing factor in PCK development. Future studies that include knowledge of context as part of a broader study should explore the ways in which context influences faculty PCK. In addition, studies that focus specifically on the interaction between context and PCK are needed.

Gaps within the Literature

Based upon the review of the postsecondary literature in science education, gaps exist in the area of science faculty knowledge for teaching. As most PCK research at the tertiary level has included teachers from multiple disciplines, there is a need for studies exploring the PCK of science faculty, especially at the subject-specific (ie., biology, geology) and topic-specific levels (ie, genetics, geomorphology). The influence of teachers' orientations has been identified as an important component in tertiary teachers' knowledge development. Studies of the nature of the interaction should continue to be explored. In addition, studies are needed to investigate the specializations of science faculty and how those specializations influence their conceptions of the content and their teaching practices.

The data collection techniques of studies performed at the tertiary level have relied heavily on teacher interviews. Research designs that incorporate multiple data sources including classroom observations would best contribute to our understanding of faculty PCK.

Context is often mentioned as an influencing factor in PCK development, however, the influence of the context in which teachers' operate on their PCK is virtually unknown. Teachers at the postsecondary levels work within many contexts such as community colleges, liberal arts colleges, and research/doctoral institutions. These environments vary geographically, demographically, and culturally. Teachers at the tertiary level also experience differences in teaching environments and class sizes (i.e., auditorium classrooms serving over 300 students, small classrooms with discussion-oriented furniture configurations serving 20 students). Studies at the postsecondary level need to explore how the social, cultural and physical environments of the school impact teachers' PCK.

Studies of discipline-specific PCK and topic-specific PCK biology faculty teaching at large doctoral/research institutions serve to better understand the knowledge of teachers operating in this context and provide needed information to support reforms in undergraduate science teaching.

Chapter 3: Method

This chapter will discuss the methods of inquiry, data collection, and analysis for this qualitative research study. A qualitative inquiry design was employed to reveal the PCK of biology faculty teaching large introductory courses.

Epistemological View and Theoretical Perspective

The design and implementation of this study is guided by the epistemological view of constructionism. From this perspective, knowledge is constructed by individuals as they engage in and interpret the world around them (Crotty, 1998). Constructionism includes the essential component of intentionality, which is the existence of an active relationship between the subject and the objects. “When the mind becomes conscious of something, when it ‘knows’ something, it reaches out to, and into, that object” (Crotty, 1998, p. 44). In addition, this knowledge base is always changing as humans continually engage in and interpret the world around them. However, knowledge construction does not take place simply as individuals encounter phenomena and make sense of them; humans enter a world in which meaning already exists. Knowledge construction is influenced by the socially agreed upon meanings of objects and phenomena of the world (Crotty, 1998). The constructionist view is that knowledge is built through individuals experiencing the world around them and the cultural meanings that are accepted by the social group in which they operate.

The epistemological view of constructionism is expressed within the theoretical perspective of interpretivism. The goal of interpretivism is to understand the experiences of individuals in which meaning is constructed as these individuals interact with and interpret the world in the regular contexts of their lives (Crotty, 1998). From this perspective, multiple truths exist such that each individual constructs a specific realty based upon their experiences and interpretations. The goal of studies conducted through the lens of interpretivism is not to identify which participant reality best the “true” reality, rather it is to provide an accurate and thorough representation of the truth constructed by each subject (Crotty, 1998).

Use of the interpretivist theoretical framework was appropriate for this research study as it is consistent with the complex process of PCK development involving a unique set of knowledge domains and experiences specific to the profession (Lee, et al., 2007; Magnusson, et al., 1999). Meaning making is the mechanism through which teachers develop PCK as they engage in the processes of planning, reflection, and teaching of specific subject matter (Magnusson, et al., 1999). The interpretivist perspective allows for the PCK conceptual framework to provide a structure for examining teachers’ knowledge, which is developed through their interactions with and interpretations of the world around them. These interactions are essential for the transformation of multiple domains of knowledge into PCK which is directing teachers practices that ultimately build student understanding of the content.

Methodology

Through the epistemological view of constructionism and theoretical perspective of interpretivism, this study utilized a qualitative approach to investigate the research questions. Qualitative studies involve researchers observing and interacting with subjects under study in their natural setting. Although a protocol may be developed for a particular investigation, the researcher serves as the instrument for collecting field data from multiple sources (Creswell, 2007). Qualitative studies aim to identify and explore emergent themes through an inductive process of data collection, interpretation, and theme building to develop a picture of complex processes (Bogdan & Biklen, 2007).

A methodology is the approach used in the design and implementation of a study to best answer the research questions (Crotty, 1998). The method of inquiry for the study involved a series of interviews and observations, which will be used to explore the "whats" and "hows" of a particular process.

Setting and Participants. This study included a purposeful sample of six biology faculty members. The study participants came from three large doctoral/ research institutions located in various regions of the United States. Relevant demographics for these universities are included in Table 1.

Table 1

Relevant Demographics of the Three Institutions included in the Study

University	12-month undergraduate enrollment for 2010	Number of bachelor's degrees in biology* compared to total degrees awarded in 2009
Red University	28,082	525 / 6,490
Blue University	37,989	834 / 8,223
Green University	60,204	647 / 11,810

Note. Bachelor's degrees include fields of biological and biomedical sciences.

Identification of the instructors occurred by selecting teachers who were engaged in teaching an introductory-level biology course during the study. An "introductory-level" course is defined as a class designed for first-year college students, which may include courses designed for either biology majors or non-majors. The biology faculty were contacted via email to explain the proposed study and invite their participation.

Participation in the study was completely voluntary. Written and/or verbal permission was retrieved from participant volunteers.

It is possible that sensitive ethical issues may arise during the course of the study. For the protection of participating biology faculty and institutions, permission to conduct the research was secured by the Institutional Review Board (IRB) of all three institutions. To protect the anonymity of the faulty and the universities, the names of the individuals and institutions were masked by the use of gender-neutral pseudonyms. In addition, all identifying information was removed from documents used in the study. Relevant university administrators were informed of the study, however, the names of the study participants were not revealed.

The study is designed to minimize the level of disruption to the professional responsibilities of the biology faculty while maximizing the quality of the data collected. Activities involving the direct participation of the faculty members were limited to a single in-depth interview, a classroom observation, and a post-observation interview.

Data Collection. Data was collected from multiple sources during the study and used to characterize participants' knowledge and perceptions for teaching large introductory biology courses. Data collected for this research included (1) documentation, (2) direct observations of biology faculty in the classroom, (3) artifacts, and (4) semi-structured interviews of biology faculty. Information was collected through direct observation of instruction in the classroom. Additionally, the participants supplied data through two interviews, their curriculum vitae documenting their professional experiences, and artifacts used in their course. Data collected earlier in the study was used to inform subsequent data collection procedures (Figure 8). The data in the study included:

1) Documentation. Participants' curriculum vitae were obtained and reviewed prior to conducting interviews. These documents will provide information about the professional experiences of the biology faculty and the current context in which they work. They also documented their professional accomplishments including, but not limited to, degrees earned, places of employment, publications, conference presentations, teaching experience, awards, and memberships to professional organizations.

2) Pre-observation semi-structured interviews. Immediately prior to the classroom observations, the participants were interviewed about their experiences and beliefs around teaching large introductory-level biology courses. Initial questions were designed to be general to allow teachers to emphasize those factors (i.e., knowledge, experiences, beliefs) which most influence their teaching practices and avoid leading them to a particular response. Example questions include:

- *What is your philosophy of instruction for large introductory-level biology courses?*
- *What is your philosophy of how students learn in large introductory-level biology courses?*
    - *What is the role of the teacher? What is the role of the student?*
- *How often have you taught large introductory-level biology courses?*
- *How did you learn to teach?*
    - *What past experiences have you had that influenced your teaching?*

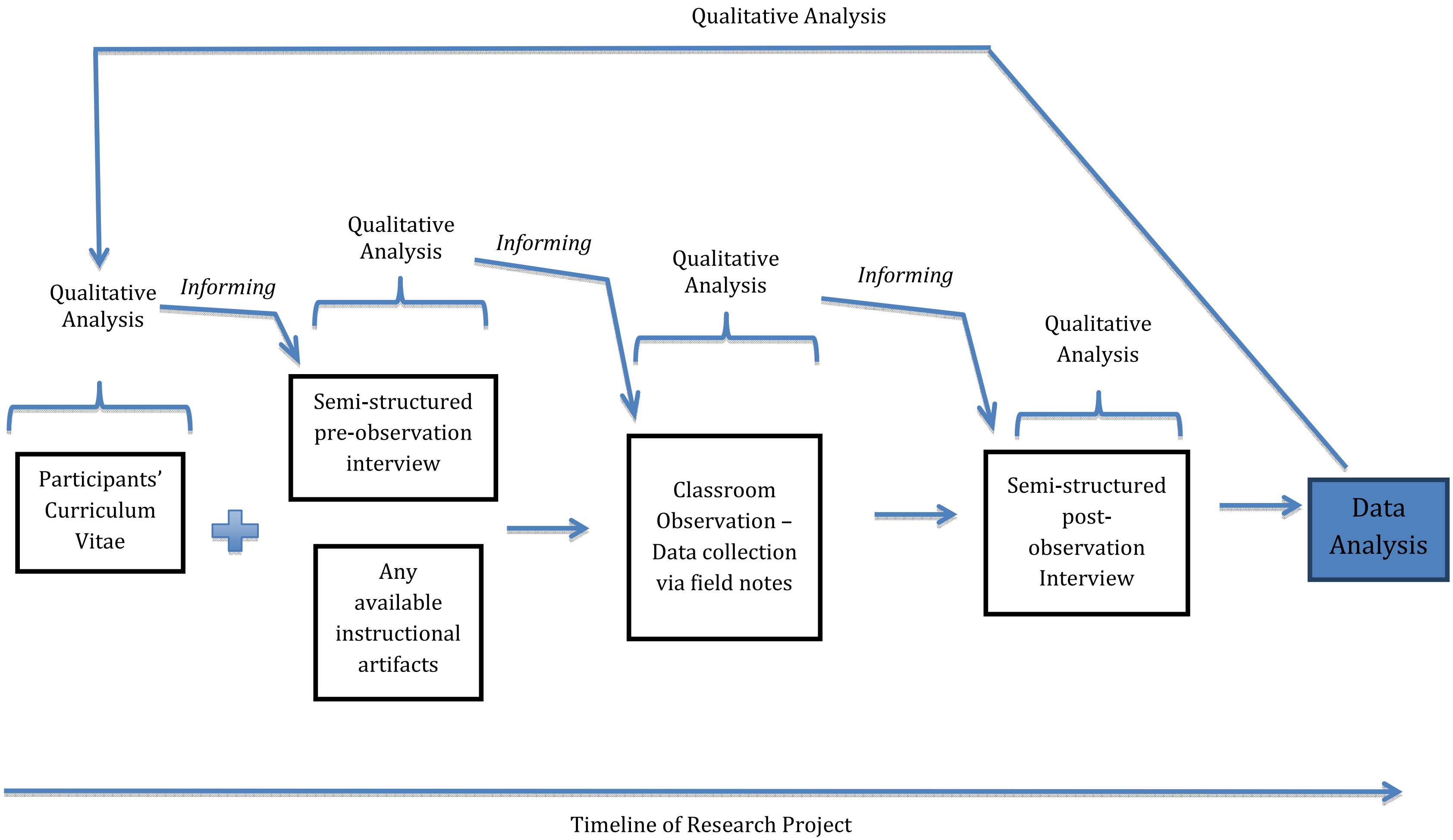


Figure 8. Data Collection and Analysis Flow Chart.

- *Describe your idea of a "good" biology instructor in the setting of a large introductory-level biology course. What are the things that you do to be a "good" biology instructor?*
- *In your current position, what are the primary factors that influence your teaching?*
  - *Who are the players in your professional world that influence your teaching practices?*
  - *Given where you are in your career track, have your teaching practices changed? If so, can you provide an example that will help me to understand this change?*

In addition, the interview was designed to gather information about the teachers' thinking with regard to their teaching the lesson. Example questions include:

- *Today, you will be teaching a lesson on an introductory level topic in biology. Can you tell me how you will go about teaching on this topic and how you prepared for class?*
- *What were your primary considerations when planning for today?*
- *(If applicable) Can you tell me about the artifacts that you generated for today's class?*
- *What are your goals for today's class?*

3) Artifacts. Any available artifacts that were generated as part of the genetics lesson were obtained from the biology faculty. At times, these artifacts were used during the pre-observation interviews.

4) Field notes of classroom observations. Each study participant was observed teaching about concepts in an introductory biology course. The researcher recorded field notes of classroom observations, which focused on the interactions between the teacher and their environment.
5) Post-observation interviews. Immediately following the classroom observations, the participants were interviewed about their thinking and experiences while teaching the lesson. Example questions include:
   - *What are your thoughts about today's lesson?*
   - *Were you presented with any challenges during the class? If so, please describe them.*
   - *Did you feel that you met your goals? Why or why not?*
     - *What evidence do you have to support this idea?*
   - *In hindsight, is there anything that you would do differently?*
   - *Additional questions regarding observations of interactions in the classroom.*

Hard copies of documents, artifacts, and field notes were stored in a secure location at the research institution. The semi-structured interviews were conducted in-person and recorded on an audio recording software. The recorded question and answer sessions were contained in electronic files stored on a computer. All data was de-identified, and participants were assigned a pseudonym for the analysis.

Data Analysis and Interpretation. The processes of data collection and data analysis occur simultaneously in qualitative research (Creswell, 2007). Throughout the data analysis process, researchers "code" their data through a process of assigning words or phrases to segments of text or images. Initially, these codes are narrowly assigned such that many categories emerge. These codes are used to identify and describe patterns and themes from the perspective of the participants. This is accomplished by aggregating similar codes together.

The data collected for the study (documents, classroom observation data, artifacts, and interviews) was collected in or converted to an electronic format prior to qualitative data analysis. The semi-structured interviews were transcribed and field notes typed into electronic word processing software. Hard copies of documents and artifacts were scanned and stored as image files. The electronic versions of the data were uploaded into a qualitative data analysis software program called NVivo. NVivo software facilitates the analysis of textual and graphic data. Codes and themes are captured and stored in the NVivo project allowing meaningful data to be identified, coded, grouped, and regrouped for analysis.

During the data analysis, the data was organized, reviewed repeatedly, and continually coded. Coding of the data occurred in three phases.

- Initial coding was conducted to identify the participant's use of specific domains of knowledge. This analysis will make use of coding categories that are selected a priori to the data analysis (Shulman's (1987) seven knowledge domains) or that emerge during the reading of the data.
- A second process of coding was performed to identify interactions that influence the participant's teaching practices. This analysis made use of coding categories that emerge from the data.
- Final coding was performed to look for confirming and disconfirming evidence to support prior coding.

At the completion of the data collection process, the data was analyzed by comparing, contrasting, aggregating, and ordering of the collected data (Creswell, 2007). Themes were generated through inductive analysis of the data. These themes were grouped and organized to address the research questions.

Validity and Reliability

In qualitative research, validity is also known as credibility and refers to determining whether the findings of a study are accurate from the standpoint of the researcher, the participants, and the readers (Creswell, 2007). Multiple strategies were employed to address validity issues as recommended by Creswell (2007):

- Triangulation of data – Data were collected through multiple data sources including documentation, survey responses, artifacts, interviews, and classroom observations.
- Researchers' bias – Every qualitative researcher brings bias to a study that may influence the data analysis and interpretation. Researchers' bias was made explicit as part of the reported findings.
- Peer debriefing – Additional researchers served as peer examiners. These individuals reviewed and asked questions about the study, allowing the researcher to address issues posed by others.

Qualitative reliability typically refers to the consistency of the research approach across different researchers including data collection, analysis, and interpretation procedures. In conducting research as the sole investigator, the researcher made use of one particular strategy to ensure reliability: maintaining consistency in the meaning of codes (Creswell, 2007). The meaning of codes should remain consistent during data analysis. To prevent a shift in the definition of codes, the researcher recorded and reviewed memos about the codes and their definitions throughout the process of coding.

Limitations of the Study

It is the nature of all research that limitations to the findings will exist. In qualitative research, the intent is not to uncover generalizable patterns and themes across people, institutions and geographic locations. In this qualitative study, the sample size was limited to a small number of individuals (n = 6) who will likely not represent the general population of biology faculty. The participants in the study were purposefully selected based upon their employment at a large doctoral/research university and active engagement in teaching an introductory-level biology courses. These individuals voluntarily participated in the study, which may result in their representing a particular subset of biology faculty willing to engage in educational research. Additionally, the teachers were recruited from various regions of the United States. Therefore, there may be effects that are specific to these locations, which would make generalizing to all biology faculty difficult. Every attempt was made to reduce the effect of geographic differences through the data collection protocols. Given the small sample size and purposeful sampling procedure, the ability of researchers to relate the findings to a broader population was extremely limited, however, the strength from these findings will help to begin to characterize the nature of the PCK of biology faculty at large doctoral/research institutions.

Chapter 4: Data Analysis and Results

This chapter consists of a descriptive profile of each participant in the study. Each profile is divided into five sections including the responsibilities and experiences of the faculty in their current position, their content knowledge, their self-identified sources of teaching knowledge, their perceptions of learners and learning, and their current perspectives of teaching and teaching practices. The final section presents the results of a cross-profile analysis.

Alex's Profile

Alex is an early-career biology instructor at Red University. After earning a doctoral degree, Alex was hired in a non-tenure track position at Red University to teach two sections of a large introductory biology course. Being in a non-tenure track position, Alex's responsibilities were primarily in the area of teaching and do not include performing research. At the time of the study, Alex had less than three years of experience teaching an introductory-level biology course designed for biology majors with an average enrollment of 800 students (400 students per section). Upon accepting the position, Alex understood that the role of 'lecturer' did not include developing curriculum for the course, but rather following the curriculum established by the inherited course materials developed by previous faculty.

In the current appointment, Alex reported having limited interactions with faculty within the department. "When you're a lecturer you're kind of isolated, that's the downside. So, you don't really interact a lot with other faculty (Interview 1 11/19/12)." Alex's interactions with colleagues were limited to administrative meetings.

Knowledge of the content. Based upon education and professional experience, Alex had well-developed content knowledge in the area of biology. According to Alex's curriculum vitae (CV 12/22/12), Alex has earned three postsecondary degrees in the area of biology. As a doctoral student, Alex gained experience in conducting research within a sub-discipline of biology. Alex engaged in several biology research projects, which culminated in multiple publications in science journals and presentations of papers and posters at professional conferences (CV 12/22/12).

Self-identified sources of knowledge of teaching. Alex had gained experience in teaching science in small classes at the secondary and postsecondary levels. After completing a master's degree, Alex attended a year-long pedagogical training program required for secondary-level teaching and subsequently served as a math and science teacher at the secondary level for four years. As a doctoral student, Alex served as a graduate teaching assistant for two years, which included teaching a laboratory that accompanies a large introductory-level course. Alex reported gaining knowledge of student difficulties with the content from teaching the introductory laboratory course. "… I know people struggled with Hardy-Weinberg and struggled with mitosis, meiosis and that's what teachers get to see when they have actually taught the labs as well, I think (Interview 1 11/19/12)."

Alex also mentioned observing several models of postsecondary instruction in multiple higher education settings. As a youth, Alex observed a parent teaching undergraduate students while accompanying them during field studies.

> "My dad was a pretty good -- biologist and lecturer, so I -- we started pretty early, I went on fields trips with him and his students, and I kind of saw the interaction that Alex had with his students, and I'm trying to have

the same very positive attitude (Interview 1 11/19/12)."

However, Alex's personal experiences in observations of many biology instructors as a student served to be primarily negative models. "I have had a lot of bad biology instructors, so I kind of learned a lot of things that I should not do (Interview 1 11/19/12)."

Perceptions of learners and learning. Alex expressed that student learning was supported by the presentation of well-organized information by the instructor, however, Alex identified a set of student behaviors considered to be critical for their learning. Alex stated that "[there's] a lot of reading in this course" (Interview 1 11/19/12) that is required of students. During class, Alex occasionally "remind[ed] them that it can be helpful to read ahead of lecture" (Interview 2 11/19/12) and made references to the textbook as Alex lectured (Field notes 11/19/12). Alex perceived that "those students that do well, they read before lecture, but those that don't do well, they probably don't read before lecture."

In the classroom setting, Alex maintained that students must remain attentive during lecture in order to receive the information that is presented. Although unsure of the types of activities that students engaged in outside of class to support their learning, Alex reported "encourag[ing] students to figure out how they learn best" and recommended that they seek out resources that will help them to gain a better understanding of the material.

Alex also maintained that students struggle with a multitude of practical issues, which can impede their learning, and recognized that minimizing these issues can support their learning in the course.

> "… students are very intense about the practical things, [and they] take a lot of emphasis away from the subject. But as long as the practical things are cleared, then the subject matter falls into place, and they can focus on it instead of stressing about what's on the quiz (Interview 1 11/19/12)."

Perceptions of Teaching and Teaching Practices. Alex taught the introductory biology course in an auditorium-style classroom with an elevated stage, which includes a computer and large screen for projecting the presentation slides. Through two wide aisles on either side of the room, students arrived at sitting in rows of individual seats with small foldable desktops. Within this setting, Alex indicated that it is difficult to have a dialogue with students. A microphone was used to enable students to hear Alex's vocalizations. However, Alex reported having difficulty hearing student responses and thus emphasized the importance of visual cues in looking for feedback from the student audience.

Alex considered the availability of course materials such as previous syllabi and Slide presentations along with the selected textbook to be beneficial for determining the course curriculum. Alex's view of the curriculum is that "it's, of course, based on the syllabus and on the [text]book (Interview 1 11/19/12)." With access to inherited materials, Alex had reviewed and modified previous presentations to develop slide shows, which were ultimately employed during the lectures. Alex purposefully designed the series of slides within the presentation to guide the explanations delivered verbally during the lecture.

Alex's view of instruction for teaching a large introductory level biology course emphasized teacher-centered practices with limited student interactions. "It becomes like a monologue, and this [way of] teaching is giving them knowledge, and then it's up to them to absorb it (Interview 1 11/19/12)." Alex considered lecture to be an overview of the detailed material covered in the textbook that "touches on the important parts" (Interview 1 11/19/12) and a means of reinforcing the readings. "Ideally, it should be a repetition. I have encouraged students to read the text before lecture, so that lecture would basically be just a reinforcement (Interview 1 11/19/12)." "And I think it's important that I keep relating to the textbook, since we are using it, right, so that they don't just go on and read, and lectures are not connected to it (Interview 2 11/19/12).

Alex emphasized delivering content to students through prepared slide shows and clear verbal explanations. Alex expressed the importance of designing slide presentations that are organized logically, are aesthetically appealing, and contain appropriate representations of biological concepts. During instruction, Alex stated that "when I feel that what I am trying to explain does not come out right, I will try explaining it again (Interview 2 11/19/12)." The explanations and representations were aspects of teaching that Alex continually worked to refine.

> "It's difficult sometimes to visualize how other people perceive you. But I'm at least trying to be aware of how I perform, how I structure my slides, I can tell a good PowerPoint lecturer from a bad one. I think most of the students can, but not all the lecturers can (Interview 1 11/19/12)."

Alex's primary means of representing the science during instruction was through verbally presenting logical explanations supported by textual and graphical depictions of the ideas. During the class observation, Alex lectured on the topic of ecological processes involving species interactions and the resulting manifestations, such as species diversity and population dynamics. Alex introduced the processes with a simplified condition in which temporal and spatial variables were held constant. The explanation then transitioned from simple to more complex processes with the introduction of varying conditions of space and time. Although the lecture involved telling stories of discovery using classic experiments, Alex's verbal explanations emphasized representing the biological processes as a set of "logical rules" with a series of "if, then" statements.

The biological knowledge was also represented on the slides using graphs, which depicted changes in population and species diversity over time. Nineteen different graphs were presented and incorporated into the lecture as Alex interpreted the graphs as logical 'if, then' statements of given conditions and resulting manifestations. Text, including 33 scientific terms, was also used to represent biological knowledge along with graphics including photos of scientists as well as maps and images of relevant geographic locations. "And so I think a good biology teacher would be one that consistently tries to improve instead of just turning the pile and reusing the same slides over and over again (Interview 1 11/19/12)."

Alex reported making use of two main strategies for breaking up the lectures and maintaining students' attention: questioning and humor. During class, Alex posed two questions verbally to the students, which elicited one to two-word responses from a small number of students (Field notes 11/19/12). The majority of responses came from students seated near the front of the auditorium in close proximity to the instructor (Field notes 11/19/12).

Clicker questions that were strategically placed within the Slide presentations provided an opportunity to have a respite from listening to the lecture. Alex reported making use of various types of clicker questions. In some instances, students responded to questions regarding the content while other questions probed for their opinions. During the classroom observation, three clicker questions were posed on two consecutive slides as part of the lecture (Field notes 11/19/12). When each slide was displayed, students were provided with approximately two minutes to discuss the question with neighboring students (Field notes 11/19/12). For each question, over 75 percent of the students selected the correct response (Field notes 11/19/12). Alex reported anticipating a high percentage of correct responses.

Alex also stressed the importance of using humor in the classroom for providing breaks during lecture. "One of the most important parts in my lecturing is that I use humor a lot (Interview 1 DATE)." Humor was also employed to break up the lecture as Alex made one joke, at which many of the students laughed in response (Field notes 11/19/12).

To assist students with practical matters, Alex communicated clear expectations to students by articulating them in the course syllabus, making administrative announcements during lecture, and "keeping updates on [the online course management system]" (Field notes 11/19/12; Interview 1 11/19/12). Alex reported responding to student e-mails during office hours in which the communications primarily focused on practical issues. During the class observation, Alex dedicated several minutes at the beginning of lecture to address administrative matters. Immediately following the lecture, three students approached Alex with individual questions (Field notes 11/19/12). One of the students asked a question concerning content, and “the two others were just practical stuff (Interview 2 11/19/12).”

Chris’ Profile

Subsequent to completing a doctoral degree and a post-doctoral appointment in a sub-discipline of biology, Chris was hired in a tenure-track position at Red University, which requires faculty to engage in research, teaching, and service. Chris’ curriculum vitae charted many accomplishments over a thirty-year period. As a prolific scholar, Chris has served as a faculty member at Red University for over twenty years and has held multiple appointments as a visiting scholar at other institutions. Chris has received numerous grants and multiple awards for research in biology and published many written works in peer-reviewed science journals and books. In supporting others in conducting research, Chris has supervised individual post-doctoral appointments, chaired and served on graduate student committees, as well as assisted undergraduate students in biology research experiences.

In the area of teaching, Chris gained experience in teaching undergraduate and graduate level biology courses, however, Chris focused particularly on developing and teaching a large undergraduate course designed for non-science majors. For over ten semesters, Chris served as the co-instructor for the course, which has had an enrollment of approximately 800 students (400 per section). Chris indicated that while different individual faculty members teach in different ways, most instructors in the biology department value teaching. Chris stated that faculty teaching is evaluated as part of the tenure process, and those with poor teaching evaluations are not awarded tenure. In addition, Chris indicated that many faculty members are interested in modifying their teaching, however, most are not provided with the necessary time and/or resources to redesign their biology courses. Most recently, Chris received an award in recognition of having a strong commitment to university teaching (CV 1/31/13; Interview 1 11/20/12).

Knowledge of content. Chris earned a bachelor's degree in biology as well as a master's degree and doctoral degree in a sub-discipline of biology (CV 1/31/13). In addition, Chris completed a post-doctoral appointment that emphasized research in the area of biology (CV 1/31/13). Over the course of completing graduate school and serving as a biology faculty member, Chris engaged in many biology research projects, which culminated in numerous publications in science journals and presentation of papers at professional conferences (CV 1/31/13).

Self-identified sources of knowledge of teaching. In the area of education, Chris taught biology courses at both the graduate and undergraduate levels. Chris described the earliest experiences in teaching large introductory biology courses as being difficult, which stemmed from having very little support. Chris did not receive "any pedagogical training of any kind as a graduate student" and learned to teach primarily through "trial and error" (Interview 1 11/20/12).

> "It was very painful for several years. So, I don't think I was very good at it for several years, -- The first time I came here, they just threw me in the class by myself into [the large introductory course] section. It was pretty bad, I think. And then I got paired up with someone who was pretty good at it. Then, I actually did some pedagogical summer course. We had one session with [a faculty member] about inquiry-based teaching, and it helped (Interview 1 11/20/12)."

In co-teaching a large introductory biology course, Chris reported having positive mentors that served as good models of instruction. "And then I had some pretty good mentors who taught with me for a while, and I would observe what they were doing. (Interview 1 11/20/12)."

Although less influential than direct experience of teaching biology courses, Chris also reported learning about teaching from a limited amount of formal training as well as reading literature pertaining to the area of undergraduate biology teaching. Chris participated in a summer course that emphasized inquiry-based teaching at the postsecondary level. This workshop was designed and administered by a biology faculty member who was engaged in science education research that focused on college teaching and learning. In addition, Chris reported learning about different pedagogical approaches from reading science education literature.

Perceptions of learners and learning. Chris stated that students "need to be active learners" and be "engaged in their own education" (Interview 1 11/20/12). However, Chris expressed that students seem to be increasingly less engaged in the learning process and do not realize that they are struggling until exam grades are posted.

> "It's the turning around thing that's hard. -- When you are on the receiving end of something [that] someone is good [at] explaining, -- that's not all it takes. So it takes internalizing it, and that's just why it's frustrating -- it's hard to get the students to engage beyond the task themselves, to struggle with it long enough that they sort of start to get the feeling for it. (Interview 1 11/20/12)"

Although unsure about the types of activities that students engage in outside of class to support their learning, Chris stated that students need to improve their awareness about their own level of understanding and take steps to "grapple with the material and make sense of it. (Interview 1 11/20/12)"

> "So we try and emphasize that they need to be active learners, so they have to become engaged in their own education. So it's not like you sit there, and I pour information into your empty cranium, and then you return that to me on an exam or something like that. So my hope is that they get actively engaged, and they say, 'I didn't get that, so I need to just do some extra reading; I need to follow up and figure out what's going on'. (Interview 1 11/20/12)"

Chris reported having knowledge of student difficulties with the content of the course (i.e., students have misconceptions about their bodies, poor conceptions of molecules, difficulties with abstractions, probability and combinatorial reasoning). Chris learned about these difficulties over the many years of students coming into office hours. "They come in and talk to you, and you say okay, here are these molecules and there are – it's here that you start to understand, they don't really understand what the molecule is." Chris stated that "it is hard to overestimate the degree to which they don't understand."

Perceptions of teaching and teaching practices. Chris taught in a large auditorium in which the rows of student seating were positioned above the stage. A podium was located at the side of the stage along with a computer, and large screen allowed for the presentation slides to be projected during lecture. Through two narrow aisles on either side of the room, students entered the classroom and sat in rows of individual seats with small foldable desktops. A microphone was used to enable student to hear Chris' vocalizations.

As the co-instructor for the large introductory biology course for non-science majors, Chris has played a significant role in designing the curriculum for the course. Chris articulated that the course goals "are primarily to help students improve and master the skills of scientific reasoning, to gain basic biological knowledge so they can understand how their bodies work and biologically relevant issues that are in the political arena (Interview 1 11/20/12)." At the start of the observed lecture, Chris displayed a recent article discussing individual genome sequencing along with a screenshot of an internet website advertising genome sequencing services (PPT 11/20/12). Chris connected the topic to the students by announcing: "You will have your genome sequenced within the next 10 years (Field notes 11/20/12)." In addition, Chris related the process of protein synthesis to them by stating that "this is the process that makes the proteins in your body – like our hair (Field notes 11/20/12)." The curriculum also included common genetic diseases that follow the rules of Mendelian genetics as well as applications of DNA analysis in forensic sciences (PPT 11/20/12).

Chris' view of instruction for teaching a large introductory level biology course emphasized teacher-centered practices along with incorporating various means of breaking up the lecture.

> "I eventually learned, okay, what is it that I have to take out, what's really important about all this stuff, like two things, three things per lecture at the most, get all the rest of that stuff out of [the Powerpoint presentation], learn how to break it up more, learn how to make it clear, learn how to be funnier (Interview 1 11/20/12)."

Chris viewed providing clear explanations to students as being an important part of the role of an instructor. "I understand, because I am really good at explaining stuff, actually, it turns out. (Interview 1 11/20/12)." These explanations of biological concepts were directly connected to the Slide presentations Chris prepared for lecture.

As a means of presenting information in an organized structure, Chris designed Slide presentations in the format of an outline (PPT 11/20/12). At the beginning of lecture, Chris briefly reviewed the current placement of the lecture within the outline structure and continued to present and build out new elements within the outline (Field notes 11/20/12).

> "Well, usually, what I am doing is I am building an outline so that it accumulates stuff over time. So, the outline comes back during the class as they move along and then switches on, you know, some demonstrations. So what [they] are trying to do is create an outline (Interview 1 11/20/12)."

The organization of the slides and the representations that they contained served as cues for Chris' explanations of the biological concepts.

Chris represented biological knowledge through an historical account of the discovery of the structure of DNA, a simplified stick-and-letter model of the DNA molecule, and analogies. Chris' explanations included a brief discussion of historical works (Hershey-Chase experiment, Chargaff's ratios, Franklin's crystallographic images, and Watson and Crick's insight) used to tell the story of the discovery of the structure of the DNA molecule (Field notes 11/20/12; PPT 11/20/12). Chris explained the process of DNA replication by identifying the complementary pairs of nucleotides in the molecule (A-T; C-G) and subsequently matching the appropriate nucleotides for a given series of nucleotides. Chris made use of analogies to explain the process of protein synthesis. "I use this analogy between DNA as a language and language as a language, right, it's letters and words and paragraphs and all sorts of things [that are built]." Chris' explanations stepped through the processes of translation and transcription in building proteins, which were related to the formation of words from the "combinations of letters in the alphabet" (Interview 2 11/20/12). In the event of mutations, some proteins resulted in unexpressed changes in the genetic code, which were compared to synonyms in language.

The biological knowledge was also represented on the slides using text, images, and models. Text was included on the slides, which highlighted 37 scientific terms. In addition, photographs of scientists and images of relevant data were displayed to support the explanations. A complex model of the DNA molecule, including individual atoms and the location of chemical bonds, was simplified to two lines representing the sugar backbone and a series of letters representing the nucleotides. This simple model was employed during the explanations of DNA replication and protein synthesis.

The interactions that Chris had with students in the instructional setting were designed to "break the lecture up into pieces" (Interview 1 11/20/12). These instructor-directed interactions consisted short dialogues with a limited number of students. During lecture, Chris engaged in brief conversations with individual students as they responded to questions that Chris posed verbally to the class (Field notes 11/20/12). Chris also responded to student-posed questions during these exchanges, however, these interactions were highly controlled by the instructor. For example, students asked questions about the spread of cancer cells, reasons for eating fruits with antioxidants, and the cause of people having Type I diabetes (Field notes 11/20/12). While providing brief explanations to these questions, Chris redirected the lecture by stating, "We can talk more later if you are interested" and "These are great questions. Thanks for that, but we have to keep moving" (Field notes 11/20/12) and returned to explaining the content displayed on the slides.

Other interactions involved multiple students responding to instructor-posed questions. Students provided answers to pre-determined questions embedded in the Slide presentation by either calling out answers in unison or selecting an answer using a clicker. Chris included these activities to provide students with an opportunity to practice answering questions similar to those on the exams.

> "Well, with translation thing, we'll do many examples, right? Because with 4 codons doing it four times, because they are using the table four times to make this whole piece and -- so there is a lot of replication in that. Hopefully, you know, that helps (Interview 2 11/20/12)."

During lecture, students were provided with approximately two minutes to discuss the question with neighboring students and enter their response (Field notes 11/20/12). After students selected their answers, Chris provided an explanation of the correct response as well as the more common incorrect responses (Field notes 11/20/12).

> "I talk about each question in turn, answer in turn like the ones that were chosen were wrong. I usually say okay, here is why this one is wrong, and here is why this one is wrong and here is why this one is right. I mean, -- not go through all five choices. It would just be more on the common choices. So I do take that opportunity to say okay, here is why this is not a good answer (Interview 1 11/20/12)."

Although describing a transmission model as the primary approach to teaching, Chris indicated that problems existed with these strategies. In terms the course structure being a series of lectures, Chris expressed frustration with the inability to address areas of student difficulties.

> "Well, that's what's frustrating about the way we do the course – it's almost too late to go back once you get to a certain point, and the students flag [the incorrect answer]. [You tell them] 'you didn't deal with Mendelian genetics very well so we are going to do that again.' -- There is not a huge opportunity to do that unless you are willing to sort of – you

> really are willing to abandon your syllabus and say I don't care if we get to DNA at the end of the semester or not, if we didn't get genetics right. But some students did get genetics right, so like 20% of the class did fine. I can't subject them to another week of Mendelian genetic, right?"

In addition, Chris was not "convinced that [clicker questions] really, really helped them on exams" (Interview 1 11/20/12). "It's frustrating, because again, I will ask a similar question on the exam after having [provided the explanations of the correct and incorrect responses] to get pretty much exactly the same distribution of answers (Interview 1 11/20/12)."

Chris also incorporated elements of "fun" into the lectures. During the classroom observation, students entered the room to popular music and a slide show playing on the screen (Field notes 11/20/12). The slide show included information about "cool biology things". Chris also stated that past courses had included a "geek of the week".

> "With science news items, we would read these three stories, and the students would vote on which one they thought was real. And then we would reveal the real one by Skyping in the author of the study or whoever is involved. And so every week, we had a different scientist Skype in class. That was really cool. The students loved that (Interview 1 11/20/12). "

Chris also used clicker questions to add elements of fun, which served to break up the lectures and incorporate students' opinions (Field notes 11/20/12; PPT 11/20/12).

Pat's Profile

Pat is a mid-career biology instructor at Blue University in a non-tenure track position. Pat's primary responsibility is to run the graduate program for secondary biology teachers, housed in the biology department, which includes teaching undergraduate and graduate level biology education courses. In addition, Pat is the lead instructor for a large introductory-level biology course. In serving in this non-tenure track position, Pat's responsibilities were primarily in the area of teaching, however, research in the areas of science and science education was permitted.

Initially, Pat's teaching was limited to biology education courses. However, Pat indicated that teaching only biology education courses would not result in adequate recognition from colleagues and administrators in the biology department. Pat determined that "jump[ing] in and do[ing] some of this university context teaching" would be useful in terms of fulfilling a set of career goals. This led Pat the role of instructor for a large introductory-level biology course designed for biology majors. As such, Pat has experience teaching undergraduate and graduate level biology and biology education courses for preservice and inservice secondary science teachers. In addition, Pat worked with colleagues on several grant-funded projects that supported designing curriculum for the large introductory biology course as well as biology education courses for the teacher preparation programs.

As a doctoral student and post-doctoral appointee, Pat generated publications from research in science. In the current non-tenure track position, Pat also engaged in research in science education. This research included studies of teaching and learning at both the secondary and post-secondary levels. Pat reported findings of these studies at professional conferences. In addition, Pat served on graduate committees and as an advisor to post-doctoral positions involving research in sub-disciplines of biology and science education. Pat also engaged in outreach activities by holding biology education workshops for teachers in area schools.

At the time of the study, Pat had approximately seven semesters of experience teaching an introductory-level biology course designed for biology majors with an average enrollment of 350 students per section. Initially, Pat co-taught the large course with another faculty member, but has served as the sole instructor of one section for four years. In this position, Pat worked with a team consisting of tenure-track and non-tenure track faculty assigned to teaching sections of the course. Collaborations included discussing the curriculum of the course and selecting an appropriate textbook. Pat has been recognized for excellence in undergraduate science teaching and contributions to the secondary science teacher education program through a promotion and number of university teaching awards (Interview 1 11/28/12; CV 12/22/12).

Knowledge of the Content. Pat has earned three postsecondary degrees in the area of biology (CV 12/22/12). As a doctoral student, Pat gained experience in conducting research within a sub-discipline of biology. Pat engaged in several biology research projects, which culminated in multiple publications in science journals and presentations of papers and posters at professional conferences (CV 12/22/12). Pat also served in a post-doctoral position, which emphasized biology research and resulted in several peer-reviewed publications in science journals.

Self-identified sources of knowledge of teaching. Pat reported receiving no formal training in the area of science education, however, Pat expressed having good models of science teaching as an undergraduate student and as an instructor of secondary science teachers. However, Pat indicated that the practicing secondary science teachers have been the most influential factor in developing as a science teacher. "It was really useful that I would also go out to visit their classrooms. I think a lot of the effective teaching practices that are available in our repertoire are actually very effectively modeled by K through 12 teachers" (Interview 1 11/28/12). Pat indicated learning various strategies of teaching from observing secondary science teachers in the classroom.

Pat also reported gaining knowledge of teaching through teaching experience, serving on graduate student committees, and reading science education literature. Pat stated that learning to teach involved "learning by doing", which involved repeated experiences of teaching the large introductory course (Interview 1 11/28/12). In the role of a co-advisor, Pat indicated that she served on a doctoral committee that involved research in science teaching in higher education. Pat reported learning more about postsecondary level teaching through assisting the doctoral student's study of college teaching. Pat indicated that this experience resulted in learning more about undergraduate teaching by reading primary literature in the area of science education and by being more reflective about changes in teaching practices.

Perceptions of learners and learning. Pat stated that student learning is based upon the social construction of ideas, which relies on opportunities for students to grapple with concepts and a workable rapport between students as well as the students and the instructor and supporting undergraduate tutors. "…the success of the teaching interaction that goes on in the large classroom really relies as much on interactions and relationships with the students as it would it if were a small classroom" (Interview 1 11/28/12). "And that rapport that we develop is really an important part of learning, because I think a lot of learning is a social activity (Interview 1 11/28/12)". From this perspective of learning, Pat indicated that students need opportunities to collaborate to make sense of the science content along with multiple exposures to concepts in different contexts.

Pat reported students face many difficulties in learning the content of the introductory biology course. Although students often report that they understood the material covered during lecture, Pat stated that students are often overwhelmed with information, scientific terms, and the complexity of reactions covered in the introductory course.

> "I think that the problem is that the students focus on the large number of reactions and the fact that there's a chemical structure that the book shows for each step in the process, and they freak out over the complexity of these reactions. They don't know what to focus on, so they focus on things like names and not on the bigger ideas (Interview 1 11/28/12)".

Pat also indicated that students struggle with issues of scale as well as the spatial relationships of cellular substances.

Pat identified particular motivational factors could influence the learning of undergraduate students. In their working toward lofty goals, Pat stated that introductory-level students only work for points. "Freshman don't do optional things, they only do things to get points. They seem to take [the task] more seriously if they are actually graded on [it]" (Interview 1 11/28/12). Pat reported awarding nominal points for students successfully completing assigned tasks in and out of class. In addition, Pat indicated that it is important for instructors to build a rapport with students, as they need to feel that the instructor cares about them. Pat stated that developing a good rapport with students enables them to feel comfortable asking questions during lecture, which results in student-driven social interactions in the classroom that facilitate their learning.

Perceptions of Teaching and Teaching Practices. Pat taught the large introductory course in a large auditorium, which did not include a stage at the front, but rather an open area at the same level of the last row of student seats. Through two wide aisles on either side of the room, students arrived at sitting in rows of individual seats with small foldable desktops. Within this setting, Pat indicated that it is difficult to have a dialogue with students or to have students work in groups.

> "The room is not really set up in a way that is easy, it would be lovely to have a physical plan where, you know, it would be easier to circulate at all the groups of students, but it's a large auditorium style classroom (Interview 1 11/28/12)."

To work in closer proximity to students, Pat walked up and down the isles. A microphone was used to enable students to hear Pat's vocalizations, however, the microphone was not used as Pat visited with students during small group work.

Pat was a member of the team of instructors that selected the textbook for the introductory biology course. For Pat, the selected textbook served to determine the curriculum for the course. Pat relied on the content of the textbook in selecting the material to cover. In addition, Pat made use of the textbook as a resource for preparing explanations and designing presentation slides. Pat also assigned readings from the textbook and provided pre-class assignments and post-class homework based upon the textbook.

Pat stated that "interrupted lectures" were the primary instructional approach for teaching the large introductory course. These lectures consisted mostly of explanations of biological concepts by the instructor with brief periods of students answering questions in small groups. These explanations of biological concepts were directly connected to the presentations that Pat prepared for lecture.

According to Pat, the generated presentation served as “the base for what [Pat] uses for teaching” (Interview 1 11/28/12). As a means of presenting information in an organized structure, Pat designed presentations in the format, which directly followed the textbook. Pat incorporated slides to align the lecture discussion with the textbook, such as the start of a new chapter. Additionally, Pat posed a rhetorical question when beginning a new topic of discussion. As an electronic copy of the presentation was made available to students prior to lecture, the organization of the slides and the representations that they contained served as cues for Pat’ explanations of the biological concepts.

During the observed instruction, Pat provided explanations of three biological processes that occur at the molecular level: cellular respiration, fermentation, and photosynthesis. In discussing the processes, Pat explained the movement and interaction of molecules within the context of the cell and relevant cell organelles. The explanations also included transitions between molecular level and sub-atomic structures. However, Pat linked these micro-level processes to objects and processes at the macro-level scale of the human body and leaves of plants. This is consistent with Pat’s view of providing explanations in lecture.

> “It’s hard for [students] to make connections and so what they focus on are the details, and there are certainly enough details to keep them busy in intro biology or in any science, I think. But, I think that one of the most important things I do is to try to pull them back up to a higher level every once in while (Interview 2 11/29/12).”

Pat represented biological knowledge of micro-level processes using text, graphics, animations, and symbolic representations of molecules. Text was used to provide abbreviated explanations of the concepts along with 34 scientific terms, which were often highlighted in purple. Fifteen graphics and an animation were incorporated into the slides as depictions of the molecular processes as well as cellular and macro-level objects. These graphics were obtained from the textbook.

> "I use the figures from the textbook both because I think the textbook has good figures and because I think that if I talked about a figure and show it on the slide…and they get confused, they can go back to their textbooks and look for that same figure to try to help make sense of it. (Interview 1 11/28/12)"

With the emphasis on molecular process, three different representations of molecular substances were included in the presentation slides: (1) the names of the material as text (i.e., oxygen), (2) the symbolic form of letters and numbers to indicate the type and amount of atoms (i.e., O_2), and (3) their molecular structures as a combination of letters and lines (i.e., O - O). Pat's explanations referred to these representations.

Working with the whole group, Pat's interactions with students in the instructional setting consisted of short dialogues with a limited number of students. During lecture, Pat engaged in brief conversations with students as they responded to questions that Pat posed verbally to the class (Field notes 11/29/12). Pat communicated to the student by say that "I am asking questions to remind you of the important points" (Field notes 11/29/12). Pat also responded to a limited number of student-posed questions during these exchanges. During the lecture session, Pat also interacted with students as they worked in small groups.

In designing a classroom in which social learning can take place, Pat had the students work in self-assigned groups over the course of the semester. Pat embedded preplanned group work in the presentation slides. Students were provided with a slide of instructions for the group work. As the students worked their small groups, Pat and the undergraduate students approached groups to facilitate discussions. The work products generated by the student groups were collected by the undergraduate tutors for grading.

As the instructor, Pat designed a series of activities for students to support their learning and to provide feedback about their level of understanding. Pat assigned activities for students to complete before, during, and after a lecture session. Students were given a reading assignment and corresponding online quiz to be completed prior to class.

> "[The pre-class assignment] introduced them to some of what I think are the big ideas and hopefully got them a little frustrated with some of this information, and then hopefully [they] passed up frustration in order to complete the homework. I also think sometimes being a little frustrated helps [them] to pay attention more, if [they've] already tried to grapple with it on [their] own (Interview 1 11/28/12)."

During class, students worked in groups to answer "Group Questions", which were based on targeted areas of weakness identified in online quiz results. Additional assignments were provided after the lecture as an opportunity to practice answering questions at same level as those on exams.

Pat stated that the assignments and summative assessments were designed to enable the instructor and graduate teaching assistants to identify student difficulties. Pat reviewed the pre-class assignment prior to the observed lecture. From identifying an area in which students struggled, Pat incorporated a "Group Question" designed to have students revisit their thinking about that particular concept. Additionally, summative assessments were a combination of multiple-choice and free-response questions. Pat stated that assessments were graded immediately after administering the exam with the instructor and graduate teaching assistant scoring the short-answer responses together. While the multiple-choice questions served to indicate broad areas of student difficulties, the short-answer responses allowed for specific areas of weaknesses to be identified.

Pat also expressed that teaching involved connecting the biology to student interests and building a rapport with students. Pat indicated that many students are aiming to become professionals in the healthcare industry. As such, Pat incorporated many references to the human body in explaining cellular respiration, fermentation, and photosynthesis. In addition, Pat developed a rapport with students through regular communication and humor. Pat reported meeting with students during office hours and making an effort to learn the names of these individuals. Pat also communicated electronically via e-mail and an online course management system, and spoke with students at the beginning and end of class. At the beginning of the observed instruction, Pat allowed students to ask questions regarding an upcoming exam (Field notes 11/29/12). Pat also incorporated humor into lectures “to enliven the atmosphere” of the classroom (Interview 1 11/28/12; Field notes 11/29/12).

Sam’s Profile

Sam is a late-career biology instructor at Blue University in a non-tenure track position currently teaching multiple sections of a large introductory biology course. In this position, Sam’s responsibilities were primarily in the area of teaching. Over the course of approximately 15 years at Blue University, Sam served as an instructor and laboratory coordinator for biology and biology-related courses. Sam elected to participate in only a limited number of activities in research and instead decided to focus on undergraduate science teaching. In addition to college-level teaching, Sam has served on committees to coordinate undergraduate biology courses offered by the local community college and Blue University. Sam also served as a consultant for numerous textbooks and online resource development projects as well as lead workshops on improving biology teaching. In addition, Sam participated in a collaborative project to design interdisciplinary instruction modules.

Sam gained experience teaching undergraduate and graduate level courses in biology, but has focused on teaching a large introductory-level course for biology majors. In addition, Sam taught biology education seminars for students serving as beginning and experienced undergraduate tutors in the introductory biology course. The undergraduate tutors were integrated into the large lecture classroom as they work with groups of students to answer questions and solve problems pertaining to the biology concepts. In the seminar courses, Sam had the tutors complete reading and participate in discussions about cognition, learning theory, and questioning techniques.

At the time of the study, Sam had approximately 15 semesters of experience serving as the lead instructor of an introductory-level course designed for biology majors with an average enrollment of approximately 350 students per section (Interview 1 2/7/13; CV 12/22/12). As a non-tenure track instructor, Sam describes the position as being "a free agent (Interview 1 2/7/13). "I do what I want in my class…and there's no pressure on me to change the way I do things maybe because I am covering the standard material (Interview 1 2/7/13)." In this position, Sam worked with a team consisting of tenure-track and non-tenure track faculty assigned to teaching sections of the course. Collaborations included reviewing the curriculum of the course, selecting an appropriate textbook, and discussing the implementation of the undergraduate tutor program. Sam has been recognized for excellence in undergraduate science teaching through awards provided by the university as well as professional science organizations.

Knowledge of the content. According to Sam's curriculum vitae (CV 12/22/12), Sam has earned three postsecondary degrees in areas closely-related to biology. In the non-tenure track position, Sam gained experience in conducting research within a sub-discipline of biology, which culminated in a small number of journal publications (CV 12/22/12).

Self-identified sources of knowledge of teaching. Although science education was a part of the bachelor's degree program, Sam stated that this formal training was not an influential factor in learning how to teach. Sam stated that observing models of teaching in large lecture courses taught by other faculty was a significant source of knowledge of teaching. As a graduate teaching assistant, Sam attended the lecture and critiqued the approaches of different instructors.

> "I would think 'That was good. You know I would do that' or something…I would be constantly making mental notes about [their teaching]. 'He left ou that one really important connecting idea', and so I think I sort of built up a reservoir of those things (Interview 1 2/7/13)."

Sam also learned to teach through "trial and error" by actively experimenting with alternative approaches to teaching. Sam's reading of educational literature and reflective practice along with feedback solicited from the undergraduate tutors also played an integral role in developing as a teacher.

Perceptions of learners and learning. At the beginning of lecture, Sam stated to the class, “We follow the constructivist theory of learning.” (Field notes 2/7/13). Sam followed this statement with an explanation of this theory using an analogy of building a house. Based upon reading studies in education, Sam indicated that in “comparing different kinds of teaching and learning that active learning is better and that listening to a lecture or listening to somebody go through their Powerpoints is not active learning.” Counter to the literature, Sam did state that a significant number of students needed to have information explained in lecture. However, Sam also expressed the importance of the social aspect of learning. When students work in groups, Sam indicated that “oftentimes somebody who’s on the wrong track will not be able to really defend their answer” and will be corrected by their peers.

Although reporting that some students are disengaged in the lecture setting, Sam emphasized the importance of having the instructional setting “be as interactive as possible, trying to create an atmosphere where students feel comfortable interrupting me or asking questions (Interview 1 2/7/13).” Sam envisioned the learning process as a series of inputs and outputs.

> “I think it’s a series of inputs which is reading, listening, digesting ideas, hopefully they’re digesting ideas as they come in and seeing if it fits with what they understand. And then the self-assessments that they get with the clicker questions, the feedback that they get in class, [and] the feedback that they get from the [online] quizzes. They have an opportunity to make adjustments (Interview 1 2/7/13).”

Sam indicated that students need to be given many opportunities to practice working with ideas and make adjustments in their thinking. Sam emphasized the notion that "repetition and practice with output are critical elements to learning (Interview 1 2/7/13)."

In terms of the biology content, Sam stated that students in the large introductory class vary in their level of preparedness for the course. Sam indicated that students without a chemistry background struggle with learning about materials and processes that are microscopic. In general, Sam stated that students often have difficulties in working with abstractions and scale.

Sam emphasized the importance of metacognition in the learning process. Sam indicated that "one of their tasks is going to be to figure out how they learn" and be able to self-assess their level of understanding. Sam reported that students that are not successful in the course are not self-reflective and do not learn from feedback provided by activities in and out of class.

Perceptions of Teaching and Teaching Practices. Sam taught the introductory biology course in an auditorium-style classroom, which did not include a stage at the front, but rather an open area at the same level of the last row of student seats. The layout of the auditorium included a wide aisle, which separated the room into two tiers of seating. Students navigated through two narrower aisles to gain access to the rows of individual seats with small foldable desktops. A desk was located at the front of the room along with a computer and two large screens for projecting the presentation slides. Through two wide aisles on either side of the room, students arrived at sitting in rows of individual seats with small foldable desktops. Within this setting, Sam indicated that it is difficult to engage in a dialogue with students.

> "It's really hard in a room of 350 students, especially in the setting which is in the auditorium, for me to engage students one-on-one (Interview 1 2/7/13)."

Sam made use of a microphone to enable students to hear the lecture.

While the material to be covered in the introductory biology course is set, Sam expressed having the flexibility to design the sequence of topics as well as to develop and include addition curriculum as part of the course. Sam emphasized the importance of "building a logical sequence of topics". Sam stated that topics are sequenced such that they are "sort of building in scales", beginning with the smallest structures and processes and transition to larger scales. In addition, Sam included content not covered in other sections of the course. "I have three units that none of the other faculty have: What is science? How does it differ from other ways of understanding the world? What is evolution? (Interview 1 2/7/13)" Sam indicated that these beginning units were important as they served as a framework for teaching the set material.

Sam described teaching as "a 75-minute performance that I do twice a week with a different script everyday (Interview 1 2/7/13)." While many of Sam's descriptions of instruction emphasized student-centered approaches, Sam indicated that explanations may still be needed to support student learning.

> "There's something deep inside me that thinks if I don't explain it to them, they're not really going to understand it. So, I'm trying to get better at just hitting the highlights, asking if there are questions, doing some probing clicker questions (Interview 1 2/7/13)."

Sam's explanations of biological concepts were directly connected to the presentation notes prepared for lecture.

Sam prepared two sets of presentation notes – an instructor version and a student version. Sam authored the text of these notes and also included graphics from a variety of sources. In generating the student version, a limited number of elements included in the instructor notes are removed. Although this provided opportunities for students to take notes, Sam indicated that "[she doesn't] want them focused on scribbling furiously. [She] want[s] them listening and thinking." In preparing for a class session, Sam reported following a ritual of reading through and modifying the presentation notes during a block of time immediately preceding the lecture.

The format of Sam's lecture included the alternation between explanations and periods of questioning. Prior to delivering an explanation, Sam posed a series of questions to the class, and many of these questions were included in the presentation notes. Most often, a small number of students provided brief responses to the questions, either individually or in unison. At other times, students did not provide a response, and Sam answered the posed question. Given the layout of the auditorium, the interaction was limited to the students located in the lower tier of seats closest to the instructor. During explanations, Sam referred to the presentation notes as they served to provide cues to the explanation of the biological concepts.

During the observed instruction, Sam provided explanations of the movement of material across a cell membrane. In discussing the processes, Sam explained both the passive and active transport of material within the context of the cell and relevant cell parts. The explanations, which focused primarily on objects and processes at the molecular level, began with the structure of molecules that make up the cell membrane. Sam's explanations then progressed to the larger context of a single cell or small group of cells at which molecules located inside and outside of the cell moved across the membrane.

Sam represented biological knowledge of micro-level processes using text, graphics, and symbolic representations of molecules. Text within the presentation notes provided lengthier explanations of concepts as compared to text found in the slide presentations of the other study participants. The text of the presentation notes included 37 scientific terms, which were often highlighted in blue. In addition, particular words, phrases, and questions were also emphasized by bolded black text as well as blue and red text. Nineteen graphics were incorporated into the presentation notes as depictions of abstract objects and processes at the cellular and molecular scales. Within the notes, the structure of molecules was represented in four ways: (1) the names of the materials as text, (2) a combination of letters and lines, (3) ball-and-stick figures, and (4) drawings of molecular structures, such as a "head and tail" drawing representing a phospholipid and a spiraling ribbon representing a protein.

Sam reported being an early adopter of clickers and incorporated pre-planned clicker questions into lectures. Although they were not assigned to groups, students worked with neighboring students in class to answer the questions. "Students are encouraged to convince their group members [about] the validity of their choices [for answers] (Interview 1 2/7/13)." By design, these questions were not embedded in the presentation notes. This provided Sam with the flexibility to incorporate the group work at suitable times during the lecture. Once the clicker question was displayed, the undergraduate tutors, who were seated among the students, stood up and engaged with the student groups. Students were given approximately two minutes to discuss the question and possible answers and then supply answers individually using their clicker device.

As the instructor, Sam designed a series of activities for students to support their learning and to provide feedback about their level of understanding. "So, they do a lot of extra work compared to what is required of students in other sections [of the course]. (Interview 1 2/7/13)." Sam assigned activities for students to complete before, during, and after a lecture session. Students were given a reading assignment and corresponding online quiz to be completed prior to class. During class, students responded to clicker questions from which they received instant feedback. Mandatory homework was also assigned and completed by students through the online course management system. In addition to the assigned activities, Sam provided students with an extensive list of online resources to support their learning including links to tutorials, animations, and excerpts from other textbooks.

Sam stated that the assignments and summative assessments were designed to enable the instructor and undergraduate tutors to identify student difficulties. In preparing for class, Sam reviewed the pre-class quiz to pinpoint questions that were problematic. "It will show me the most common wrong answers, and so I kind of make mental notes to make sure that I emphasize [those concepts] (Interview 1 2/7/13)." In addition, Sam often incorporated a clicker question to have students revisit their thinking about that particular concept. Additionally, summative assessments were a combination of multiple-answer and free-response questions. Sam's rationale for using the multiple-answer question format was to "design assessments that are good measures of who knows the material well versus who knows it kind of versus who doesn't know it well at all (Interview 1

2/7/13)." Sam stated that assessments were graded immediately after administering the exam with the instructor and graduate teaching assistants scoring the short-answer responses together. Sam indicated that the combination of multiple-answer questions and short-answer responses provided more accurate information about the level of student understanding.

Sam expressed making use of various forms of feedback to improve approaches to teaching. "For a long time, I lamented the fact that I had no evidence that my techniques were any better than me getting up and just talking for 75 minutes twice a week (Interview 1 2/7/13). Working with a colleague who also teaches the course, Sam designed and began administering a pre-test and post-test assessment to determine students learning gains. "My kids rocked it, so I feel like there are some significant learning gains going on (Interview 1 2/7/13)." Sam also stated that the undergraduate tutors are a valuable resource. Sam reported soliciting feedback from the undergraduate tutors on a regular basis as they attend the lecture. In addition, Sam made use of feedback provided by students in the course evaluation. Based upon their responses, Sam expressed making an effort to be more approachable and connect with students in a variety of ways such as incorporating jokes in lecture.

Terry's Profile

Terry is a mid-career biology instructor at Green University. Terry was hired in a tenure-track position at Green University, which requires faculty to engage in research, teaching, and service. Terry has served as a faculty member at Green University for over ten years and held a single previous appointment as a visiting professor at another institution. In the position at Green University, Terry's primary responsibilities included teaching large introductory biology courses, engaging in science education research, and performing service in the area of science education.

In support of conducting educational research, Terry received numerous grants. Terry served as the co-principal investigator (PI) on larger grants funded by federal government agencies as well as the PI on mid-sized and smaller grants awarded by state agencies and institutional offices. The projects included both individual and collaborative efforts to perform research in the area of teaching and learning of biology at the postsecondary level. Terry worked on several projects with other faculty with similar appointments in the biology department at Green University. From this research, Terry authored multiple written works published in peer-reviewed science education journals and presented findings at professional conferences.

In the area of service, Terry advised many undergraduate students majoring in biology as well as mentored graduate students who were awarded teaching fellowships. Terry also served as a reviewer for multiple science education professional organizations to review articles submitted for publication and conference presentations. Additionally, Terry aided in the development of a biology textbook.

In the area of teaching, Terry gained experience in teaching undergraduate level biology courses as well as graduate level biology education seminars. Terry focused particularly on developing and teaching a large undergraduate course designed for biology majors. For over 20 semesters, Terry served as the instructor for multiple sections of the course, which has had an enrollment of approximately 350 students per section. Terry stated that a team of faculty is engaged in teaching large lower-level courses. According to Terry, these faculty members experiment with different instructional approaches, share ideas about their classroom experiences, and provide feedback to each other regarding teaching practices. In addition, Terry indicated that teaching collaborations between the biology education faculty and biology faculty are beginning to emerge. Terry received multiple awards in recognition of a strong commitment to university teaching (CV 1/31/13; Interview 1 2/1/13)

Knowledge of content. Terry earned a bachelor's degree and doctoral degree in a sub-discipline of biology (CV 1/31/13). In addition, Terry completed a post-doctoral appointment that emphasized research in the area of biology (CV 1/31/13). Over the course of completing graduate school and serving as a biology faculty member, Terry engaged in many biology research projects, which culminated in several publications in science journals and presentation of papers at professional conferences (Interview 1 DATE; CV 1/31/13).

Self-identified sources of knowledge of teaching. Without receiving formal training in the area of teaching, Terry reported gaining knowledge of teaching from working with good mentors and through "trial and error" (Interview 1 2/1/13). Terry stated that a graduate advisor stressed the importance of teaching by telling a story and that this person served as a good model for lecturing. As an undergraduate student, Terry worked with a tutor who instructed students to examine information and practice making sense of it. According to Terry, this tutor served as a model for helping students deconstruct and reconstruct ideas. Terry also reported learning how to teach through experimenting with various instructional approaches.

Terry stated that collaborations within and across departments served as a significant influence in developing knowledge of teaching. As part of biology department that includes biology education faculty, Terry stated that "our function as well is to do research in how to make teaching better" and bridge research and practice in teaching large introductory courses (Interview 1 2/1/13). Terry worked closely with colleagues in the biology department to conduct educational research, share ideas about teaching and learning, and provide critical feedback about teaching practices. Additionally, Terry stated that collaborations with faculty in another science department led to improvements in the design of assessments and means of administering exams in the large class setting.

Perceptions of learners and learning. In regard to student learning, Terry stated that, "It doesn't matter how well I explain it. That will only take them so far. To really understand it, they have to be able to do it themselves (Interview 1 2/1/13)." Terry indicated that learning could be limited to a series of facts, or it could entail being able think about and apply information to alternative situations. To target the application of biological knowledge, Terry stated that students need opportunities to practice working with the concepts in various contexts. Working in groups or individually, Terry also stressed that students learn by providing verbal and written responses to questions. Terry indicated that students sort out their own ideas as they practice explaining the concepts themselves.

Terry presented several challenges that students face in learning biology. Terry stated that "most of the problems I see with students is not that they can't learn the content; it's that they don't know how to study effectively (Interview 1 2/1/13)." Terry indicated that many students are passive and are not accustomed to working through complex information and debating with their peers. While identifying self-assessment as an important factor in student learning, Terry expressed that many students have difficulty assessing their own level of understanding. Based upon this difficulty, Terry indicated that students tend not to make improvements to their study practices and do not recognize a problem exists "until they bomb on the test" (Interview 1 2/1/13).

Additionally, Terry stated that students tend to be passive in their learning and seem to compartmentalize information based on testing. From questioning students about their study strategies, Terry reported that students often engage in passive activities such as read the textbook and watch the recorded podcast of lectures. Following exams, Terry stated that students think to themselves, "'Okay, the first test is done. Everything in the first test is gone, so I don't have to worry about that [information] anymore' (Interview 2 2/4/13)." Terry indicated that students' use of passive approaches impedes their learning and the compartmentalization of information limits their ability to make important connections.

Perceptions of Teaching and Teaching Practices. Terry taught the introductory biology course in a large auditorium-style classroom, which did not include a stage at the front, but rather an open area at the same level of the last row of student seats. Students arrived through doors at the highest and lowest levels of seating. Students selected the location of their individual seats by walking through one of two wide aisles on either side of the room. Within this setting, Terry indicated that it is difficult to walk up and down the stairs when visiting with students during in-class activities. A microphone was used to enable students to hear Terry's vocalizations when addressing the whole group. However, Terry muted the microphone when visiting with students individually or in small groups.

Terry indicated that the course is designed for biology majors and includes a pre-established curriculum in terms of the covered topics. Terry stated that for a major's course, “the content is still very important, because I have to prepare them for upper level courses (Interview 1 2/1/13).” According to Terry, most of the students were pre-health care majors with other students majoring in chemistry, engineering, and other science disciplines. Terry stressed the importance of developing curriculum that is “relevant to [students’] own lives or at least something relevant to their futures (Interview 1 2/1/13).”

In terms of a general instructional approach, Terry stated that “straight lecture doesn’t work, it doesn’t work for a lot of students.” Terry reported making use of more student-centered practices. Prior to class, Terry exposed students to new material by assigning textbook readings and pre-class quizzes. Terry expressed the importance of providing ways for students to put this information together and make connections between the concepts. Terry indicated that the instruction was often designed a case study or problem-solving activities. Terry’s observed instruction included the combination of a short interactive mini-lecture, a pre-planned student activity, and a whole group activity. (Field notes 2/4/13).

With the presentation slides available to students prior to class, Terry designed the slides to facilitate the interactive mini-lectures. Terry structured the presentations slides to include important content as well as empty space to allow students to add information. “One of the things I noticed is that sometimes students will be so busy writing everything that comes out of my mouth and copying down what’s on the slide, they are not thinking (Interview 1 2/1/13).” The elements included on the slides supported Terry in explaining and representing the science as well as setting the stage for the planned student and whole-group activities.

Terry stated that this approach to teaching about the cell was influenced by students' poor conceptions of cells as simple bags of enzymes. During the mini-lecture, Terry explained the problems with a more traditional view of cellular structures as a list of cell parts using an analogy of viewing cars as a set of discrete automotive parts. Terry made use of a traditional graphic of a cell along with images and video of actual cells. Then, Terry's explanations shifted to providing the context of a problem. Terry discussed a common genetic disorder starting with explanations that started with larger-scale issues such as symptoms and gradually moved to conditions at smaller scales, such as organ, tissue and ultimately the cellular level. Terry's explanations set the context for the planned student activity.

Terry emphasized the importance of providing students with opportunities to practice developing and articulating their own explanations of concepts. In addition, Terry indicated that students need "to compare their answers with their neighbors, see if they agree or disagree, support their answers to think-pair-share, be able to argue their answers (Interview 1 2/1/13)." With the instructions projected on the screen, Terry instructed students to complete an in-class activity while working in small groups. Terry encouraged the students to discuss their ideas with their peers and individually generate a drawing that represented their conceptions of a cellular process. As students worked through the activity, Terry walked around the auditorium and met with students "to see what they are doing and thinking (Field notes 2/4/13; Interview 1 2/1/13)".

After small group work, Terry described having students work through the problem as a class. "Instead of just writing down the answers, I will ask them, 'Okay, you tell me, what should this be?' And sometimes I will deliberately write something wrong and wait for somebody to catch it and say 'wait a second, that's not right'. (Interview 1 2/1/13)". During the later part of the observed class session, Terry facilitated a whole group discussion in which the students and instructor worked together to solve the problem posed in the student activity. In generating a drawing, Terry made use of an interactive pen display, similar to a tablet computer, which acts as a projected white board. Terry posed questions to the whole group, and the student responses served to provide instructions for Terry to create a drawing to represent a group-constructed solution (Field notes 2/4/13).

Terry designed activities for students to complete outside of class to support their learning. Terry made use of a flexible online assessment system, which provided students with the pre-class quiz. Terry selected and/or modified quiz questions such that they were directly connected to the textbook reading and included material that Terry deemed important in the course. In addition to the textbook reading and pre-class quiz, Terry created a study guide consisting of a series of "broad questions that [target] things that I know they tend to have trouble with or they tend to approach in a factual manner (Interview 1 2/1/13)."

Terry designed the course assessments to influence students' studying behaviors and to identify areas in which students experience difficulties. Terry stated that a colleague "found that students who have short answer tests changed their behaviors and use more active in-depth studying techniques than they did for multiple choice (Interview 1 2/1/13)." In addition, Terry stated that free-answer responses revealed more about students level of understanding.

> "[Short answer responses are] much more revealing as to what [students] know and don't know, where they have trouble. So even though it's a lot more work on my part, I have become convinced I want to do this…even if it's a big class (Interview 1 2/1/13)."

Terry reported grading the exams, along with a number of selected upper-level undergraduate students, immediately after the testing session. Terry stated that they scored the short-answer responses together using a rubric.

Terry's expressed making use of various forms of feedback to improve approaches to teaching. Terry identified other biology education faculty as a valuable resource for constructive feedback concerning teaching practices. In addition, Terry stated that positive feedback from current and past students reinforced the use of particular instructional methods.

Morgan's Profile

Morgan is an early-career biology instructor at Green University hired in a non-tenure track position, which included combined responsibilities in the areas of educational research and biology teaching. At the time of the study, Morgan was in the second semester of the position and worked as part of the team that included Terry. During the first semester of the appointment, Morgan worked with other biology education faculty through engaging in research projects and observing the instructional practices of two faculty mentors who were teaching large introductory biology courses.

As a graduate student and in the current non-tenure track position, Morgan engaged in educational research that involved studies of biology teaching at the college level. From these activities, Morgan authored multiple written works published in peer-reviewed science education journals as well as delivered presentations at professional conferences, which emphasized discipline-based educational research.

In the area of service, Morgan recently joined a national network of faculty focused on improving undergraduate biology education (CV 2/2/13). Morgan has also served as a committee member and manuscript reviewer for biology education organizations that focus on university level teaching.

As a graduate student, Morgan gained experience in teaching undergraduate level biology courses as well as a graduate level seminar in biology education. In the position at Green University, Morgan focused particularly on teaching a large undergraduate course designed for non-science majors. At the time of the study, Morgan was in the first semester in serving as the lead instructor for a single section of the course, which had an enrollment of approximately 300 students. Morgan reported working with a team of faculty charged with teaching large lower-level courses.

Knowledge of content. Morgan earned three postsecondary degrees including a doctoral degree in the area of biology (CV 2/2/13). Over the course of completing graduate school, Terry engaged in a biology research project, which culminated in a small number of publications in science journals (Interview 1 2/4/13; CV 2/2/13).

Self-identified sources of knowledge of teaching. Morgan received formal training in the area of biology teaching through coursework that culminated in a graduate certificate in college teaching. Morgan indicated that the classes “definitely offered a lot of preparation” (Interview 1 2/4/13). Morgan also mentioned that serving as a graduate teaching assistant “was a good introduction into leading my own class (Interview 1 2/4/13).” However, Morgan identified performing research in the area of biology education as a primary source of knowledge of teaching. “My research focus is on biology education research, so I have a much richer background in education and learning and teaching theory than most instructors do. I think that’s a huge asset (Interview 1 2/4/13).”

Morgan also reported having good models of teaching as a student and quality mentors in the current position. “There are certainly some mentors of teaching that I’ve seen and spent a lot of time either observing or taking classes from that were influential in the past, and I think what I learned there still influences me (Interview 1 2/4/13).” Morgan also mentioned having a number of colleagues “who teach these sorts of classes and I’ve been lucky to be able to kind of learn from them, especially the logistics of a course this large.” According to Morgan, these faculty members openly share information about their teaching experiences. In addition, Morgan works with two faculty mentors who regularly observe Morgan’s class and provide feedback about the observed teaching practices. (Interview 1 2/4/13)

Perceptions of learners and learning. Morgan stated that students come to the classroom with prior knowledge about biology as “they’ve been living in the biological world their whole lives and have quite a few ideas about how it works (Interview 1 2/4/13).” Morgan described learning as building and connecting new ideas onto existing knowledge as well as adjusting conceptions that are inaccurate. Morgan further indicated that learning involved struggling to solve a problem and making use of feedback to develop solutions. According to Morgan, students learn through connecting ideas on their own either individually or working with peers.

Morgan also identified areas of student difficulties in the learning process. Morgan indicated that students have little experience in being critical of ideas and struggle to evaluate their own conceptions. Morgan stated that many students want to be 'right' more than develop an understanding of the content. Morgan indicated that many students are uncomfortable with being 'wrong' and thus they tend to generate obvious solutions to problems rather than struggle to develop a more complex response. In addition, Morgan reported that students struggle with making use of detailed data as they often extrapolate beyond the boundaries of the data to make inappropriate claims and struggle to see how the information fits into a broader conception of biology.

Perceptions of Teaching and Teaching Practices. Morgan taught the large introductory biology course in the same auditorium-style classroom as Terry at Green University. Morgan also had students work in small groups during class, and some students stood up or turned around in their seats to engage in discussions with neighboring peers. Morgan made use of a microphone addressing the whole group. However, Morgan muted the microphone when visiting with students individually or in small groups.

Morgan described holding different views of the curriculum for students who are biology majors and those who are non-majors.

> "I do think that my philosophy for non-majors is a little different than majors. My overall objectives are for students to be more interested in biology when they leave the class than when they started, to have more skills and thinking like a biologist. And by that I mean being a critic of biological information that they come across, considering these sources of information, being able to…draw reasonable conclusions given data, and I also hope that students recognize the relevance, especially non-majors, of biology in their everyday lives (Interview 1 2/4/13)."

Morgan stated that the curriculum consists of four units that are designed to be "relevant to students lives" covering broad issues in biology. "Then, I select the content that I am going to teach [within each unit] based on what they need to know to understand this sort of bigger problem (Interview 1 2/4/13)." In meeting the goals of the course, Morgan emphasized the importance of including example studies for students to understand the design of scientific studies and means of drawing appropriate conclusions.

Morgan stated that, "I don't know that I would say that my philosophy of instruction is substantially different for a large class versus a smaller class (Interview 1 2/4/13)." Morgan reported making use of a combination of short lectures, small group work, and whole group work during instruction, but that the amount of time spent in each instructional approach differed between class meetings. Morgan reported "lectur[ing], at most, 30 minutes (Interview 2 2/5/13)." However, Morgan also stated that students completed small group assignments during class "for at least 30 minutes, if not 45 minutes or the whole class period, in some cases (Interview 2 2/5/13)." On other occasions, Morgan indicated that students worked in groups for shorter amounts of time to answer a question, and then reconvened to engage in a discussion as a whole group.

Morgan provided explanations of biology concepts during the mini-lectures. Although Morgan's perceptions of teaching did not emphasize formulating explanations, Morgan did supply explanations during the observed instructional session. As a review of previously covered material, Morgan explained the process of natural selection and concept of carrying capacity. These explanations discussed these ideas in a context relevant to students as Morgan referred to the many bacteria found in "your digestive tract". Then, Morgan introduced a related topic, which was the focus of the small group assignment: antibiotic resistance. Morgan discussed the history antibiotic discoveries and subsequent reported resistance of the medication. Morgan explained the phenomenon of antibiotic resistance using the context of bacteria previously discussed. Starting with the introduction of an antibiotic into the environment, Morgan's explanations provided a step-by-step process that ultimately manifests in antibiotic resistant bacteria. Morgan made use of presentation slides to support these explanations (Field notes 2/5/13).

Morgan represented biological knowledge of the concept of natural selection on a small number of presentation slides using text and graphics. Text was used to provide abbreviated explanations of the concepts along with eight scientific terms. Eight graphics were incorporated into the slides including timelines and graphical depictions of processes. Morgan displayed a single slide of text that provided instructions for a small group assignment.

Morgan designed small group activities and assignments for students to complete in class. Morgan reported that the small group activities ranged from students spending a short amount of time discussing a question to their spending nearly the entire class period completing an assignment. Morgan stated that the activities are often structured as problems or case studies for students to solve. Morgan indicated that students worked in instructor-assigned groups to complete the activities and submit work products for grading.

With the support of the faculty mentors, Morgan reported making used of a pre-established system of conducting small group exercises in the context of a large class. Morgan described confidentially assigning students of varying levels of prior knowledge of biology to small groups based upon the results of an assessment administered at the beginning of the course. Morgan required that the students sit with the members of their assigned groups during lecture. During the observed instruction, Morgan projected a seating chart for students to locate and sit with their assigned group. In addition, Morgan emphasized the importance of providing instructional support for student groups to function effectively. Morgan reported providing guidance for students on how to be a "friendly critic" with group members and assigning roles to students.

Morgan, as the instructor, also played a role in small group work. Morgan reported visiting with various student groups.

> "For the group assignments where it's mostly them working in groups, I'll go around the room, and so will my TA, and we'll answer questions, and if something keeps coming up, I'll turn on my mic and address it. An then I will just walk around the room and talk to the groups to make sure that they're staying on task and being a thorough as I want them to be (Interview 1 2/4/13)."

During the observed instruction, Morgan walked around the auditorium and engaged in discussion with student groups. Morgan also indicated that students must complete their work in a set period of time and provided multiple warnings as they approached the deadline for submitting the group assignment.

In addition to small group work, Morgan reported having students engage in whole group discussion. "There are other classes, where we do very active things, but we've come back together as a group a lot and I sort of facilitate a discussion of those ideas (Interview 1 2/4/13)."

> "I randomly call on groups, some groups have numbers so I call numbers, and they have to be prepared to share what they talked about. And so that gives us a lot of different ideas on the board, and then we just sort of

> discuss our way through those until we're at some sort of consensus on what the answers should look like (Interview 1 2/4/13)."

The observed instructional period did not include this type of whole group discussion. However, Morgan facilitated a whole group discussion toward the end of the class session in which students posed questions regarding the upcoming exam.

Morgan assigned activities for students to perform outside of class to support their learning as well as inform instruction. Morgan reported assigning select readings in the textbook. "I don't ever assign the whole chapter for students to read; I select the sections that are relevant to what we're learning (Interview 1 2/4/13)." Morgan stated that practice problems were assigned through the online course management system for students to practice questions similar to those on the exams. Morgan reported making use of students' responses to practice problems to identify student difficulties and guide the explanations and discussions in class. Morgan also posed questions for students to answer in their "learning journals".

> "They do weekly what I call a learning journal where they respond to some sort of prompt. They're all aimed at sort of encouraging metacognition about their own learning. And this week I asked them to identify the concepts they though would be covered on the exam, something they are struggling with, and how they would solve that problem, and how they would figure out what they still found confusing before the exam."

An optional activity included posting and responding to questions on the course discussion board. Morgan reported posting questions for students as well as responding to student questions. Morgan indicated that students also posted questions and responses.

Morgan indicated that an instructor's grading system can influence student's behaviors. Morgan emphasized the importance of "mak[ing] sure that I am rewarding them for the behaviors that I want them to engage in and note rewarding them for behaviors that I don't want them to engage in (Interview 1 2/4/13)." Morgan reported incentivizing student activities by awarding points for graded assignments such as small group work, individual work performed in class, online assignments, and summative assessments.

Morgan expressed the importance of building a positive rapport with students as a means of encouraging students to actively engage in the instruction and make the course an enjoyable experience. "It's a performance to teach a class that large, so I think that there are some important social skills [needed] there (Interview 1 2/4/13)." Morgan described building this rapport by providing both structure and flexibility in teaching. Morgan stated that "creat[ing] a standard for how the class is going to work", "communicat [ing] expectations, and "be[ing] adaptable to how things are going" were important elements to building relationships with students. Morgan also praised students for their level of engagement in performing the small group activities and participating in whole group discussion (Field notes 2/5/13). In addition, Morgan incorporated elements of fun into instruction by playing music as students entered the classroom as well as making jokes during lecture.

Cross-Profile Analysis

Following the development of the six individual faculty profiles, a cross-profile analysis was conducted with the research sub-questions guiding the analysis process. Based upon the analysis, eight distinct knowledge domains were identified as making up the PCK of the six biology instructors. In addition, four social interactions and experiences along with four teacher perspectives were found to influence the PCK of the biology faculty. The following discussion will describe the eight knowledge domains, four social interactions and experiences, and four teaching perspectives.

Knowledge domains. This study design was intended to investigate the types of knowledge that biology faculty use in teaching large introductory courses. In the process of analyzing the six faculty profiles, eight domains emerged which made up the PCK of the biology faculty. These included (1) knowledge of content, (2) knowledge of context, (3) knowledge of learners and learning, (4) knowledge of curriculum, (5) knowledge of instructional strategies, (6) knowledge of representing biology, (7) knowledge of assessment, and (8) knowledge of building rapport with students. Of those listed, seven domains were identified in prior PCK research, and one domain was not previously identified in the literature (knowledge of building rapport with students). The following results include a description of the eight knowledge domains as they pertain to these six biology faculty members.

Knowledge of content. The first knowledge domain was the faculty's knowledge of the content. In conducting this research, it was assumed that the biology faculty made use of their knowledge of biology for teaching. The methods employed were not designed to capture information regarding their subject matter knowledge beyond the degree noted in the curriculum vitae of the faculty. Based upon the supplied documents, all of the participants in the study earned postsecondary degrees, including doctoral degrees, in the area of biology or biology-related fields. In addition, all of the participants engaged in biology or biology-related science research and have successfully published journal articles and/or delivered presentations at professional conferences. Given their educational and professional biology backgrounds, it was assumed that the study participants had sufficient content knowledge for teaching an introductory-level undergraduate biology course. However, the findings of this study of biology faculty reveal that the participants had developed knowledge in several domains: knowledge of context, knowledge of curriculum, knowledge of learners and learning, knowledge of ways to represent biological knowledge, knowledge of instructional strategies, knowledge of assessment, and knowledge of ways of building rapport with students. The following discussion describes the participants' knowledge in these areas.

Knowledge of context. The second knowledge domain was the faculty's knowledge of the context. This includes the context in which they are teaching as well as the institutional context in which they work. All six study participants had similar knowledge of the teaching context. They engaged in teaching an introductory biology course in an auditorium-style classroom to a large student population. In this setting, all of the faculty made use of technology for projecting information onto a large screen for students to view and microphones for students to hear their vocalizations.

In terms of the institutional context, the biology faculty recognized that their positions were held within the biology departments of their home institution. They had knowledge of the department culture as well as the teaching responsibilities of their position within the department. Faculty provided differing descriptions of their departments in terms of (1) the time and resources allotted to support their teaching, (2) professional development, and (3) collaborative environments.

Knowledge of curriculum. The third knowledge domain was the faculty's knowledge of the curriculum. The six study participants had knowledge of the curriculum for their specific course. However, the descriptions of curriculum differed between the faculty teaching a course designed for students majoring in biology from the faculty teaching a course for non-majors. Alex, Pat, Sam, and Terry taught an introductory course for biology majors. Whether teaching a macro-level (organismal and environmental level biology) or micro-level course (cellular and molecular level biology), they had knowledge of the topics included in the curriculum. These four faculty members indicated that the 'majors' courses had an established curriculum with a pre-determined set of included biology topics. Several stated that the curriculum was directly connected to the material presented in the textbook. Some indicated that the purpose of the course was to prepare students for upper-level biology coursework. Chris and Morgan taught an introductory course for non-majors. These faculty members described having more flexibility with developing curriculum. They also reported having similar goals for the non-majors courses including students developing a basic understanding of biology that is relevant (their bodies, current issues in biology) as well as the process of science in terms of generating knowledge (study design, interpreting data, formulating conclusions).

Knowledge of learners and learning. The fourth knowledge domain was the faculty's knowledge of learners and learning. The study participants reported having knowledge of learners in the context of a large introductory biology course. All of the instructors indicated that students arrive to the course with some level prior knowledge about biology. In describing the general student body, the faculty reported that the students' possess a wide range of prior knowledge, which varies from a well-developed understanding of introductory biological concepts to naïve and/or poorly developed understandings. The faculty identified more general student difficulties in learning biology such as the scale and abstractions of biological objects and processes. However, those instructors that actively reviewed students' written responses in assignments and assessments had a more sophisticated knowledge of individual learners' incoming conceptions as well as their developing ideas and difficulties in learning biology over the course of a semester. Additionally, several of the faculty described students as passive learners who engage in primarily passive behaviors such as listening to lecture and reading the textbook. They also stated that students experience difficulties in assessing the level of their own understanding.

Each of the biology faculty members had knowledge of student learning, however, the level of knowledge in the area of student learning varied between participants with some emphasizing independent actions and behaviors and others on collaboration. All of the participants indicated that learning requires more than listening to the delivery of explanations by experts during lecture. They also reported that learning is supported by students' reading of the textbook or other supplied reading materials. In general, they agreed that students need to practice working with new information and to make use of feedback to assess their own level of understanding. However, the faculty differed in their understanding of learning theory and their ability to describe specific actions or behaviors beyond reading that support student learning. Chris and Alex indicated that students should engage in independent tasks to support their learning such as completing assigned readings, remaining attentive during lecture, and seeking out additional resources. Pat focused almost entirely on students collaborating in groups to make sense of biological concepts. Sam, Terry, and Morgan described a combination of individual and group activities such as students practicing formulating their own explanations, debating with peers, and self-assessing their own conceptions. These four participants indicated that students learn through the social construction of ideas, which is consistent with the social constructivist theory of learning.

Knowledge of ways of representing biology. The fifth knowledge domain was the faculty's knowledge of ways of representing biology. While this study did not intend to capture detailed information about the explanations that faculty delivered during lecture, the data analysis did reveal that these biology faculty had knowledge of developing explanations of biological objects and processes. The study participants were not asked to provide information regarding their explanations in the interviews; however, their explanations were observed during the classroom observations. Several faculty made use of analogies in their explanations of biological processes. Also, four of the five faculty, who taught micro-level topics, explicitly transitioned between molecular level and cellular level scales as well as made connections to objects and processes at a larger scale (tissue, organ, organ system, or organism).

In addition, the faculty differed with regard to the context of their explanations. Pat and Sam did not deliver explanations of biology in any particular context. Alex and Chris provided explanations within the context of classic experiments and historical accounts of discoveries in biology. Terry and Morgan designed their explanations around specific contexts pertaining to the human body – a genetic disorder of the lungs and bacterial population of the digestive tract.

All of the instructors made use of visual representations of biology. Within the presentations slides, the primary representation was text, which usually consisted of abbreviated explanations and scientific terms. The faculty also made use of graphical depictions of biological objects and phenomena, animations, and authentic images and video.

Knowledge of instructional strategies. The sixth domain of knowledge was the faculty's knowledge of instructional strategies. The study participants reported having knowledge of instructional strategies, which included lecture, questioning techniques, small group work, and whole group discussion. Lecturing involved the delivery of expert explanations of biology from the instructor to the students. Questioning strategies involved the instructor posing questions for the students to answer within the class session. These questions were either posed verbally by the instructor or displayed on the screen from the presentation slides. Small group work consisted of students collaborating with a limited number of neighboring students to complete an assigned task during instruction. Whole group discussions consisted of the instructor facilitating a social interaction in which students posed their own explanations of biological objects and phenomena. The instructor guided the discussion through questioning and provided clarifications to students' novice explanations.

The repertoires of strategies varied between the instructors. The instructional strategies described by the study participants are included in Table 2.

Table 2

Repertoires of Faculty Instructional Strategies

Instructional Strategy	Alex	Chris	Pat	Sam	Terry	Morgan
Lecturing	X	X	X	X	X	X
Questioning Techniques	X	X	X	X	X	X
Small Group Work			X	X	X	X
Whole Group Discussion					X	X

Alex and Chris identified that their primary instructional approach was lecturing with 'breaks' provided by a nominal number of clicker questions. Pat and Sam reported making use of lecture, questioning techniques, and small group work in class. Terry and Morgan described their implementation of all four instructional strategies.

Knowledge of assessment. The seventh knowledge domain was the faculty's knowledge of assessment. The study participants reported having knowledge of assessment. All of the faculty members indicated that summative assessments were administered in their biology courses, however, they described using various formats to assess students' understanding. Alex and Chris reported giving exams that included only multiple-choice questions. Pat, Sam, Terry, and Morgan indicated that their tests were a combination of multiple-choice style questions and short answer questions. Sam described using multiple answer questions for which there may be more than one correct response. Pat, Sam, Terry, and Morgan stated that students' written responses to short answer questions served to be a better measure of students' level of understanding than their answers to multiple-choice questions.

All of the instructors reported making use of formative assessment techniques. The faculty described informally assessing students' level of understanding in the classroom during some type of interaction between the instructor and the students. These interactions occurred during verbal questioning sessions, posing clicker questions, small group work, and whole group discussions. Some of the instructors indicated that online pre-class quizzes provided a means of informally assessing students prior to lecture.

Nearly all of the instructors stated that assessments are a source of feedback. They indicated that assessments provided feedback to students about their own level of understanding. Pat, Sam, Terry, and Morgan reported that various assessment instruments were used to identify area of student difficulties and served to inform their future instruction.

Knowledge of building rapport with students. The eighth and final knowledge domain was the faculty's knowledge of building rapport with students. Different from having knowledge of learners and learning, building rapport with students, either collectively or on an individual level, involves relationship building. Five of the six instructors described various ways of developing a connection with students. The study participants reported having knowledge of strategies for building rapport with students in the large lecture setting by (1) providing structure and (2) incorporating elements of fun. The faculty indicated that providing structure was a means of reducing student anxiety by setting clear expectations and maintaining regular communication. They reported communicating with students through conversations before and after class, meetings during office hours, electronic mail, discussion boards, and online course management systems. Nearly all of the participants indicated incorporating elements of fun, such as humor and music, into the classroom to develop a positive rapport with students. Only one of these five instructors directly connected building rapport with supporting student learning.

Social interactions and experiences. In addition to knowledge domains, this study explored the self-identified social interactions and experiences of faculty as being integral to their development as teachers. The analysis of the data yielded four social interactions and experiences: teaching experience, models and mentors, collaborations and interactions with faculty, and science education research and literature.

Teaching experience. Many of the faculty reported gaining knowledge of teaching from their own experiences in teaching. Chris, Pat, Sam, Terry stated that they learned to teach through 'trial and error' in the classroom. The instructors varied with regard to the amount of teaching experience. Alex and Morgan did not refer to teaching experience as influencing their development as postsecondary teachers, however, this may be due to their being early career instructors with relatively lower levels of classroom experience.

Models and mentors. All of the study participants reported gaining knowledge of teaching from observed models of instruction. While Alex stated observing primarily 'bad' models of teaching, the other five instructors stated that they had observed 'good' models of instruction at the secondary and/or postsecondary level. For some, mentors also played a role in their learning to teach. Chris, Terry, and Morgan indicated that they had 'good' mentors who played an important role in their development as a teacher during the early part of their careers as college instructors.

Collaborations and interactions with faculty. Five of the six study participants reported having interactions with other faculty that influenced their teaching perspectives and practices. The instructors' perceptions of their professional obligations and teaching/research load of their position played a role in shaping the amount and types of interactions. For example, Alex was in a non-tenure track position and perceived teaching to be the primary role of the position. However, Alex indicated having interactions with faculty that were limited to administrative meetings. Terry was in a tenure track position and perceived teaching and research to be the responsibilities of the position. Terry reported that part of the duties included meeting with other faculty who were engaged in similar teaching and research. Terry indicated that these interactions took place at regularly scheduled group meetings and informal meetings in faculty offices.

The individuals with whom the participants interacted also differed with respect to their level of expertise in education. Alex, Chris, Pat and Sam reported having little to no interaction with faculty who specialized in science education in their career. However, Terry and Morgan stated that they had regular interactions with faculty who are scholars in the field of science education.

Science education research and literature. In general, the activity of performing educational research is a human endeavor, which is centered around teaching and learning. Research is often conducted by multiple scholars working as a team and seeks to build knowledge within the discipline. The literature serves as a means of communicating ideas and findings related to studies to facilitate an ongoing conversation among scholars as well as practitioners. For this study, faculty engaging in science education research and reading and/or discussing science education literature are included as social interactions and experiences. The study participants varied with respect to their level of engaging in and/or having experience with scholarly work in science education. Alex did not report having any knowledge of the science education literature nor experience in the area of performing educational research. Chris indicated having read science education literature, however, Chris did not identify it as a primary source of knowledge about teaching.

Pat and Sam reported being familiar with science education literature as they both engaged in teaching science education courses. Both indicated that reading the primary literature and discussing it with students increased their knowledge about teaching and learning. Pat also stated that serving on a doctoral committee for a science education research project was beneficial. Terry and Morgan reported engaging in multiple science education research projects that focused on teaching and learning in the context of large introductory biology courses. Both indicated that this research served to directly inform their teaching practices.

Teaching perspectives. In addition to knowledge domains and social interactions and experiences, this analysis yielded important information regarding a third factor that influences faculty PCK: teaching perspectives. Seeking to probe for knowledge, the interview protocol included phrases such as ‘philosophy of instruction, philosophy of how students learn, challenges faced in teaching’. The elicited responses yielded data about their knowledge domains but also provided information about their beliefs of instruction, student learning, and challenges faced in teaching. As such, ‘perspectives’ is considered to be a combination of beliefs and knowledge. Based on the analysis of the data, the instructors described four perspectives of teaching, which influenced their PCK and ultimately their practices: (1) views of context for learning, (2) views of instructional context, (3) views of influencing student behavior, and (4) views of time and resources for grading.

Views of context for learning. The study participants described different perspectives about the setting in which learning takes place. Alex and Chris expressed perceptions of student learning that revealed their perspective that learning primarily took place outside of the classroom. Pat, Sam, Terry, and Morgan indicated that learning took place both in and out of the classroom; however, their perspectives varied with regard to the proportion of learning occurring in and out of the instructional setting. This manifested in varying amounts of student activities taking place in the classroom as well as differing amounts work to be completed outside of class. Alex and Chris provided only a limited number of activities for students during lecture. In contrast, Pat, Sam, Terry, and Morgan designed relatively more activities and had students working in small groups. Pat, Sam, and Morgan provided relatively more assignments for students to complete outside of class as compared to Alex, Chris, and Terry. Interestingly, Chris assigned the least amount of work to be completed outside of class.

Views of instructional context. Nearly all of the study participants described the auditorium-style classroom as presenting challenges for teaching large lecture sections. However the perspectives of the faculty with regard to the context posing insurmountable challenges differed. Those instructors who held the perspective of the challenges being insurmountable favored teacher-centered instructional approaches. The instructors who viewed the context as being 'workable' exhibited more student-centered practices.

Views of influencing student behavior. Four of the six faculty indicated that student behavior could be influenced by the format of assessments or incentives through awarding points. This perspective resulted in instructors incorporating short answer questions in exams and assigning points to important tasks.

Views of time and resources for grading. Finally, the faculty had varying perspectives regarding the amount of available time and resources for grading. Those with the perspective of having little time and/or resources for grading administered exams, which were comprised only of multiple-choice questions. Regardless of it being time-consuming, Pat, Sam, Terry, and Morgan reported making use of short answer questions as part of assessments. They also stated that they made use of available resources, such as undergraduate tutors and graduate teaching assistants, to assist with grading.

Chapter 5: Discussion, Implications and Future Research

This chapter discusses the findings of the study along with implications and directions for future research. The first section revisits the key aspects of the literature and presents the findings of this study in the context of this body of work. The second section includes a discussion of implications of these findings, and the final section describes suggestions for further research.

Discussion

In this section, the findings of the study are reported to answer the research questions. The overarching research question for this study was: What is the nature of the PCK of biology faculty at large research institutions? In terms of describing and modeling the PCK of teachers, research has focused on examining various aspects of teachers' ideas, behaviors, and artifacts. PCK continues to remain an elusive construct even as the various domains of knowledge that build PCK and the manifestations that result from PCK become better defined and the methods of data collection and analysis improve in design. The three sub-questions for this research serve to reveal the PCK of biology faculty for teaching large introductory-level biology courses.

1) What are the types of knowledge that biology faculty use for teaching?

In Fernandez-Balboa and Stiehl's (1995) study of the collective PCK of 10 experienced university professors from multiple disciplines, the researchers identified five components of PCK that emerged from the data analysis; these include knowledge of: (1) subject matter, (2) students, (3) instructional strategies, (4) the teaching context, and (5) one's teaching purposes (Figure 4). However, these findings did not provide information about the PCK of faculty in teaching a specific discipline. Two other studies at the higher education level sought to capture the PCK of faculty teaching specific topics in science. Both of these studies imposed a previously constructed model developed by Magnusson et al. (1999) in analyzing the data. As a result, the findings were limited to four pre-established domains of knowledge: (1) knowledge of science curriculum, (2) knowledge of students' understanding of science, (3) knowledge of instructional strategies, and (4) knowledge of assessment. These studies were not designed to explore the PCK of faculty for teaching in a particular discipline of science.

Results of this study revealed that the six participants had knowledge in eight distinct domains. Seven of these domains were previously identified in the literature pertaining to either secondary and/or postsecondary level studies (Geddis, 1993; Gess-Newsome, 1999; Grossman, 1990; Lee, Brown, & Roehrig, 2007; Lee & Luft, 208; Magnusson et al., 1999). These included knowledge of content, knowledge of context, knowledge of curriculum, knowledge of learners and learning, knowledge of representing biology, knowledge of instructional strategies, and knowledge of assessment. The faculty had similar knowledge in the areas of content, context, curriculum, representing biology, assessment. However, the participants varied in their knowledge of learners and learning and instructional strategies.

Prior literature refers to knowledge of learners and learning as the knowledge that teachers have about students to support them in developing specific scientific knowledge such as knowledge of the ways in which students learn science, students' prior conceptions and naïve conceptions, the variation in students' developmental and ability levels, and ways in which students learn (Cochran deRuiter & King, 1993; Lee & Luft, 2008; Magnusson, et. al, 1999). The faculty differed in their knowledge of student learning. Two instructors emphasized learning as primarily an independent endeavor. The remaining four instructors focused on the importance of student collaboration in the learning process. These participants indicated having knowledge of the social constructivist theory of learning.

Fernandez-Balboa and Stiehl (1995) reported that the 10 faculty members from multiple disciplines in their study collectively had a significant repertoire of instructional strategies including lecturing, questioning, and group activities. In this study of biology faculty, the participants spanned a continuum of instructional strategies. Each of the six instructors had knowledge of lecturing and questioning techniques. Two of the faculty primarily made use of lecturing with minimal questioning. Four instructors had knowledge of strategies for small group discussions and activities, and two of these instructors also had knowledge of facilitating whole group discussions. These four participants were those that described student learning as being consistent with the social constructivist theory of learning.

One new domain was identified from the study: knowledge of building rapport with students. This new domain is distinct from the knowledge of learners and learning as well as the knowledge of instructional strategies. While teachers' knowledge of learners and learning refers to their knowledge of the ways in which students learn science along with students' prior conceptions and difficulties in learning science (Cochran deRuiter & King, 1993; Lee & Luft, 2008; Magnusson, et. al, 1999), this new domain refers to the ways in which an instructor establishes a relationship with students either as a collective body or as individual learners. Fernandez-Balboa and Stiehl (1995) included "creating a learning environment" and "motivational strategies" as part of the knowledge domain of instructional strategies. These included strategies such as "[be] fun and exciting", "bug them to learn on their own", "give a pep talk", "use humor", and "take a break". For this study of biology faculty, the aforementioned strategies would not be included in the knowledge domain of instructional strategies, which is reserved for those strategies tied to the teaching of content. The new domain of knowledge of building rapport with students encompasses strategies reported by the biology faculty such as having regular communication with students and incorporating elements of fun.

2) What social interactions and experiences influence the PCK of biology faculty? Studies of secondary science teachers identified classroom experience as an essential component of PCK development (Baxter & Lederman, 1999; De Jong et al., 2004; Geddis et al., 1993; Gess-Newsome, 1999; Grossman, 1990). These studies indicate that effective PCK develops as teachers spend more time with students in the classroom. However, research has not investigated the influence of teaching experience on PCK at the postsecondary level. Among the biology faculty, the variation in amount of teaching experience was not aligned with their PCK. The instructors with more knowledge in the areas of instructional strategies and learners and learning had varying amounts of teaching experience. Similarly, those with less knowledge in these domains varied in terms of their teaching experience.

The literature also lacks information about the social interactions and experiences that influence the PCK of instructors at the postsecondary level. Studies have reported on faculty-identified barriers to implementing reformed teaching practices (Fernandez-Balboa & Stiehl, 1995; Ebert-May, 2011) In contrast, this study sought to identify the institutional constructs that influence social interactions and experiences supporting instructors' development of effective PCK. In addition to teaching experience, models and mentors played an important role in the development of the biology faculty as teachers. Engaging in collaborations and interactions with other faculty, which focus on teaching and learning, were also influential. Performing educational research and/or reading and discussing science education literature was also significant in developing effective PCK and served to directly inform the teaching practices of some faculty.

3) How do the teaching perspectives of biology faculty influence their PCK?

Many models of PCK include a 'black box' labeled as beliefs, orientations, or perceptions. This study yields data that sheds light on the contents of this box for biology faculty teaching large introductory courses. Most of the literature includes studies that attempt to classify instructors into various categories of orientations based upon the participant-described approaches to teaching (Kember & Gow, 1994; Mertz & McNeely, 1990; Trigwell, Prosser, and Taylor, 1994; Prosser, Trigwelll, and Taylor, 1994; Trigwell and Prosser, 1996). Burroughs-Lange (1996) reported faculty's conceptions of their roles as an instructor to be (1) designer of the learning environment, (2) evaluator of student learning, (3) nurturer, and (4) motivator. However, these studies did not attempt to connect faculty orientations to the instructors' knowledge of teaching or actual teaching practices. This study of biology faculty identified four teaching perspectives that influenced their PCK development and resulting manifestations in the classroom: (1) view of context in which student learning takes place, (2) view of instructional context for engaging in reformed teaching practices, (3) view of assessment and incentives to influence student behavior, and (4) view of amount of time and resources available for grading student work products. These teaching perspectives directly influenced the teaching practices of faculty in the areas of instructional strategies and assessment, which, in turn, impact the knowledge development in multiple domains.

In addressing the overarching question of this study, a model was developed based upon the discussion of the three sub-questions to illustrate the nature of the PCK of the biology faculty (Figure 9). The social interactions and experiences created in the institutional setting are the basis for biology faculty developing knowledge and perspectives with regard to teaching. The four teaching perspectives can be viewed as sliding scales in which faculty can reside at different locations between the two endpoints. These perspectives influence the development of knowledge within the eight identified domains and ultimately the manifestations of teaching.

Although all of the study participants demonstrated having knowledge within the eight domains, the amount and/or level of sophistication differed between instructors. From analyzing the interview responses and classroom observations, three categories of PCK emerged: (1) PCK as an expert explainer, (2) PCK as an instructional architect, and (3) a transitional PCK, which fell between the two prior categories. Alex and Chris had the PCK of an expert explainer. Terry and Morgan had the PCK of an instructional architect. Pat and Sam had a transitional PCK that was a combination of expert explainer and instructional architect.

Implications and Future Directions

This study was intended to inform faculty, researchers, and administrators about the PCK of biology faculty teaching large introductory-level courses. The six biology

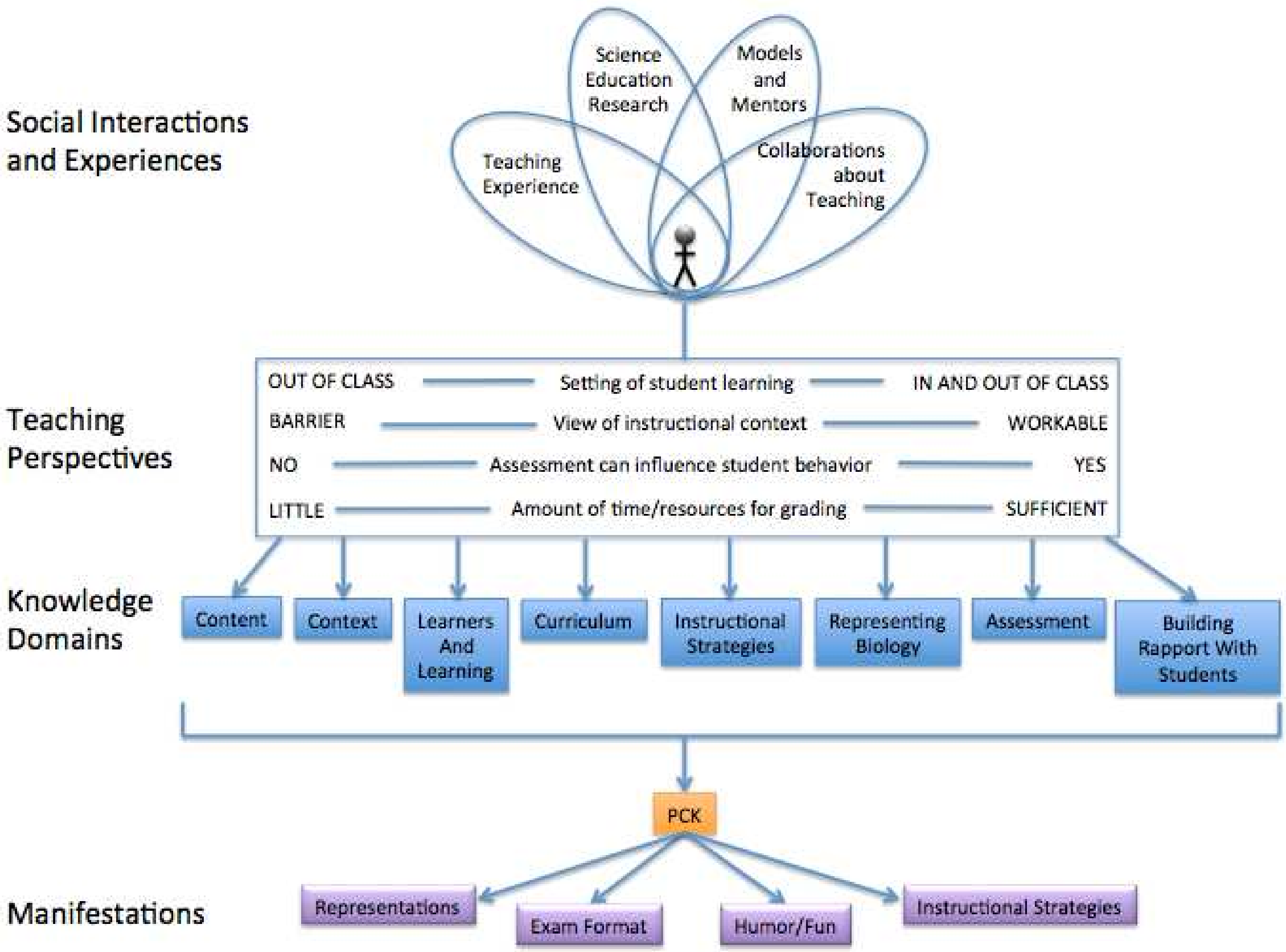


Figure 9. Model of the PCK of biology faculty.

faculty in this study possessed a range of knowledge in the area of learning theory and instructional strategies. From this and other studies, faculty include instructional strategies, motivational strategies, and strategies of building rapport with students as a collective set of teaching practices. It is important that faculty be able to distinguish between these types of strategies.

In addition, it provides some insight into the factors that affect the PCK of postsecondary teachers. This study suggests that the PCK of biology faculty is influenced by four specific perspectives of teaching and learning. In addition, it suggests that constructs within the institutional setting can shape the social interactions and experiences of biology faculty that ultimately influence their PCK. These findings can serve as a foundation for the development of applicable guidelines for faculty development in biology departments at large research institutions.

From this study, it is apparent that further research is needed with regard to biology faculty PCK development over time. It would be important to study how PCK transforms over years of teaching experience. For this, conducting a longitudinal study focusing on the PCK development of biology faculty would be useful. Future research could also examine various institutional settings and constructs and seek to reveal those that support the development of effective PCK for biology faculty.

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APPENDIX A: INTERVIEW PROTOCOL

Arizona State University

Biology Faculty at Large Research Institutions:

The Nature of their Pedagogical Content Knowledge

Interview Protocol

In this interview, I am going to ask questions to gain information regarding your teaching practices as the instructor of a large introductory biology course. Some of the questions will seek to obtain background information about your thoughts and experiences that have influenced your teaching. The final set of questions will concern the planned instruction for the classroom observation. As I mentioned in the recruitment letter, we will meet again after the classroom observation for a few more questions regarding your thoughts about the lesson. In providing answers to the posed questions, please be as complete as possible in your responses. I may ask follow up questions to understand your thinking.

<u>Pre-observation Interview:</u>

- *What is your philosophy of instruction for large introductory-level biology courses?*
- *What is your philosophy of how students learn in large introductory-level biology courses?*
    - *What is the role of the teacher? What is the role of the student?*
- *How often have you taught large introductory-level biology courses?*
    - *How did you learn to teach?*
        - *What past experiences have you had that influenced your teaching?*

- *Describe your idea of a "good" biology instructor in the setting of a large introductory-level biology course. What are the things that you do to be a "good" biology instructor?*
- *In your current position, what are the primary factors that influence your teaching?*
    - *Who are the players in your professional world that influence your teaching practices?*
    - *Given where you are in your career track, have your teaching practices changed? If so, can you provide an example that will help me to understand this change?*

(Questions regarding classroom observation)

- *Today, you will be teaching a lesson on genetics. What are your goals for today's class?*
    - *What do you intend the students to learn about this idea?*
- *Why is it important for students to know this?*
- *What are some of the difficulties that you face in teaching about this idea?*
- *Can you tell me how you will go about teaching on this topic and how you prepared for class?*
- *(If applicable) Can you tell me about the artifacts that you generated for today's class (e.g., Powerpoint, assessments, readings, handouts)?*
- *What were your primary considerations when preparing for teaching about this idea?*
    - *What are the most common difficulties that students have in learning about this idea? How did you come to know about these student difficulties?*

- *Did these student difficulties influence your planning and /or generation of the artifact(s)? If so, how?*
- *Were there any other factors influencing your planning and /or generation of the artifact(s)?*

<u>Post-observation Interview:</u>

- *What are your thoughts about today's lesson on genetics?*
- *Were you presented with any challenges during the class? If so, please describe them.*
- *Did you feel that you met your goals? Why or why not?*
    - *What evidence do you have to support this idea?*
- *In hindsight, is there anything that you would do differently?*
- *Additional questions regarding observations of interactions in the classroom.*