3-12-2008

Prospective faculty developing understanding of teaching and learning processes in science

Jose I. Pareja
University of Missouri-St. Louis

PROSPECTIVE FACULTY DEVELOPING UNDERSTANDING OF TEACHING AND LEARNING PROCESSES IN SCIENCE

By

José I. Pareja
M.S. Biology (Ecology), University of Missouri-St. Louis, 2006
M.Ed. Secondary Education (Curric. & Instr.), UM-St. Louis, 2004
Lic. Biology, Universidad Nacional Agraria, 1999
B.S. Biology (Biotechnology), Universidad Nacional Agraria, 1998

A DISSERTATION

Submitted to the Graduate School of the

UNIVERSITY OF MISSOURI- ST. LOUIS
In Partial Fulfillment of the requirements for the Degree

DOCTOR OF PHILOSOPHY

In

TEACHING AND LEARNING PROCESSES
with an emphasis in Science Education

October, 2007

<u>Advisory Committee</u>

William C. Kyle Jr., Ph.D.
Chairperson

Joseph Polman, Ph.D.
Co-chair

Charles Granger, Ph.D.

Bette A. Loiselle, Ph.D.

ABSTRACT

Historically, teaching has been considered a burden by many academics at institutions of higher education, particularly research scientists. Furthermore, university faculty and prospective faculty often have limited exposure to issues associated with effective teaching and learning. As a result, a series of ineffective teaching and learning strategies are pervasive in university classrooms.

This exploratory case study focuses on four biology graduate teaching fellows (BGF) who participated in a National Science Foundation (NSF) GK-12 Program. Such programs were introduced by NSF to enhance the preparation of prospective faculty for their future professional responsibilities. In this particular program, BGF were paired with high school biology teachers (pedagogical mentors) for at least one year. During this yearlong partnership, BGF were involved in a series of activities related to teaching and learning ranging from classroom teaching, tutoring, lesson planning, grading, to participating in professional development conferences and reflecting upon their practices.

The purpose of this study was to examine the changes in BGF understanding of teaching and learning processes in science as a function of their pedagogical content knowledge (PCK). In addition, the potential transfer of this knowledge between high school and higher education contexts was investigated.

The findings of this study suggest that understanding of teaching and learning processes in science by the BGF changed. Specific aspects of the BGF involvement in the program (such as classroom observations, practice teaching, communicating with mentors, and reflecting upon one's practice) contributed to PCK development. In fact, there is evidence to suggest that constant reflection is critical in the process of change. Concurrently, BGFs enhanced understanding of science teaching and learning processes may be transferable from the high school context to the university context. Future research studies should be designed to explore explicitly this transfer phenomenon.

To my wife Wendy.

ACKNOWLEDGEMENTS

To my family

-My parents: Dad and Mom, Tio Jorge and Tia Chito, for their unconditional love and support. Without them I would have not started nor finished this journey.

-My surrogate mom: Lili, for her love and great cooking and showing me what trust and humility means.

-My siblings: Enrique, Francisco (& Fabiana), Ximena (& David), Andres, Ginny (& Augusto), José H. (& Jodi), for their unconditional support, cariño and friendship.

-My Nephews and nieces: Augusto, Marigi, Ariana, Maria Fernanda, Aerika, Elena, Cristina, Ana Paula, Emanuel, for making me laugh and constantly reminding me, in their own way, what live is about.

To my friends

-Carlos and Pedro, for showing me what true friendship is.

-Rodrigo, Andrea and Gustavo, for their cariño, friendship and brotherhood.

-Adrian and Adriana, for their friendship, unconditional support and showing me how to look at birds from a passionate perspective.

-Diego S. and José Hidalgo, for their friendship, sportsmanship and lively spirits.

-Andrew Shaw, for his guidance, support, mentorship and most important his friendship and his fatherly support here in St. Louis.

-The Shaw family: Pam, Mark, Matt, Melissa, Michael, & Catherine, for adopting us.

-Okongo Akura (Okosh) and Village 14, for their commitment to helping those in dire need, their fellowship during our Kenya trip, and for showing me that Peruvian time is on time when compared to Kenyan time.

-Paulo, Eloisa, Ben (& Therese), Shane, Jenny, Nicole, Danielle, Beth, Jeff, Patrick, Steve, and other friends and graduate students from the biology department, who in one way or another provided me with an intellectual support system and cultural richness that helped me developed in more integral way, religiously, scientifically, and artistically.

-Sandi, for reviewing my vignettes, for her sincere support and friendship, but most important of all for showing me how a good teacher teaches and taking me to the ball game.

-Donna, for allowing me to observe and learn how a great teacher operates in a science classroom.

-Monya, Len, Kathleen, and Jodi, for sharing their experiences, work ethics, and listening when in need.

-Chuck McWilliams, for his professionalism, mentorship and friendship.

-David Fortus and Ana Switzer, for their indirect support, role model and research support.

-The CISTL Cadre, whom I wished were my cadre.

-Markham College friends and students.

<u>To the MOSTEP Crew</u>

-MOSTEP Teachers, PI's, partners and students, especially the BAT team.

<u>To the University of Missouri faculty/ Staff</u>

-Committee members Bette, Bill, Chuck and Joe, without them this entire process would not have been a success. Their mentorship and professionalism have been invaluable assets to my development as a professional and an independent learner. Their uniqueness has added different levels of expertise to my background.

-Patricia, for her mentorship, role model, openness and providing me with rich experiences related to science education (GEAR-UP and RAISE) that could not have been possible if she did not leave her door open.

-Carl, for his trust, showing me how to play good racquetball, and showing me how to think like an administrator and act as a leader.

-Jim, for showing me a different level of technology appreciation and science education research, and providing one more role model to choose characteristics from. I almost forgot, thanks for the endless supply of deer meat.

-Hal H. and Wendy S. for their mentorship in SKILLS and providing a great framework for me to plan my Kenya professional development project.

-Peggy C. & Kathleen Haywood for their comments and guidance through initial stages of my dissertation.

-Sandi Abell for her mentorship, friendship and role model.

-Maryann, Connie and Pat, for their helpfulness, unconditional support and assistance during my graduate program.

-The College of Education and the Graduate School for their support to my endless conferences.

To my friends from the TLC

-Brian (Sincere support and Tech support)

-Sana, Olena, Andre, Garon, Rick, & Mike, for their unconditional support in video editing, webpage design and Spanish lessons.

-And, all the other members of the floor staff and administrative staff that constantly had to deal with me.

To my Reviewers

-Margaret S., Marty H., Katie P., and a fourth person that wanted to remain anonymous. Also, thanks to the Writing Lab at UMSL for reviewing many parts of my dissertation, and finally thanks to my committee members again for double checking my document.

Institutions

National Science Foundation (Grant Award # 0338341)

College of Education Division of Teaching and Learning

Institute for Mathematics & Science Education and Learning Technologies

UM - St. Louis Biology Department

Whitney Harris World Ecology Center

Special thanks to:

Mr. E. Desmond Lee, without his support I would not have started or finished my graduate studies.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

CHAPTER 1

Introduction

Given the changing context in higher education; that is, the increase in diversity of students, the development of new technologies, and the increase in emphasis on learning outcomes, the next generation of faculty members require a range of abilities, skills, knowledge and understanding that goes beyond what faculty members have possessed previously (Austin, 2002; Wulff & Austin, 2004). Typically, being a good researcher was enough to become an acceptable faculty member; whether you understood teaching or learning processes was not a consideration (Elton, 2000; Rowland, Byron, Furedi, Padfield & Smyth, 1998). This long held criterion of an effective university faculty member is slowly being questioned.

There are three components identified by Pruitt-Logan, Gaff and Jentoft (2002) and Wulff & Austin (2004) as important in faculty development: Teaching, Service and Research (TSR). Although all three components are important, and to a certain degree interact with each other (Kogan, 1994), I believe teaching is paramount in the overall professional development of faculty. As a teacher, you become responsible for the development of future professionals, not only in your field, but in other fields as well. For example, a biology faculty might teach biology for majors or biology for non-majors at some point in his/her career. Being effective in teaching either course is crucial. From a non-major perspective for instance, future K-12 teachers enrolled in the course will learn part of their content knowledge. Teaching accurate concepts in appropriate ways, and at the same time building an awareness of ethical and societal implications of polemic themes in biology, such as cloning and evolution, becomes critical. Similarly, being an effective pedagogue in a biology major class is also important since future biologists may eventually become faculty themselves, starting the cycle again. For this reason, this dissertation focuses solely on the teaching component.

Historically, teaching has always been considered a burden by many academics, especially those academics in the realm of science (Hickok, 2006; Wulff & Austin, 2004). According to the Higher Education Research Institute (HERI, 1999) and the National Center for Education Statistics (NCES, 1999), faculty spend on average 59% of their time teaching, 23% doing service and 18% doing research. Traditionally, and still true for most higher education institutions (HEI), evaluation of faculty performance has been based on these three domains. The latter, a composite of papers published, presentations, projects funded and awards, has often been weighted as most important (Rowland et al., 1998), especially when determining who gets promoted on the academic ladder towards full professorship. Not surprisingly, one can understand why some academics view teaching as a burden and/or an unimportant side task.

For decades, higher education faculty have been the only people who could teach without "knowing" how to teach (Elton, 2000; Norman, 1999; Nowlis, Clark & Rock 1968). Like most faculty, science academics learn how to teach by "doing" during teaching assistantships, by observing their graduate advisors and peers, or by recalling high school learning experiences. Often, teaching assistants are thrown into teaching in a swim-or-sink manner with no preparation, advice, or supervision, thus they feel that is how one learns to teach. Likewise, new faculty members dive in head-first with no or little formal education or preparation in pedagogy (Dobson 2001; Park & Ramos, 2002; Wulff & Austin, 2004). Hence, suitable teaching skills are not learned or transmitted effectively from one level to the next, and positive learning environments are not always created when teaching at the higher education level. This hit or miss approach has an effect on the overall performance on graduate students as future researchers and professors (MOSTEP, 2004; Wulff & Austin, 2004). In the sciences, the lack of good teaching programs is not the only factor contributing to a weak development of graduate students as teachers. For example, the culture behind what a graduate teaching assistantship (GTA) means often plays an important role. Graduate teaching assistantships in science are often seen as a way to fund their careers. Conversely, in education a GTA position is more often seen as a chance to experience teaching first hand (Deel, 2004; Park & Ramos, 2002; Wulff & Austin, 2004). The importance of a well planned, mentored and comprehensive GTA is not emphasized enough in many science departments (Wulff & Austin, 2004).

Because of the ineffectiveness of past approaches and the research evidence over the last two decades (Pruitt-Logan et al., 2002; Smeby, 2000, Swami, 2002; Wulff & Austin, 2004), efforts at universities and institutions like the Pew Foundation, the

Carnegie Foundation and the National Science Foundation (NSF) have focused on the improvement and development of today's and future faculty (Boyer, 2000; Wulff & Austin, 2004). GK-12 (Graduate students in K-12 classrooms) is one such project launched in 1999 by NSF to improve the effectiveness of teaching in institutions of higher education. A big part of NSF's efforts are directed towards improving the teaching ability of future professors by engaging them in a series of activities where they are partnered with pre-collegiate teachers and specialists in the pedagogical arena who mentor and guide them during their academic program. Graduate teaching assistants in university classrooms rarely have the opportunity for individual observation and mentorship from experienced teachers (Dobson, 2001; Elton, 2000; Norman, 1999; Nowlis, et al. 1968; Park & Ramos, 2002).

This dissertation focuses on a cadre of biology graduate teaching assistants (BGTA) who are part of the Missouri Science Teaching Educational Partnership (MOSTEP), a GK-12 NSF sponsored project. Biology GTA's who are part of MOSTEP will be referred to as biology graduate fellows (BGF). Other biology GTA not participating in MOSTEP will be referred to as BGTA.

Statement of the Problem

Teaching in higher education is an important component of faculty duties. Over 45% of Ph.D.'s in sciences are employed in academe in the first few years after receiving their degrees (AAU, 1998; National Science Foundation- NSF, 2004). Biology graduate students tend to consider teaching, at various levels, as a more viable option than other scientists (NAS, 2000). Additionally, faculty play a key role in the development of future professionals; they are the ones who teach general courses, specialized courses and continuing educational courses. For decades, however, faculty understanding of teaching and learning processes has been questioned and examined (Elton, 2000; Wulff & Austin, 2004). This study scrutinizes how biology graduate fellows' understanding of teaching and learning changes as a result of their participation in MOSTEP- NSF's GK-12 project. Specifically, it addresses the following research questions:

1. How does the experience of participating in MOSTEP change BGF understanding of pedagogy (i.e., teaching and learning processes)?

- How do BGFs pedagogical content knowledge (PCK) change as a result of their participation in MO-STEP?

2. How do these changes experienced by the BGF transfer, if at all, to a higher education context?
   - Which component of pedagogical content knowledge (PCK) has the potential to transfer to a higher education setting?
3. What are the main sources of PCK?
   - What interactions could have been critical to the development of PCK?

Significance of the Study

It has been argued that faculty, particularly those in science, have a poor understanding of the teaching and learning processes (Dobson, 2001; Elton, 2000; Norman, 1999; Nowlis, et al., 1968; Park & Ramos, 2002; Rowland et al., 1998). This lack of understanding leads to the establishment of non-conducive/ineffective learning environments (Fisher & Taithe, 1998; Graaff, Andernach & Klaassen, 2006; Norman, 1999; Rowland et al., 1998). MOSTEP is a professional development project that tries to bridge this lack of preparation by developing a partnership between high school teacher mentors (experts in pedagogy) and prospective faculty. Therefore, investigating any changes in BGF understanding of teaching and learning as a result of their participation in MOSTEP at the level of pedagogical content knowledge becomes central. Finally, understanding the transfer potential of knowledge and skills across educational contexts (high school to higher education) could also be beneficial. Accommodating this kind of intervention programs as part of future faculty academic preparation may be desired.

Definition of terms

1. *Pedagogical Content Knowledge* (PCK). PCK could be summarized as the knowledge base one possesses, resulting from the interaction between subject matter knowledge and pedagogical knowledge, which provides a teacher with the ability to translate subject matter to a diverse group of learners in certain contexts (Shulman, 1986). This comprises: a) conceptions about what it means to teach a specific subject matter (e.g., what is the instructors orientation); b) knowledge of curriculum goals, objectives, scope and materials available in a content area; c) knowledge of instructional strategies for teaching

the particular subject matter (e.g., activities and representations); d) knowledge of student's understanding, (e.g., possible misconceptions, areas of difficulty and requirements for learning) in a subject area; and e) knowledge of assessment (e.g., uses and methods of assessing learning) in the subject area (Grossman, 1989; Magnusson, Krajcik, & Borko, 1999, Veal & MaKinster, 1999)

2. *Teaching Practice* (TP): TP refers to the act of teaching in a classroom. For example, how a participant teaches a particular topic, what s/he does, how they move, how they interact with the students and how they use different instructional strategies (Hammerness, 2002).

3. *Subject Matter Knowledge* (SMK): SMK refers to the actual subject content knowledge. In the case of MOSTEP, it refers to what a participant knows about particular topics in biology. Most of BGF's knowledge probably comes from their undergraduate, graduate course work and literature reviews for their research.

4. Professional Growth: Professional growth is defined as changes over time in the behavior, knowledge, images, and self perception of BGF.

5. *MOSTEP* (Missouri Science Teacher and Educational Partnership). MOSTEP was a science enrichment, and science education program, that fell under NSF's GK-12 category. The program partnered future teacher scholars (i.e., biology graduate students) with pre-collegiate biology teachers for at least a year. On average, ten graduate students worked with ten biology teachers every year for a period of three years. I was a BGF for the first two years of the program.

6. *Understanding*. The term understanding does not necessarily refer to knowing a concept by merely recalling its definition. It can actually cover six different levels of understanding according to Wiggins and Mc Tighe (1998). Basically, one who completely understands can explain, interpret, apply, have a perspective, empathize, and have self-knowledge with regards to a particular concept. Some areas of understanding may be more developed than others in an individual.

7. Understanding by Design model (UBD). The UBD model refers to the different curricular design strategies and guidelines described in the Wiggins and McTighe (2001) book "Understanding by design." The "backward design model" is explained by Wiggins and McTighe as a part of UBD. In a nutshell, what the "backward design" model

proposes is that you design your curriculum/instruction and lessons starting with: **1)** the national or state standard (What is worthy for students to understand?), then you move to **2)** the assessment piece (What is the evidence of student understanding?) and finally **3)** you design your activities/lesson (What learning experience and teaching promote understanding, interest and excellence?). In contrast, according to Wiggins and McTighe (2001), “most teachers begin with textbooks, favored lessons, and time honored activities rather than deriving those tools from targeted goals or standards.” (p. 3)

Summary

“Improving higher education, and specifically, strengthening the preparation process for future faculty, has become a significant issue in higher education” (Wulff & Austin, 2004, p. 3). It has been discussed by various stakeholders (employers, government agencies, doctoral students, graduate deans) that the next generation of faculty must command a range of skills where research abilities and appreciation of a variety of ways of knowing are probably most important. Faced with a diverse array of students, faculty must understand how the teaching and learning processes occur, and learn how to translate that into effective teaching. It is no longer adequate for graduate students to become “clones” of current faculty members (Graff, Pruitt-Logan & Weibl, 2000 in Wulff & Austin, 2004). National programs such as Creating Stewards of the Discipline, Preparing Future Faculty (PFF) projects, and Changing the Culture of Doctoral Education US Nation (2003) have been created to subsidize this lack of teaching preparation. GK-12 is such a program and it provides an environment to study pedagogical changes amongst prospective faculty. Hence understanding how these programs are effective is crucial. In particular, determining the effect such programs have in the development of PCK would be important. This study, therefore, focuses mainly on three aspects: A) How does biology graduate fellows’ understanding of teaching and learning change? and B) To what degree do these changes have the potential to transfer across educational contexts? and C) What factors contribute to these changes?

Personal Biases

Because of the social context in which research operates acknowledging my biases in this study is important. What I would like to discuss is how my participation in the program as the researcher, as a former high school teacher and as a participating fellow may have influenced this study.

At one level, instrument development and my interpretations of the results were mainly guided by my research experience in science and science education. At a second level, my former experience as a high school science teacher provided me with additional insights into the observations, interviews and data analysis process. At a third level, my active participation as a fellow gave me a unique inside look and experience of the dynamics between teachers and fellows. Additionally, working with each fellow as part of this cadre provided me a degree of professional and personal proximity with fellows. This proximity had the potential of me interfering with the BGF's pedagogical development as it probably did at some points. Finally, my interactions with the PI's, regarding some evaluation of the program, gave me another perspective on how the program worked from a philosophical and administrative point of view, but such knowledge also provided a venue for bias.

Being an outsider and an insider proved to be challenging at multiple levels. One of the toughest challenges was learning how to maintain an appropriate rapport with the fellows while reducing my biases when gathering data. I believe that having a suitable relationship with the subjects allowed for better access to their understandings of teaching and learning while developing an environment of trust without biasing my observations. However, I realized and embraced that not biasing my observations was close to impossible, since individuals' construction of knowledge happens in a surrounding where factors (such as, people- friends, strangers, teachers, researchers; environmental factors- warm days, dull days, bad days; social interactions, language and experiences) influence how we make sense of the world around us. My position as an active part of their social learning environment had an influence in BGF development of PCK. For instance, the questions added "on the fly" during the semi-structured interviews, when I thought there was a need to probe further in BGFs description or explanation of the phenomenon discussed, was a potential for bias. The fact that my interventions required fellows to reflect on their practice was also influential as was later confirmed by fellows' statements. Finally, the fact that every BGF asked me for my opinion at one point or another is another example of the potential for me to have an influence on the outcomes of this study. These instances delineate the objectivity and subjectivity that such studies are prone to and that one needs to embrace. In the end, I observed, accumulated, accommodated, provided a context to be reflective, and made sense of the observation outcomes. This interpretive role and the moments described above had implications in the final interpretation and analyses of the data reported herein that I had to embarce.

I also believe that pedagogical content knowledge (PCK) was an adequate construct to guide my interpretations and to provide me with a framework to look at the understanding of teaching and learning from multiple perspectives as related to the identified components of PCK in the literature review and frameworks (i.e., assessment, curriculum, student, instructional strategies). Moreover, my teaching experience, my experience as a student, and research experience, in combination with PCK helped shape instruments like the vignettes into what I believe were adequate tools.

Overall, I believe this emic and etic approach provided me with powerful perspectives that helped me in my own understanding of the changes regarding teaching and learning processes that BGF experienced. This emic and etic position, combined with the use of PCK as a guide for my analyses, allowed me to explore and craft a representation and description of the described phenomenon subject to my biases.

CHAPTER 2

Literature Review

"Scientific inquiry is the same in all fields" (NRC, 2002, p. 2) (e.g., physical, life or social science). As such, it is linked either implicitly or explicitly to some overarching theory or conceptual framework that guides the entire investigation. As a result of this process, scientific knowledge is changed, challenged, refined, verified and built upon (NRC, 2002). The purpose of this review is to survey the body of literature that informed the questions, educational theories, and paradigms used as frameworks for this study.

Pedagogical Content Knowledge (PCK)

Pedagogical content knowledge was first proposed by Shulman (1986) as the knowledge "which goes beyond knowledge of the subject matter to the dimension of subject matter knowledge for teaching" (p. 9). He suggested that for a particular subject area, such as ecology, PCK includes "the most powerful analogies, illustrations, examples, explanations, and demonstrations- in a word, the ways of representing and formulating the subject that makes it comprehensible for others" (Shulman, 1986, p. 9). The concept of PCK was further developed by the Knowledge Growth in Teaching Project (Shulman & Grossman, 1988). This project studied how teachers gained new understanding of content, and how these new understandings influenced their teaching. Researchers in this project described PCK as a synthesis of three knowledge bases (or domains) for teaching: subject matter knowledge, pedagogical knowledge, and knowledge of the context. Each of these knowledge bases has the potential to influence the development of PCK in differential ways, as expressed in a hypothetical model proposed by Magnusson et al. (1999, see Figure 1). Moreover, Shulman (1987) suggested that pedagogical content knowledge was the best knowledge base for teaching:

> The key to distinguishing the knowledge base of teaching lies at the intersection of content and pedagogy, in the capacity of a teacher to transform the content knowledge he or she possesses into forms that are pedagogically powerful and yet adaptive to the variations in ability and background presented by students. (p. 15)

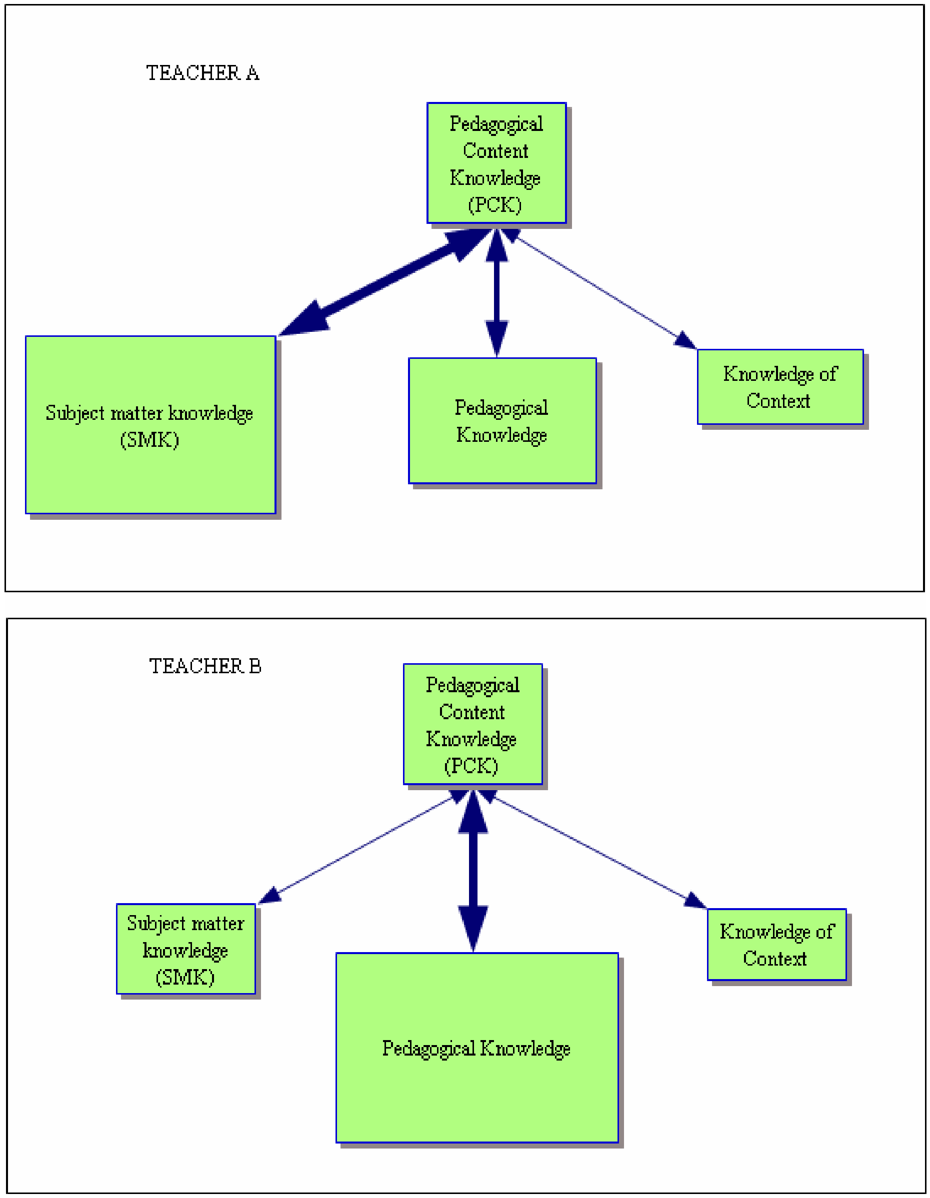


Figure 1. Hypothetical model showing the differential influence of variations (in knowledge bases) in the development of PCK. The amount of knowledge in a domain is depicted by the size of the rectangle and thickness of the line represents the relative influence upon one another. From: Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources and development of pedagogical content knowledge. In J. Gess-Newsome & N.G. Lederman (Eds.), Examining pedagogical content knowledge (pp. 95-132). Dordrecht, The Netherlands: Kluwer. Used with permission of the authors.

Since the inception of PCK, research has stemmed in various directions. Some studies have addressed questions related to how students learn to teach subjects they already know or are in the process of acquiring (Grossman, 1990; Magnusson et al., 1999). Other studies have linked content expert/teachers and PCK (Shulman, 1986);

novice/expert teachers and PCK (Clermont, Borko & Krajcik, 1994; MacDonald, 1992; Van Driel, Verlopp & De Vos, 1998); experience and PCK (Clermont et al. 1994; Hoz, Tomer & Tamir, 1990); values and PCK (Gudmundsdottir, 1990; Mellado, 1998; Shkedi & Horenzyk, 1995); and curriculum and PCK (Appleton, 1998; Stark, 2000).

As a consequence of these studies, two results are observed. First, many interpretations of PCK were coined by the community of researchers (Van Driel et al. 1998) which varied in their conceptualization of PCK and its components (Cochran, DeRuiter & King, 1993; Fernandez-Balboa & Stiehl, 1995; Grossman, 1990; Shulman, 1987). These multiple conceptualizations led to the establishment of an ambiguous meaning for PCK and its components (Loughran, Mulhall, & Berry, 2004). In a post-hoc review of the literature Abell & Lederman, (2007) also stated that PCK was not defined clearly. Nevertheless, I believe the conceptualizations provided by Magnusson et al. (1999), and Veal and MaKinster (1999), in the form of block diagrams (models of PCK), do provide an appropriate outline of what PCK is and its components. For example, Magnusson et al. (1999) proposed one model that showed the relationship among domains of teacher knowledge (see Figure 2) and a second model that showed the relationship among components of PCK (see Figure 3). Concurrently, Veal and MaKinster (1999) proposed a model that outlined how PCK related to pedagogy by depicting finer levels of PCK (General PCK, Domain specific PCK and Topic specific PCK) embedded in pedagogy (see Figure 4). Veal and MaKinster's second model showed how different components of PCK were related to each other (see Figure 5). Magnusson et al. (1999), and Veal and MaKinster (1999) agreed that the development of a teacher's PCK was a multifaceted, non linear, and a complex process. Despite the differences of conceptualization, PCK has become an accepted academic construct (Loughran et al., 2004).

Second, pedagogical content knowledge (PCK) was embraced by many of the well known educational reform documents (e.g., Benchmarks for Scientific Literacy, AAAS, 1993; and the National Science Education Standards, NRC, 1996*)* as a way of guiding reform in science education and helping describe the knowledge that expert teachers should possess. Interestingly, in the Educational Testing Service (ETS) study guide for principles of learning and teaching, the components of PCK can be matched with confidence to the guide's learning categories. In turn, these categories correspond to the different test items in the PRAXIS examination (ETS, 2004). According to Van Driel et al. (1998), teaching practices are determined to a large extent by teachers' PCK. Hence the relation between a PRAXIS test and PCK seem relevant.

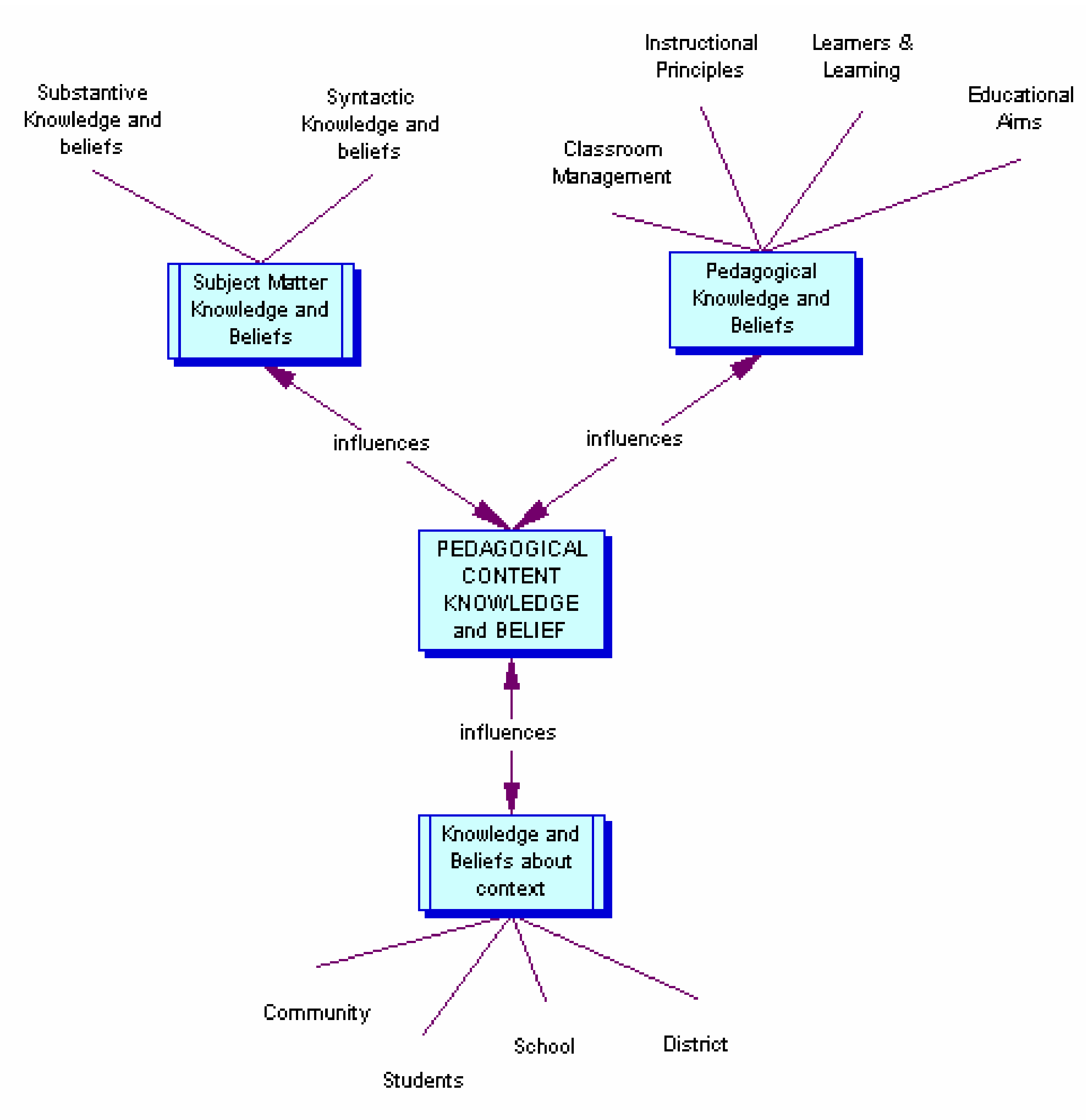


Figure 2. A model of relationship among the domains of teacher knowledge. From: Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources and development of pedagogical content knowledge. In J. Gess-Newsome & N.G. Lederman (Eds.), Examining pedagogical content knowledge (pp. 95-132). Dordrecht, The Netherlands: Kluwer. Used with permission of the authors.

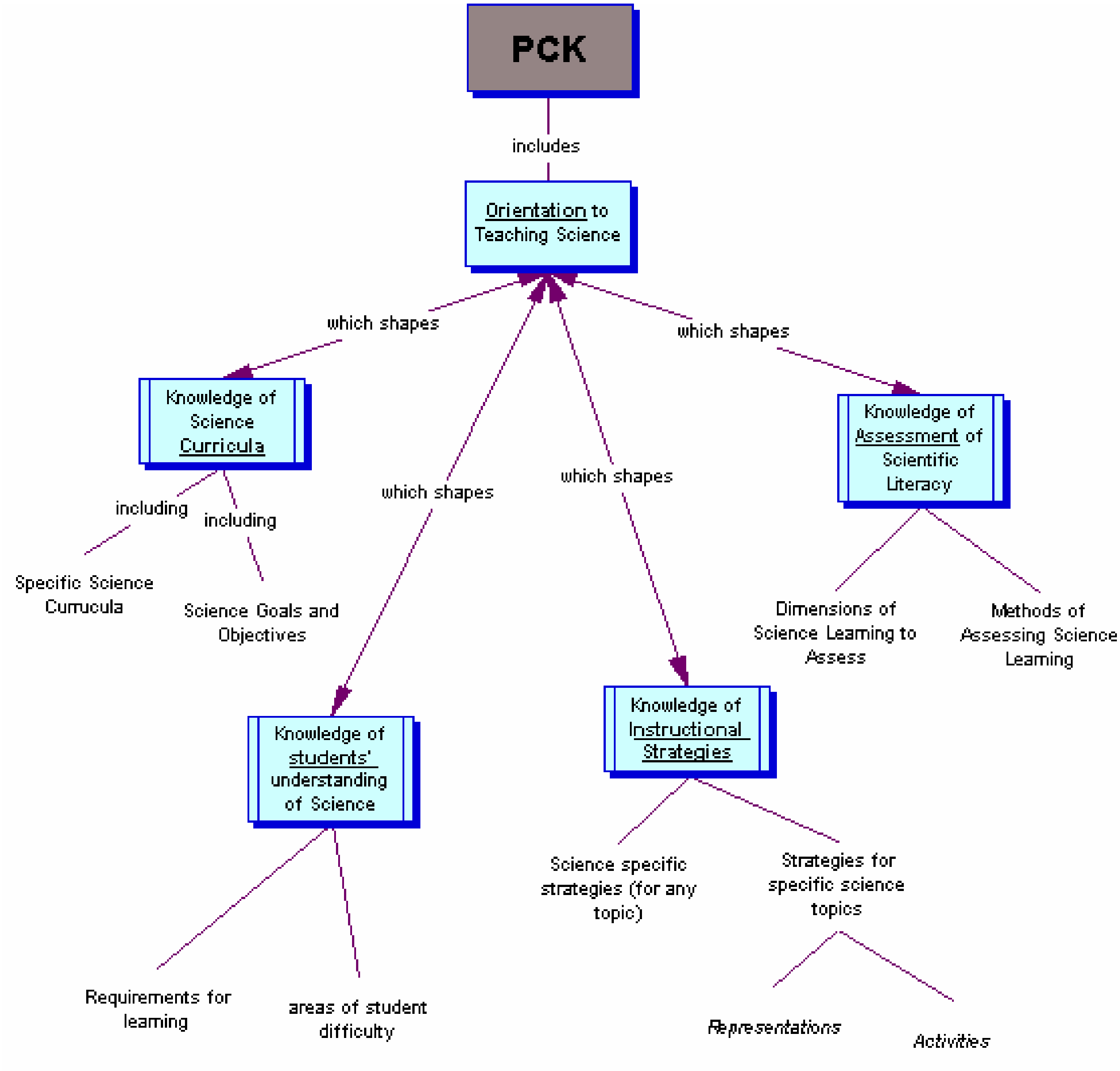


Figure 3. Components of pedagogical content knowledge for science teaching. From: Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources and development of pedagogical content knowledge. In J. Gess-Newsome & N.G. Lederman (Eds.), Examining pedagogical content knowledge (pp. 95-132). Dordrecht, The Netherlands: Kluwer. Used with permission of the authors.

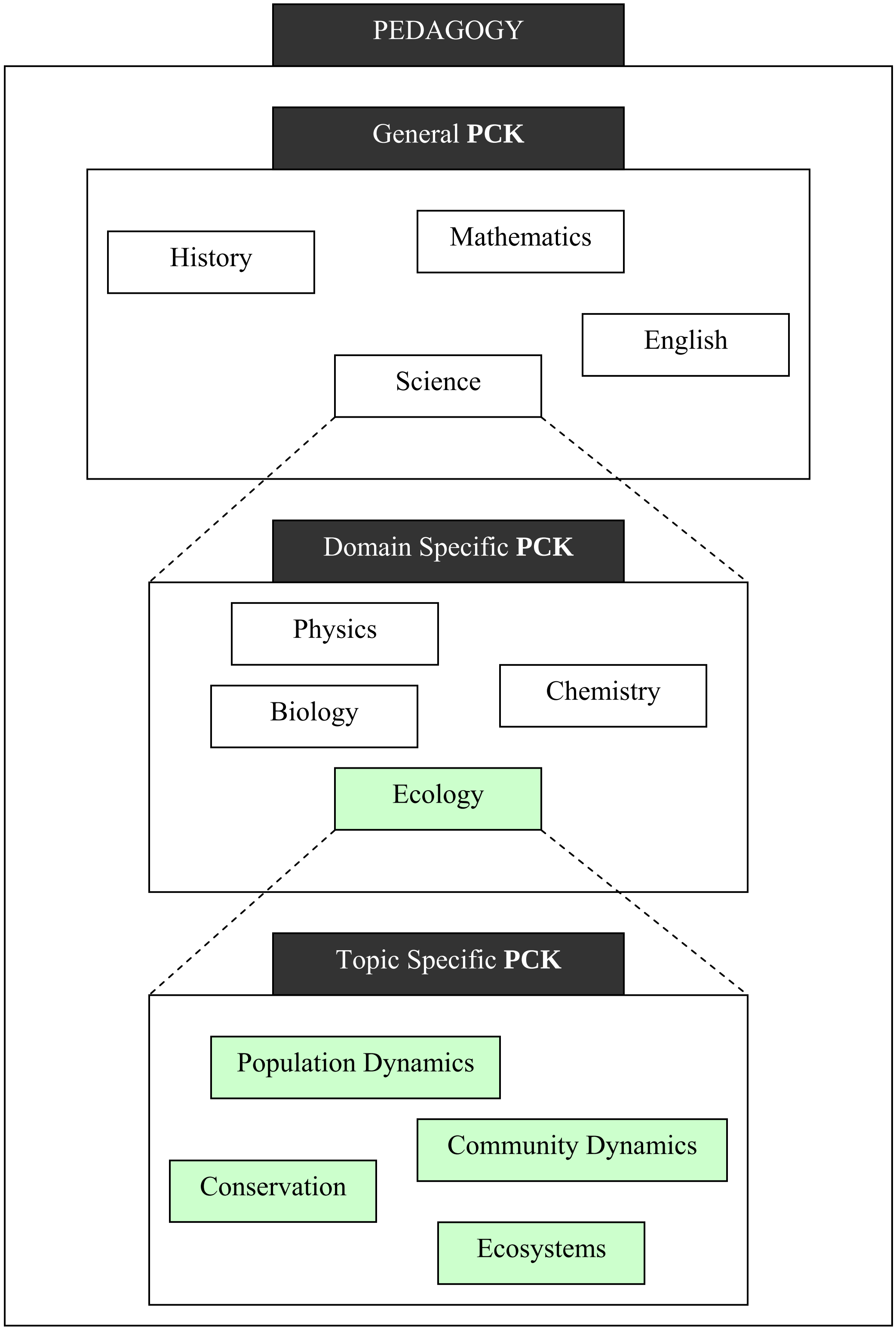


Figure 4. General taxonomy of PCK organized in a hierarchical way. Adapted from: Veal, W. & MaKinster. (1999). Pedagogical content knowledge taxonomies. Electronic Journal of Science Education, 3(4), 1-17. Retrieved 2/19/2005. Modified with permission of the authors.

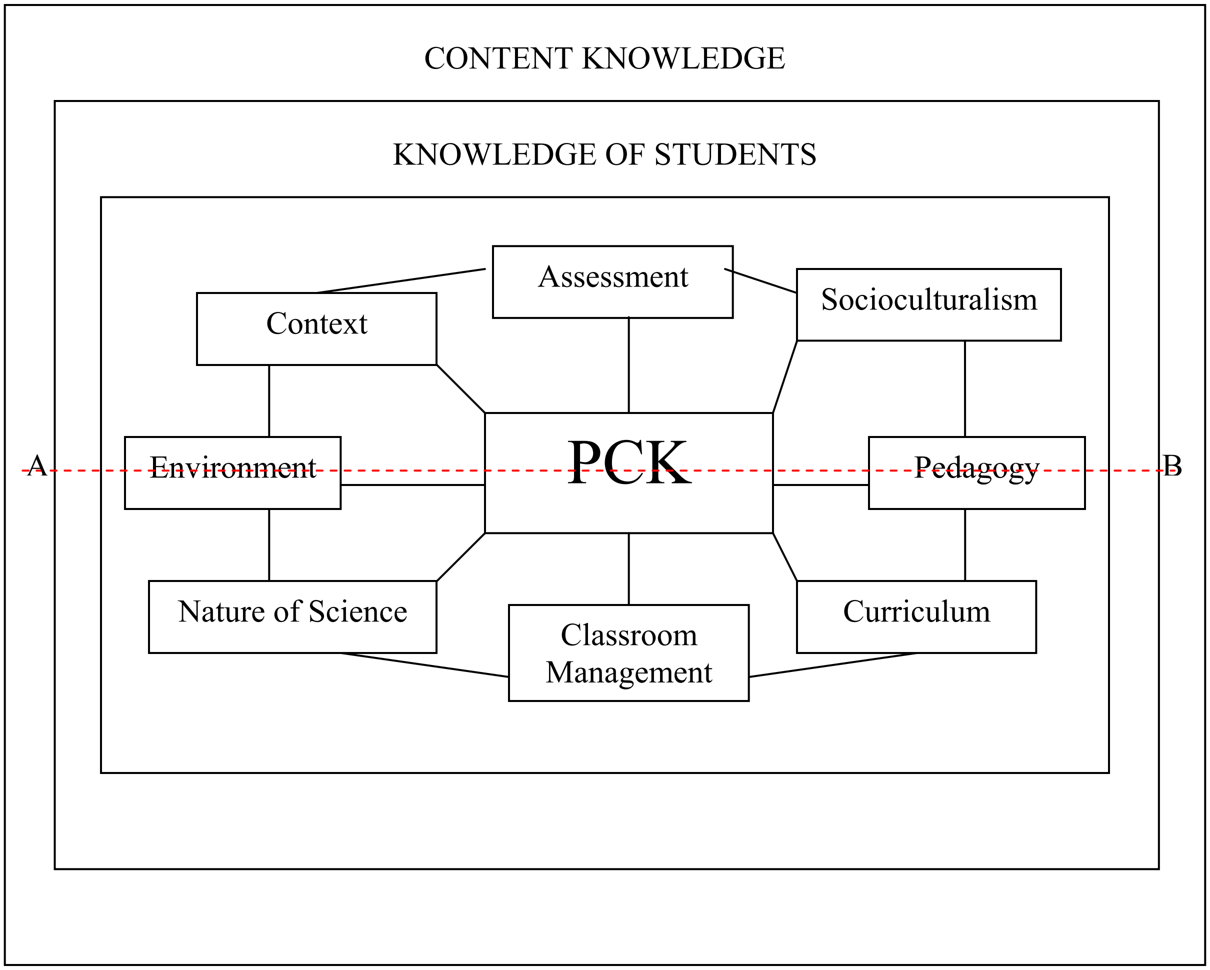


Figure 5. Taxonomy of PCK attributes. This diagram details a hierarchical structure for PCK and its attributes (Top View). The central location of PCK signifies its importance. The surrounding attributes are all connected, representing an integral nature of the epistemological components. If looked from the side (Cross section A→B) content becomes the base of the pyramid and PCK the pinnacle, where assessment, pedagogy and the other components are part of the third layer of a four layered pyramid.
From: Veal, W. & MaKinster. (1999). Pedagogical content knowledge taxonomies. Electronic Journal of Science Education, 3(4), 1-17. Retrieved 2/19/2005. Modified with permission of the authors.

Overall, I believe Veal & MaKinster's operational definition of PCK gives an accurate portrait of the complexities behind translating ones specialized knowledge (science) for a general audience to understand. This expanded definition of PCK outlines nicely the intricacies behind the concept of PCK.

> Pedagogical content knowledge is the ability to translate subject matter to a diverse group of students using multiple strategies and methods of instruction and assessment while understanding the contextual, cultural, and social limitations

> within the learning environment. The term translate is used instead of transform (Shulman, 1987), because content is adjusted to fit a teacher's understanding of the students. For example, just as Spanish words are translated into English, science concepts are translated into understandable units of meaning for students. When a person translates a phrase or idea from one language to another, the translator must know; the audience's level of understanding, the correct words to use, the order in which to place words, the cultural context, hand gestures, and social innuendoes. When the principles of translation are applied to science, the teacher must have the associated knowledge of a translator (knowledge of students, content, pedagogy, context, and environment) to properly convey his/her message (chemistry or physics) and/or provide appropriate opportunities for students to discover various science concepts and content within an activity or laboratory. (p. 12)

Based on this background, pedagogical content knowledge becomes a suitable construct to evaluate the fellows understanding of teaching and learning processes. Particularly, the models proposed by Veal & MaKinster (1999), in combination with those proposed by Magnusson et al. (1999), provide a framework for my study (Figures 1-5). I used both of the models in combination with the ETS study guide as a tool to analyze the collected data.

Components and classification of PCK

Understanding the classification models proposed by Magnusson et al. (1999) and Veal & MaKinster's (1999), help further clarify the concept of PCK and the role that each of the identified components has in relation to the construct of PCK. For instance, from a classification point of view and taking Veal and MaKinster's model as a starting point and making parallelisms with Magunsson's et al. models, at the most general level we find the acquisition of teaching skills (pedagogy) by all teachers, regardless of their subject. For example, the idea of wait time, group work, teaching methods, questioning, and planning will fall in this area. In this sense, pedagogy only becomes a component of PCK when used within the specific parameters of educational content areas. The next level, general PCK (or subject specific PCK in Magnusson et al., 1999) alludes to the use of specific pedagogical approaches while teaching a particular discipline. For example, the learning cycle could be considered a general PCK strategy for science when focusing on science concepts. Domain-specific PCK (or topic specific PCK in Magnusson et al., 1999) narrows our focus to a particular subject, for example ecology. The last level in the classification scheme refers to topic-specific PCK. This basically narrows the scope, within a domain, to topics such as population dynamics or ecosystems processes. For example, the idea of appropriate activities and representations (such as good analogies) would be important at this level (see Figure 3 and 4). In theory, "a teacher who has knowledge at this level of PCK should have a solid repertoire of skills and abilities in the previous three levels" (Veal & MaKinster, 1999, p. 9).

In terms of components of PCK, Grossman's (1990) model initially included four sections: a) knowledge of the curriculum; b) knowledge of instructional strategies; c) knowledge of student's understanding, conceptions and misconceptions; d) and knowledge and beliefs about the purpose of teaching. Magnusson et al. (1999) expanded on Grossman's model and conceptualized PCK as consisting of five components: "orientation towards science teaching;" "science curriculum knowledge;" "knowledge of students understanding of specific science topics;" "assessment" and "instructional strategies." Components are obviously interconnected. For instance, Darling-Hammond, Ancess, & Falk (1995) found that engaging teachers in assessment strategies helped their development of a curricular vision for their teaching, as well as provided a focus for how to connect learners to those learning goals. The separation of PCK into components is but an artifice that is the result of the reductionist nature of human beings, to help in our understanding of such concept. Much like scientists do to understand, a) the reproductive behaviors of birds by looking at its components such as mating rituals, plumage dimorphism, diet, genetic code, and song/call characteristics, or b) how matter behaves when heated by breaking the macro into a micro and looking at kinetic theory and atomic composition of matter. Thus, understanding the whole (PCK) by looking at its parts (components) allows us to scrutinize pedagogy from multiple angles and have a better insight on the phenomena. For example, how does this idea apply to a science class studying population ecology? Lets say that the teacher asks her students the following question, "What do you think will happen to the population of anchovy if the temperature of the water rises by 2 degrees centigrade?" The student's provide the following answers: a) nothing happens, or b) the population of anchovy will plummet. The teacher then replies with the following question: Why do you think the population will plummet? Based on this scenario we can look at this interaction from multiple angles. For example, the student –teacher interaction could be examined from an assessment, instructional strategy, or a learning angle. If we look at the interaction from an assessment angle, we could speculate that the teacher is assessing students in a formative way to check for their understanding of what may have been explained previously in class, or else she could be looking at what prior knowledge they are bringing to the class. Moreover, if we look at it from an instructional strategy angle, we could speculate that the teacher is using a discussion/questioning approach where an open-ended question has been used. She is also accepting multiple answers and an atmosphere of collaboration could be a potential product of this. In addition, the teacher's reply could entail an inquiry approach where the answer is not given to the student, but because the teacher is asking further questions the students reflect and expand on their answers. We could argue that learning was facilitated by the instructor. Finally, one could speculate that depending on the student's answers to the teacher's question, the teacher might decide to change the direction of the class depending upon if she feels the students are under-prepared or not, hence changing the curriculum and lesson plan. Concurrently, these decisions could be taking place in a matter of seconds. Each unique angle provides a perspective into the interaction, but all together they could give a much better picture of what is really going on.

Counts (1999) argued that enhancing any of these components of PCK will most likely enhance PCK as a whole. It is only when the teacher is able to integrate them all at the right time, for the right students that enhanced (effective) teaching will occur. This dissertation focuses primarily on four of the five components that Magnusson et al. (1999) outline. These components are: assessment knowledge, student knowledge, instructional strategy knowledge and curriculum knowledge. I decided not to include orientation towards teaching science because it is a broad and varied construct. Moreover, selected components have been complemented with areas from the PRAXIS series ETS study guide (2004) that I believed were relevant to each component and would strengthen their importance for my analysis (see Appendix A).

Knowledge of assessment. Knowledge of assessment refers to the knowledge a teacher has regarding different tools and strategies one could use to assess learning. For example, one of the reasons that teachers assess at an individual level is to provide the teacher, the student and the parents with information about student progress. A second reason, at a more administrative level, is to provide other stakeholders such as school administrators, politicians and policymakers, with information for comparative purposes across classrooms, districts, states, national and international levels. For this particular study, assessment will be limited to strategies used by teachers to assess science learning in their classrooms. In particular, it is focused on MOSTEP fellow's knowledge of what they understand by assessment per se, the types of assessment (i.e., forms of assessment and tools to assess) and their uses, to enhance learning and inform teaching in the classroom. Formative and summative use of assessment is especially considered in this dissertation.

Knowledge of curriculum. According to Magnusson et al. there are two types of curricular knowledge: a) knowledge of goals and objectives and b) knowledge of specific curriculum programs. Both of these types are critical components for planning instruction and are embedded in lesson planning. Hence knowledge about lesson planning has been included in this component of PCK for evaluative purposes.

Knowledge of instructional strategies. According to Magnusson et al., this type of knowledge includes what is known as subject-specific and topic-specific strategies, which were outlined previously. For this study a break down of instructional strategies into three main sections, that includes these two types, is proposed. These sections are: a) major methods of instruction (where subject-specific strategies belong), b) topic-specific strategies (such as activities and representations) and c) communication techniques (such as tone of voice and questioning techniques per se).

Knowledge of student learners. According to Magnusson et al. (1999) this category pertains to knowledge teachers have of students: a) pre-requisites for learning certain concepts and prior knowledge, b) areas students find difficult, c) approaches to learning science, and d) alternative conceptions or misconceptions. For this study, a break down of student knowledge into two main components was utilized. These components were: a) learning processes (this includes all of Magnusson et al. sub-components) and b) student diversity in the classroom as a means to understanding diverse learners in science. These definitions are consistent and complementary to Magnusson et al. (1999) definitions of components of PCK. For more details see Appendix A.

Sources of PCK

Grossman (1989) identifies various sources that can help teachers acquire PCK: 1) apprenticeship of observation, 2) subject matter knowledge, 3) teacher education, and 4) classroom experience. Apprenticeship of observation refers to instances where the teacher, or prospective teacher (e.g., BGF), learns by observing directly or indirectly other teachers. Indirectly, as a student (e.g., high school or undergraduate) BGF could remember what worked for them and how the concepts were taught to them. Directly, as a prospective or pre-service science teacher in training (e.g., student teaching or internship) or as a teaching assistant in the case of most graduate students, observing the lead professor or senior TA's. As students we remember learning experiences well, especially those that had meaningful and strong positive impact and those that were ineffective. Hence, the typical approach most prospective science faculty would have is imitating their preceptors' contingent on their experience. This source of PCK may be "the most powerful source of instructional strategies and curricular knowledge" (Counts, 1999, p. 25) for a teacher. The subject matter knowledge of the prospective science teacher is developed primarily in science courses taught by faculty (NSTA, 1998; in Duggan, 2005). Therefore, it is very important that prospective faculty are well prepared in the art of science pedagogy to ensure that future professionals receive a quality and thought provoking education. Teacher education (pedagogical knowledge), usually translates in participation in specific science method classes, though as Counts (1999) notes the course may need to overcome the knowledge and beliefs already developed in the apprenticeship of observation. Most likely, these knowledge, beliefs and experiences are going to be deeply intertwined and embedded in ones' cognitive structure or mental framework of how to teach science. Hence prior knowledge becomes critical to ones future learning (Ausubel, 1968). Finally, the experience of teaching provides the student with a context in which to practice what has been learned (Van Driel et al., 1998). Based on these observations, experience will probably contribute more to the development of components, such as knowledge of students' misconceptions or preconceptions, curricular knowledge and instructional knowledge. Clermont et al. (1994) suggest that "the growth of PCK in beginning teachers is generally slow and incremental" (p. 419).

Most of these components have been studied extensively during research in K-12, but the applicability/ understanding of the construct does not distinguish boundaries when moving across educational settings. What might vary is the context in which the teaching takes place with respect to the curriculum. Students in undergraduate and graduate school still have misconceptions, they also respond best to appropriate guidance, classroom sequences and clear objectives, not to mention good scaffolding activities and questions that help critical thinking. In addition, classes at this level need to be managed in different ways, but still need to be managed. Certain topics need to be taught in particular ways for faculty to be successful in their instruction.

Constructivism and PCK

Constructivism, around since the 1600's, can be viewed as an educational paradigm. A paradigm represents "simply the most informed and sophisticated view that its proponents have been able to devise, given the way they have chosen to respond to ontological, epistemological, and methodological questions" (Denzin & Lincoln, 1994, p. 108). Contemporary proponents of constructivism as a theory of learning argue that knowledge can be effectively constructed and deconstructed. By constructing on the learner's prior knowledge and allowing the learner to socially interact with the constructs within their reality, constructivists believe that meaningful learning will occur. Spivey (1997) further emphasized that individuals are considered "constructive agents and view the phenomenon of interest (meaning or knowledge) as built instead of passively received by people whose ways of knowing, seeing, understanding, and valuing influence what is known, seen, understood, and valued" (p. 3). As Shulman (2000) points out "understanding begins with what is already inside the learner's head…If you are going to teach someone, you want them to move from muttering vaguely to trying to state more explicitly… that is the essence of pedagogy putting the inside out, working on it together while it is out, then putting the outside back in" (p. 133).

Cochran, King and Deruiter (1991) present an interesting definition of PCK from a constructivist perspective:

> Pedagogical content knowledge is an integrated understanding that is synthesized from teacher knowledge of pedagogy, subject matter content, student characteristics, and the environmental context of learning. In other words, PCK is

> using the understandings of subject matter concepts, learning processes, and strategies for teaching the specific content of a discipline in a way that enables student to construct their own knowledge effectively in a given context. (pp. 10-11)

This definition gives a clear picture of how constructivist learning theory is related to PCK. From a constructivist perspective, understanding that knowledge is built by the learner based on his/her characteristics (e.g., prior knowledge and misconceptions) within a social context or learning environment (undergraduate setting or high school classroom) that provides a basis for teaching.

An individual must be involved actively in the learning process (as a student, as a teacher and a reflective practitioner) to have meaningful long-term, multifaceted benefits in his/her mental and conceptual frameworks (Dewey, 1910; Hogan & Pressley, 1997; Piaget, 1950; Schön, 1983). Constructivist learning theory applies to this study not only as a teaching approach that biology graduate fellows' should be cognizant about, but also as an important paradigm of learning about teaching and learning processes.

University Teaching and PCK

University teachers (professors/ faculty) are considered content specialist and, for the most part, they are firmly grounded in content knowledge. Hence, based on Magnusson's et al. (1999, p. 119) hypothetical model of differential influences (Figure 1), content will probably have the largest influence in university science teachers' development and shaping of PCK. Additionally, taking pedagogical courses, a purported component of PCK and a knowledge base that influences the development of PCK, is not a requirement for teaching at universities, in spite of the fact that various studies suggest some form of faculty in-service program should be mandatory (Buskist, 2000; Pruit-Logan et al., 2002; Rowland et al., 1998; Wulff & Austin, 2004).

Only a handful of studies have focused on the development of PCK in higher education (Counts 1999; Fernandez-Balboa & Stiehl 1995; Lenze & Dinham 1994; Major & Palmer, 2002; Swami, 2002). These researchers determined that through personal reflection and collegial discussion, faculty were able to acknowledge students' difficulties (lack of pre-requisite coursework, preconceptions and content constraints). Faculty claimed that they knew about these difficulties from personal experience, either as teacher or student in the course (i.e., observational learning, Bandura, Ross & Ross, 1963; Lortie, 1975; Woolfolk, 2001); or shared experience from faculty who previously taught the course. Fernandez-Balboa and Stiehl (1995) suggest that university teachers across various disciplines construct and use generic PCK in very similar ways and their belief systems influence how they present subject matter to the students. In addition, they found that five generic components of PCK emerged as a result of their study: a) the subject, b) the students, c) the instructional strategies, d) the teaching context, and e) one's teaching purposes. All components emerging from this study are found in Veal and MaKinster's (1999) taxonomy of PCK attributes model and are constituents of Magnusson, Krajcik, and Borko (1999) PCK models. Finally, Fernandez-Balboa and Stiehl (1995) pointed out that their findings open the conversation for resolving the dichotomy between scholar and teacher. As Kreber (2002) suggests, teachers should be scholars of teaching and not just scholars or just teachers.

Interventions like MOSTEP could result in interesting changes at the level of prospective faculty's PCK. Swami (2002) found that there is no difference at the college level of how faculty, with teaching background in K-12 and without teaching experiences, perceive teaching (i.e., perception about subject matter knowledge, PCK, and pedagogical knowledge in their classes) in introductory level science courses. He also found that faculty teaching at a research level I university had higher perceptions about subject-matter knowledge, while faculty at a non-research institutions had higher perceptions about pedagogical knowledge and PCK. It is clear from the review of literature that there is room for speculation about this matter.

Based on this review of PCK (i.e., components, sources, application to college settings) I used PCK as a construct to explore BGF change during this study. I based my analyses on Veal & MaKinster's (1999) taxonomy of PCK and Magnusson, Krajcik, and Borko (1999) PCK model, while keeping in mind the role of constructivism as a learning theory in this process. In this sense I saw MOSTEP fellows actively constructing and deconstructing their understanding of teaching and learning processes within a social context (their reality). Additionally, I explored the understanding of how PCK, at different levels (contexts), had the potential or not to transfer to a higher education setting.

Inquiry

Curiosity is the starting point in science. When we see the coloration patterns during a sunset, or the formation of a rainbow, we wonder: How is this possible? What is going on? Questions are asked, we start inquiring. We ask questions to help us understand our curiosities regarding a phenomenon (e.g., rainbow or sunset coloration), we get involved in some form of inquiry.

In science education the use of the term inquiry has been ambiguous. In the National Science Education Standards (NSES), published by NRC (1996), scientific inquiry is defined as “the diverse ways in which scientists study the natural world [“questions”] and propose explanations [“answers”] based on the evidence derived from their work [systematic data gathering] ” (p. 23). In the NSES content standards, different propositions have been made as to how a teacher could and should change his/her teaching emphases to promote inquiry (NRC, 1996, p. 113). One example is that students should develop abilities necessary to do scientific inquiry (i.e., students should get involved in the process of investigation) and they should develop understanding about scientific inquiry (i.e., students should be able to reflect about the major underpinnings of scientific inquiry). Additionally, in the NSES when they refer to inquiry as science content they basically refer to students learning about the nature of science (NOS) or scientific inquiry, that is, reflecting about the major underpinnings.

In a synopsis about inquiry as an organizing theme for science curricula, provided by Anderson (2007) in the Handbook of Research on Science Education (2007), Anderson talks about three forms of inquiry: scientific inquiry, inquiry learning and inquiry teaching. He says that these forms of inquiry were initially identified from the NSES. Interestingly, he argues that the NSES does not “set out clear definitions of what constitutes inquiry” (p. 811). He does, however, focus on two aspects of inquiry: inquiry learning and inquiry teaching. On the one hand, inquiry learning, he says is seen as synonymous to constructivist learning where “learners construct meaning for themselves, such meanings are dependant upon prior constructions, the understandings are context dependant, and they are socially constructed” (Anderson, 2007, p. 821). On the other hand, inquiry science teaching he says “may refer to teaching science AS inquiry (helping students understand how scientific knowledge is developed) or teaching science

THROUGH inquiry (having students take part in inquiry investigations to help them acquire meaningful conceptual science knowledge)" (Lunetta, Hofstein, & Clough, 2007, p. 396). For example, engaging students in laboratory inquiry has ranged from activities that are highly structured to open-ended (Lunetta et al., 2007). The latter, open ended, is interpreted in the NSES as a laboratory where learners are involved in "asking questions, completing an investigation, answering the questions, and presenting their results to others" (NRC, 2006, p. 123). NSES recommends that teachers should put less emphasis in activities that verify science content and more emphasis on activities that investigate and analyze science questions. However if the concept of inquiry is not well defined, or else is used carelessly to define multiple ideas regarding teaching and learning, observation and determination of teacher behavior and classroom strategy could become difficult and meaningless.

Transfer of PCK and teaching practices

Transfer is defined by the NRC "as the ability to extend what has been learned in one context to a new context" (NRC, 2000, p. 51). Hence, the "processes of learning and the transfer of learning are central to understand how people develop important competencies… It is especially important to understand the kinds of learning experiences that lead to transfer" (p. 51). In addition, "Transfer lies at the heart of the educational system. Most educators want learning activities to have positive effects that extend beyond the exact conditions of learning" (Bransford & Schwartz, 1999, p. 61). In this particular case I looked at the potential of transfer of PCK from a high school setting to a higher education setting.

How have people classified Transfer? Salomon and Perkins (1989) described two kinds of transfer: Low-road transfer (LRT) and High road transfer (HRT). LRT "involves automatic and spontaneous transfer of highly practiced skills with little need for reflective thinking" (p. 118). The key for LRT lies in practicing a skill often, in different situations, until it becomes automatic. This could be seen as analogous to a surgeon practicing a surgical procedure to apply in the operating room, or a teacher using basic teaching questioning strategies often enough that it becomes automatic during a conference presentation for instance. HRT involves applying, in a conscious way, abstract knowledge learned in one situation to a new situation. This can happen in one of two ways: you may learn a strategy intending to apply it in the future (i.e., forward reaching transfer <FRT>- projection), or if you are faced with a situation and look back on what you have learned to help you in the new one (i.e., backward reaching transfer <BRT>- in retrospect) (Woolfolk, 2001). We tend to use knowledge in situations where it is obviously appropriate (Driscoll, 1994, Singley & Anderson 1989).

How does transfer work? "Transfer between tasks is a function of similarity, that is, the degree to which the situations share common elements" (NRC, 2000, p. 73). The more similar a situation is (e.g., classroom dynamics) to the new situation the more probable transfer will occur. For example, while analyzing case studies in education or medicine, there is a higher chance to apply what was learned from the study if the person recognizes or identifies (i.e., by projection or in retrospect) with the situation portrayed in the study. The vignettes used in this study were developed with this idea in mind. Moreover, according to Singley & Anderson (1989) in all learning domains, the development of expertise "occurs only with major investments of time, and the amount of time it takes to learn material is roughly proportional to the amount of material being learned" (NRC, 2000, p. 58). This means that the more time fellows spent teaching or reflecting on their teaching practices the better prepared and more probable for PCK to transfer between contexts, i.e. high school to university or vice-versa.

"The first factors that influence successful transfer is degree of mastery of the original subject" (NRC, 2000, p. 53). In this particular case it will be how much PCK the fellow has acquired and reflected upon as a result of his/her experience in MOSTEP. For example, motivation is one factor that affects transfer because it relates to the amount of time people are willing to devote to learning, hence master the subject. Fellows are in this case learning about teaching and learning processes. If fellows see the usefulness of what they are learning, then they will be more careful to reflect on what they are learning if they see how this will impact them in the future (FRT). Challenges are another factor that will affect learning and therefore transfer. Tasks that are too difficult could cause frustration in someone's learning, resulting in little or no transfer. On the other hand, whenever learners can see usefulness in what they learn and how this may have an impact on others, then its potential to transfer increases. Context also affects transfer. People can learn in one context and fail to transfer to another context. Research indicates that transfer across contexts is especially difficult if the subject, for example how to teach in this study, is experienced in a single context rather than multiple contexts (Bjorl & Richardson-Klavhen, 1989). One way to deal with this lack of flexibility is to ask learners to apply what they are learning to different scenarios, contexts or example cases (Mann, 2002). In this case, for example, fellows reflected upon common teaching practices in higher education and were asked to propose a way of teaching the same topic during different instances throughout the project. This allowed the researchers to observe any changes. It becomes important to have learners choose and evaluate strategies, consider resources, and receive feedback about their teaching approach so transfer occurs in a more predictable and dynamic way.

Why would a change in PCK and beliefs result in a change in practice? From my previous discussions, pedagogical content knowledge is one factor that could greatly affect teacher practice; beliefs and their interaction with PCK are another. Tsai (2002) suggests that "teacher's beliefs about the nature of science, in many cases, are related to their beliefs of learning and teaching" (p. 771). Consequently, instructional plans and teaching practice will most likely be affected by these beliefs. Grossman (1989) and Swami (2002) suggest that teacher's beliefs about the subject matter combined with their beliefs of schools, students, learning, and the nature of teaching "powerfully affect their teaching" (Grossman, 1989, p. 31). A teacher's belief about how to "best" teach a topic within a subject could be based on previous experiences as a learner or as a teacher. For example, as a learner (in high school), when I learned about the human circulatory system, visual representations of the heart and direction of blood flow was the best way for me to grasp the concept of double circulation. Additionally, memorizing each structure and function of the system, that is veins, arteries and heart, was crucial for my understanding of this system. I always remembered this class and I was able to transfer my understanding of circulation to animal physiology, a college class that dealt with understanding different vertebrates' circulatory systems. When I was a teacher I used this same approach in all my classes, always believing that it was the best way to learn because I learned it that way. My practice was based on my beliefs. I learned that not all of my students grasped the circulatory system with only a diagram and some memorization of structure-function. My understanding of PCK was ill-constructed to see that the context, previous knowledge of students, and diversity of pedagogical strategies could have helped me in reaching more students if these components of PCK were orchestrated wisely to guide my practice. I always attributed the lack of understanding of my students to the fact that they were lazy and did not want to learn or did not care about learning. Hence, they failed their tests. My strong beliefs about how to teach this particular subject were hard to change. In addition, my lack of knowledge (PCK, content knowledge, pedagogical knowledge) was enough to allow my beliefs to prohibit the use of these knowledge bases for teaching.

I think this experience is a typical illustration of how beliefs and knowledge base (PCK, CK) about teaching affects teaching practices. This same situation occurs with future faculty (graduate students) when they become faculty. From this example, we can see that to fully understand the potential of how teaching practices transfers from one setting, high school, to another setting, higher education, we need to explore how PCK and beliefs transfer across these settings.

CHAPTER 3

Research Design and Methodology

Introduction

The research design was based on a multi-case study approach where a chronological structure was followed (Yin, 2003). Descriptive quantitative data were used to complement the research findings in this study. The guiding questions fall under two main areas of educational research themes: Teacher Change (PCK) and Knowledge Transfer (PCK).

Research Method

Berg (2000) and Merriam (1998) describe case studies as the gathering of information, and intensive analyses of an individual, setting, program, intervention, event, or group to effectively understand how it operates and functions. According to Yin (2003), when "the investigator has little control over events, when "how" or "why" questions are being posed, and when the focus is on contemporary phenomenon within some real-life context, then a case study will be the preferred strategy" (p. 1). An exploratory and descriptive time series analysis was chosen, because the analysis aligned with the main goal of this study, which was to document and describe changes over time for each BGF regarding PCK.

Participants and their Settings

Participants for this study belonged to a larger group of biology graduate fellows (BGF) involved in the MOSTEP program and were purposefully selected based on their backgrounds. Variables such as teaching experience, number of years in the biology program, number of years in MOSTEP (i.e., if they were new BGF or 2nd year BGF), and their degree program (i.e., M.S. or Ph.D.) were taken into account in the selection process. For instance, fellows chosen had little or no teaching experience prior to MOSTEP, they were in their first or second year in MOSTEP, they were either at the beginning or at the end of their graduate programs, and they were either on a PhD track or a Masters track. It is important to mention that alternates were identified in case logistic problems emerged and fellows decided not to be part of the study. Two fellows were dropped from the study; one ceased to be part of the MOSTEP program, and the second one claimed the demands of the graduate program was too much, and hence s/he declined participation. From a logistics and communication point of view including these fellows in the study would have been challenging. However, in the near future knowing about their experiences in MOSTEP could most certainly be informative. Finally, an important reason for selecting fellows with a variety of backgrounds was to increase the diversity of cases and hence provide a broader perspective on the effectiveness of the program.

Two fellows were selected from the first year of implementation of the program and two fellows from the following year. The following is a brief description of the participant's teaching and learning background and the context in which they have worked.

Chris (9th grade)

Chris loved animals when she was young. She enjoyed watching documentaries about living things and she adored pets. She realized in college that she wanted to study something that would give her the ability to work in a field that had strong connections to ecology, general biology and zoology. Later, during her graduate studies, Chris narrowed her focus and decided to investigate organisms in terms of evolution and population biology. Chris took several life science courses at the undergraduate and graduate level. She had also published a series of scientific articles in peer-reviewed journals.

Chris was a doctoral student whose interest was in ecology and evolutionary processes. She was in her last years of doctoral work and was part of the MOSTEP program only for one year. She worked mainly with high school honors biology and general biology students during this year. Her previous teaching experiences were as a teaching assistant in undergraduate biology classes for majors and non-majors. She mainly taught laboratories and discussion sessions. When needed, she would do small recitations during these two sessions to cover material in class that remained unclear to the students. In other occasions she had tutored students at the same level. On several occasions Chris mentioned not knowing anything about teaching. Chris's assigned district served nearly 6200 students (73% White, 23% African-American, 4% Hispanic, Asian and Native American), of those 2000 were in grades 9-12. The district had a mixed socio-economic make up. The school district has been given several educational awards at the state and national level. Chris' fellow teacher had more than 6 years of experience teaching biology to 9th grade students.

Tyler (Environmental Science)

During his childhood Tyler enjoyed reading and learning about exotic animals. In particular, he enjoyed learning about those features that made animals "cool," exotic and unusual. This fondness was influenced further by the inheritance of wild life magazines from his uncle. He also liked diving, and as part of this activity he was exposed again to more exotic animals. As part of his diving job and other jobs like, working at zoos and training dolphins, he claimed to have learned "a little more about animal ecology, animal conservation."

Tyler was a graduate student whose interest was in ecology, evolutionary processes and geographic information systems. He was in his last year of study for his Master's degree and he was part of the MOSTEP program only for one year. His teaching experience was limited to informal educational settings for the general public. Tyler's assigned district served nearly 12,000 students (32% White, 65.9% African American, 3.1% Hispanic and Asian), of those 3800 were in grades 9-12. 51.8% of students receive free or reduced cost lunches. The district was accredited. Tyler's mentor teacher had more than 15 years of experience teaching.

Alex (9th grade)

For Alex, knowing that he wanted to be a biologist became clearer during his junior and senior years in college. During high school, he was very good in life sciences, and because of this his interest in pursuing a career in biology was triggered. It was not until later in his junior and senior years of college that he made the final decision.

Alex was a Master's degree student whose interest was in ecology. He had just started the Ecology, Evolution and Systematics program at the same time he was recruited for the MOSTEP project. He was part of the MOSTEP program for two years. He had no previous experience teaching. Alex had a B.S. in Environmental Science. Alex's assigned district was the oldest school district in the county. The district lies adjacent to the inner city and is fully accredited by the state. The senior high school (enrollment 306, 40% minority, 51% of students are eligible for a reduced of free lunch) is fully accredited by the North Central Association of Colleges and Secondary Schools. His fellow teacher had taught biology (general and advance placement) for more than 10 years.

Kate (9th grade)

For Kate, the idea becoming a full-time biologist transpired after her first year in a non-thesis Master's degree program. Her interest was triggered after taking an animal communication and cognition class and later getting involved in a research project in that area. On a more personal level, when Kate was asked what she felt her strengths in biology were, she said that she was good at thinking about big ideas, synthesizing "stuff" and creating something new out of that.

Kate was a doctoral student whose interest was in behavioral ecology. She was in her last years of a doctoral program (6-7 years). She was part of the MOSTEP program for two years. During her years at the university she was exposed to a diverse array of graduate student's responsibilities. From teaching, mainly introductory courses as a lab assistant and discussion leader, to being a member of the biology graduate student association and peer discussion groups of selected topics (such as behavioral ecology). Kate had a B.S. in Agriculture and a M.S. in Vertebrate Zoology. Kate's assigned district was founded in 1894. It served nearly 6000 students (98% African-American, 1% White, 1% Hispanic and Asian). The high school had an enrollment of 1200 students (98% minority, 52% eligible for a free or reduced price lunch). The school district was provisionally accredited by the State. Her fellow teacher had taught biology for more than 9 years to 9th grade students.

Procedures

A series of instruments were used to gather data. Among the instruments and artifacts used were: tests, documents (e.g., lesson plans, teaching philosophies), surveys, interviews, video-tapes and vignettes or case studies. Data were collected in a systematic and time orderly fashion. Fellows were notified, well in advance, when and where the interventions were going to take place through a series of emails and verbal communications. All fellows were exposed to the same number of interventions; however, for some fellows additional data were collected.

Data Sources and Data Collection

1- Pre/ Post tests. Three different tests were administered: a) a content knowledge test, b) a pedagogical knowledge test and c) a topic sequence test. Tests were multiple-choice and had a small constructive response component. They were given at the beginning of the program and end of the program. Tests were used to depict changes in fellow's pedagogical and content knowledge. Due to the lack of post data for some of the fellows, these tests were only used to describe the subject's prior knowledge when appropriate.

2- Documents. Two different types of documents were collected/ requested from each fellow: a) undergraduate, graduate transcripts and curriculum vitae (CV), and b) lesson plans. Other documents, such as teaching statements or fellow classroom notes, were also collected if I thought they would be valuable to further triangulate information. For example, one of the fellows had written a teaching philosophy statement at the end of the program, so this document was also collected.

- Transcripts and CV's were requested from fellows, to further evaluate the content knowledge and previous teaching experiences of each fellow. Regarding content, the number of different courses taken related to life sciences and those related to education were noted. Additionally, these documents were used to develop and extend questions for individual interviews. For example, if a fellow had some summer school teaching experience (CV information), then questions regarding what the experience was like were asked.

- Lesson plans were used as additional indicators of change. They came in three forms. *One* type of lesson plan was requested after each video recording (see video recording section 5). These lesson plans (two in total) were used as a vehicle to discuss video episodes using a technique known as video-stimulated recall (McMeniman et al., 2000; Keith, 1988). This exercise helped *validate interpretations* of video episodes, thus facilitating the evaluation of patterns regarding *PCK, CK* and *teacher practice*. In addition these lessons were also compared and contrasted against more formal lesson plans that fellows had to complete for the program (2nd Type and 3rd Type). The *second* type of lesson plans were those mandatory by the program (i.e., two per academic year).

These lesson plans followed Madeline Hunter's planning model (see Appendix B). These lesson plans were enacted by the fellow in one form or another and sometimes these same lessons were the ones video taped. A *final type* of lesson plan was the undergraduate/ graduate lesson plan that fellows were asked to complete. They were given free range as to the topic within biology that they were supposed to plan and also they were allowed to write up the lesson in whatever format they chose. They were actually encouraged to write the lesson in any format. That is, they did not have to use the format provided by the program. Some parameters, such as length of class, level of instruction and type of instructional approach were suggested. With this type of lesson plan, patterns in PCK, Practices and Transferability of skills across settings were observed.

3- Survey. One survey was used in this study. The survey was a weekly time allocation sheet (WTAS). It gathered information about fellows' weekly time allocations with respect to teaching, mentoring, lesson plan preparation, curriculum discussions, and it had an "other" field for any activity not covered in the survey (see Appendix C). Each week fellows logged on to the university Blackboard CMS system called "My Gateway" and completed a WTAS Flash Light online survey. Then, the data were downloaded as a spreadsheet and processed. Patterns of mentoring and time allocated to each activity were related back to patterns observed in *PCK, CK and teaching practices*. For example, if a fellow spent a lot of time with their mentors, working, discussing curriculum implications and/or teaching practices, this helped understand or verify information obtained during interviews about potential changes in the fellows' teaching practices or PCK.

4- Interviews. Three different interview sets were completed. Interviews were MP3 recorded and transcribed verbatim. The first semi-structured interview set consisted of two interviews (Pre and Post experience) and lasted 30 minutes to one hour. In the pre-interview, fellows were asked questions regarding their beliefs and perceptions about ways of teaching particular lessons at different levels and in different contexts (see Appendix D, D.1). Most of the questions in the first interview allowed information to be gathered about their prior knowledge and understanding of teaching and learning processes. In the post-interview, appropriate questions were repeated and some questions were added as a reflection exercise (see Appendix D, D.2). A second semi-structured interview was conducted where fellows were shown some instances of their practice using video footage. During playback they were asked questions to reflect on their practice through different instances in the enacted lesson (see Appendix E) that McMeniman et al. (2000) call video stimulated recall. The third semi-structured interview dealt with the debriefing and discussion of vignettes (see vignettes after video recordings section). These instruments were key components to evaluate change (see Appendix F). Interview questions were sent one week in advance in the case of set one and three. Interview questions for the video stimulated recall exercise were not sent one week in advance. Each interview transcript was analyzed using QSR NVivo 2.0 software in a stepwise manner.

5- Video Recordings. Video recordings were shot in two different instances, at the beginning and end of the program's appointment period (i.e., high school academic year.) Fellows were allowed to pick the topic to be taught in each instance. They were asked to choose between a laboratory and hands on activity. The use of teacher-centered strategies, such as lecturing, were discouraged. A minimum of 35 minutes of teaching was required. Videos were burned to a CD/DVD and given to fellows to use at their discretion for self reflection of their teaching before they were interviewed a week after lesson presentation. No fellow actually viewed the video beforehand. The video was analyzed independently to look for trends in *PCK, CK,* and *practices of teaching*. The video was also used during follow up interviews to stimulate recall of the fellow's classroom experience. A VSR protocol was used (see Appendix E, E.1).

6- Vignettes. Vignettes, or case studies, are descriptions of a teaching situation that represent a problem scenario (Miles, 1987; see Appendix F). In other words, it is a way of contextualizing teaching and learning in the form of a narrative. Vignettes could be written descriptions, video recordings or audio recordings (Smith, 1994). The prepared vignettes were used to simulate a real class situation and later on when the BGF was interviewed it was used as a stimulus for the participant to reflection about his/her classroom practices. Two written scenarios were put together (i.e., population biology and evolution scenarios) and were handed to the fellows in three different instances: beginning of the program, middle of the program and end of the program. The first scenario was repeated at the end of the program. The distribution of this instrument followed a variation of the microgenetic method used by Veal (1997) to study the evolution and development of prospective secondary teachers. The microgenetic method describes a procedure where participants receive multiple encounters to a similar stimulus over a period of time. The scenarios represented a "typical" higher education biology lecture class. The vignettes were used to reveal pedagogical content knowledge changes and to a certain extent the potential transfer of PCK to a higher education context. Two topics in ecology (population biology and evolution) were carefully selected to be representative of content in high schools and higher education (see Appendix F). Components of the vignettes were: an introduction of the setting, a description of the participants, an explanation problem, a description of the interacting dimensions found in the classroom, dialogues and a few major events worthy of attention by the teacher (Veal, 1997).

Important Considerations for data collection and data analysis

It is important to note that for some fellows there were a different number of data sets. For example, second year fellows (i.e., Kate and Alex) had at least two more lesson plans and two more video taped sessions. In addition, Kate developed a teaching philosophy that was shared in writing, something no other fellow did. Finally, to gather information about returning fellows' first year experiences, a series of informal observations and *a posteriori* questions were used during the research intervention. However, if, during any of the following interviews, BGF mentioned some of their past MOSTEP experiences, the fellow was encouraged to provide a more in depth account of the event described through further questioning.

Data Processing and analysis

Each fellow's case was analyzed independently through comparative analysis using a combination of sentence and paragraph open coding approach (Strauss & Corbin, 1998). In this study the majority of categories used to organize the data did not emerge as a result of the coding, instead data units were coded based on pre-determined categories informed by the research question (see Appendix A). However, if a category did emerge it was included in the analysis. Once this coding process was completed for each individual case, the results were analyzed and interpreted for each case. The interpretation was conservative and parsimonious in nature. This means that simplicity prevailed (*aka* Ockham's Razor), and the best interpretation and explanation of the results were selected. A member check of the interpretation with those participants who had the time and were available was done. One may assume that research subjects would best know the meanings of their words, but this is not always the case, hence this technique is not free from criticism as a validation technique (Bloor, 1997). But, it still a valuable source of data. A time series analysis was used taking into consideration the chronology of the events to evaluate BGF changes in PCK (see Appendix G).

The cases were cross examined to search for patterns across each case in the form of similarities and differences. This was done at a broader level (i.e., component level), and helped develop further understanding of the studied phenomena. In general, an analytical induction approach (Merriam, 1998) was used, which looked at parts within each case to understand the phenomenon. For a summary of how information about each construct was evaluated, collected and analyzed, see Tables 1 and 2. Both of these tables facilitate the overall understanding with regards to data processing. Each table shows a different perspective of how the data were analyzed.

Trends in PCK

To evaluate PCK, the coded data instruments (such as vignettes, interviews, video, and lesson plans) that could potentially serve as sources for explanations of fellow's changes in points of view regarding PCK were analyzed. Those components summarized in the theoretical framework were the main focus. But, when a new idea was prevalent or a theme emerged this was noted, interpreted and analyzed too. Additionally, trends in PCK were triangulated using the different sources whenever possible.

The following paragraph is a summary of how data were processed. The construct of PCK and, in particular, the assessment component of PCK, for an individual case can serve as an example. Once data coding was finished, sorted into categories and sub-categories, and the coded units were checked and discussed by an outside individual, a particular component (e.g., assessment) of a main category (e.g., PCK) was selected. Using QSR's In-vivo 2.0 software a composite file (single document), that sorted the different coded units (paragraphs or lines) from different files (e.g., vignette coded file, reflection coded file) in a time series way was generated. When necessary, a Boolean descriptor was used to include sub-trees (sub-categories) and relevant components of the analyses. Once the document was created it was analyzed in two ways. One way was by looking for trends in PCK/assessment in a chronological order throughout instruments (e.g., interviews, vignettes, videos and reflections). A second way was by looking for general trends within the instruments, considering the chronology of instrument distribution (e.g., vignettes #1, #2 and #3, written and interview sections). Once the assessment portion was processed it was compared, contrasted and complemented with other components of PCK when pertinent. Interpretations were challenged with alternative explanations when relevant and a brief summary was provided at the end of each section when appropriate. This process was repeated multiple times and each case was read multiple times and emailed to the participants to corroborate my interpretations. One outside researcher was asked to read sections of the cases to verify if the interpretations were consistent.

Vignettes

Analyses of the vignette were done by comparing answers in the vignette instrument and other instruments, and also by comparing and contrasting between vignettes, based on delivery time (pre/ post) as explained above. Vignette statements were further used to strengthen the conceptual understanding of fellows teaching and learning processes. Furthermore, part of the vignette exercise required fellows to critique the teacher's pedagogical practices. Thus, it can be assumed that any critique is based on fellows' knowledge about pedagogy and in particular PCK since they were operating in a life science teaching and learning context. In other words, a fellow's critique could be used as a way of assessing each fellow's understanding of teaching and learning.

Table 1: Summary Table of Data Sources, Collection and Analysis

Data Instrument	Type of data that could be obtained	Frequency of use, ways of using it
Pre/ Post test (Content Knowledge)	- Content Knowledge (CK) (e.g., Ecol., Evol. & Syst.)	Twice. Pre Post manner to compare changes if any.
Pre/ Post test (Pedagogical Knowledge)	-Pedagogical Content Knowledge (PCK)	Twice. Pre Post manner to compare changes if any.
Topic Sequence Test	-PCK	Twice. Pre Post manner to compare changes if any.
Academic Transcripts (Undergraduate/ Graduate)	-CK -PCK	Once. The number of courses taken in subject area could be an indirect measure of BGSCK. Likewise for PK useful as pre-requisite for PCK.
CV	-Background knowledge (e.g., Teach. Experience or related practices)	Once. Activities that may be related to teaching and communication skills. Previous experience in pedagogy.
Weekly time allocation survey sheets (WTASS)	-PCK (Sum Data)	Weekly. Pooled data to see trends in time allocation. Use of data to triangulate with other qualitative data sets.
Video Recordings	-PCK -Teaching practice (TP)	2-4 Video Recordings. At the beginning of the year and end. 2nd year fellows had at least 4 videos. Used for fellows to identify to reflect on their teaching practices
Lesson Plans	-PCK -TP	2 or more. Checking design and structure of teaching.
Semi-Structured Interview (MOF)	-Background knowledge -PCK -Transfer to Higher Education (THEd)	30-60 min. (1) General interview, (1) final interview (pre/post), (2) video stimulated recall interviews (VSR) and (3) vignette interviews.
Informal and Formal Observations	-PCK -THEd -TP	Many. During discussion group meetings, and off-campus (bar discussions)
Vignettes	-PCK -THEd	1-3 Vignettes. Two of them similar in structure and one of them dealing with a similar concept but in a different context (Higher Education)

Table 2: Summary Table of Construct looked at, experience in MOSTEP that may contribute to the change in the construct and the data source that may provide some evidence of change.

Description	MOSTEP- GK12 (Sources for change)	Data Source
Subject Matter Knowledge i.e. Ecology concepts	-Graduate Courses taken -Undergraduate Courses -Teaching at High School (foundational concepts) -Research interest	-Pre/ Post Test (SMK) -Weekly survey -Graduate classes taken/ undergraduate
Pedagogical Content Knowledge (PCK) / Pedagogical Knowledge -Knowledge of students -Knowledge of instruction/ strategies -Communication (Clarity, understandableness) -Knowledge of the curriculum -Assessment -Environment and context -Orientation	- Summer Workshop (E.g., Sequence of learning) - Teacher Mentor - Field exposure, experience in high school class - Lesson plan - Vignettes reflection - Video reflection - Discussion Group meetings - Informal fellow meetings	-Semi structured interviews (Pre/ Post, vig, video) -Video (content analysis) -Lesson plan preparation -Pre/ Post Test PCK, PK -Vignettes (written) -Weekly survey (*freq. of mentor and teaching encounters*) To Establish Base: -Back ground: CV, transcript, interview Pre
Pedagogical Skills & Practice (PSP) - Wait time - Fostering & guiding discussion - Organizing lessons (S-M-E) - Preparation for class - Time management during class - Communication (Clarity, understandableness) - Recognition of individual differences - Educational policies & procedures - Type of instruction	- Change in PCK and SMK - Field exposure, experience in high school class	-Video (content analysis and reflection) Pre/ Post -Lesson plan (UG/ HS) To Establish Base: -Fellow Weekly survey
Transfer	- Lesson plan - Vignettes reflection - Video reflection - Discussion Group meetings - Informal fellow meetings (Plug-in)	- Vignettes - Interview - Lesson plan

Validity and Reliability

The validation of interpretations was achieved by applying a constant comparative method (Denzin, 1994; Lincoln & Guba, 1985) and by triangulation of data. Yin (2003) suggests establishing a chain of evidence, using multiple sources of evidence, and having draft reports of the case study reviewed by cornerstone players or key informants, as three tactics to be used to ensure *construct validity*. All these tactics were used in this study. Additionally, Yin (2003) states that: "*internal validity* is only a concern for causal (explanatory) case studies" (p. 36). Since this study was more descriptive and exploratory in nature, issues with internal validity should only be considered in relation to the rigor with which the study was conducted and not the extent to which alternative explanations or causal patterns happened. In this study, internal validity was addressed by considering rival explanations when appropriate, by using a time-series analyses approach. *External validity*, which deals with generalization of findings, is often a criticism against single case studies, however in this particular study four different cases were used. A multi-case study approach was used where replication logic was the norm. Finally, in terms maintaining *reliability,* a case study protocol was developed (see Table 3). Additionally analysis and re-interpretation of data and data coding were reviewed by outside readers and a member check was also performed.

Summary

These case studies describe how future college professors' understanding of pedagogy changed as a result of their participation in MOSTEP. Patterns were evaluated across cases and within cases that emerged or were products of this intervention. Multiple data collection instruments were used and included: interviews (pre/post), documents, reflective statements, observations, videotapes and pre/post test items. Abell (2007) said that "studies that use multiple methods over time to understand teacher knowledge seem to be the richest" (p. 1123). Thus, a multi-method approach to study PCK seems to be appropriate. Furthermore, all interviews were transcribed in a step-wise manner, and video instances relevant to the phenomenon were also transcribed. Analysis of the data was accomplished by analytical induction (Merriam, 1998) using constant comparison to refine findings (Lincoln & Guba, 1985). Ultimately, data were organized using pre-determined coding schemes and some coding schemes that emerged from the data. The use of multiple collection techniques, outside reviewers, and multiple artifacts, as a means of triangulation, assisted in achieving an acceptable degree of validity and reliability in this study.

Table 3: Project timeline. The following timeline shows the different data collection methods used organized in order of occurrence. Each fellow was asked to complete each item.

MOSTEP Assessment item	START date/ type of assessment item & mode of Delivery	Due dates or Date Range
PRE-TEST -EEECI- Ecology, evolution concept test -AAPP-Assessment. Approaches to pedagogical practices SRT Test -TLCT- Learning cycle test	**START: Aug 04** Paper/ Pencil Paper/ Pencil Paper/ Pencil Paper/ Pencil	-ALL TESTS in Aug 08
GENERAL INTERVIEW -Interview (30-60min)/ Personal (Recorded)	**START: Aug08** Personal Interview (Appointment)	-Aug 08- Aug 11
SURVEY -Weekly allocation time sheets	**START: Aug 21** Online (Mygateway- Blackboard system)	-Aug 12- May 12, 2006
VIGNETTE #01 -Reading and Reflection Questions -Interview (30-60min)/ About vignette (Recorded)	**START: Aug 21** Online/ Electronic (email) Personal interview (Appointment)	-Aug 12- Aug 16 -Aug 18- Aug 23
LESSON PLAN/ VIDEO/ Interview #1 (VSR1) -Lesson plan (Lab or activity preferred) -Videotaping of enacted lesson plan -Interview (30-60min)/ About video (Recorded)	**START: Sep 12** Paper copy & Electronic (email) Digital video Personal interview	-Sep 12- Oct 07 -Sep 12- Oct 14 After lesson had been handed in -1 Week after lesson was enacted (Max. 1week)
VIGNETTE #02 -Reading and Reflection Questions -Interview (30-60min)/ About vignette (Recorded)	**START: Nov 07** Online/ Electronic (email) Personal interview (Appointment)	-Nov 07- Nov 11 -Nov 14- Nov 18
Graduate/ Undergraduate Lesson plan -Select any topic you would teach in an undergraduate class (Specific instruction)	**START: Nov 28** Paper copy & Electronic (email)	-Jan 2006
VIGNETTE #03 -Reading and Reflection Questions -Interview (30-60min)/ About vignette (Recorded)	**START: Mar 13** Online/ Electronic (email) Personal interview (Appointment)	-Mar 13- Mar 18 -Mar 20- Mar 24
LESSON PLAN/ VIDEO/ Interview #2 (VSR2) -Lesson plan (Lab or activity preferred) -Videotaping of enacted lesson plan -Interview (30-60min)/ About video (Recorded)	**START: Apr 03** Paper copy & Electronic (email) Digital video Personal interview	-Apr 03- Apr 28 -Apr 03- May 05 After lesson had been handed in -1 Week after lesson was enacted (Max. 1week)
REFLECTIVE STATEMENT -One page experience about MOSTEP experience	**START: May 01** Electronic (email)	-May 01- May 05
FINAL INTERVIEW -Interview (30-60min)/ Personal (Recorded)	**START: May 08** Personal interview (Appointment)	-May 08- May 12
POST-TEST -EEECI- Ecology, evolution concept test -AAPP-Assessment. Approaches to pedagogical practices SRT Test -TLCT- Learning cycle test	**START: May 12** Paper/ Pencil Paper/ Pencil Paper/ Pencil Paper/ Pencil	-ALL TESTS in May 19

CHAPTER 4

Results & Interpretations

Herein the results and interpretations are presented for the four case studies. Each case study is organized in **four** parts. Part One provides an overview of the BGF's background regarding teaching/learning experience and motivation to join the program. Part Two describes each participant's perceptual changes over time and points of view with regards to PCK, with a focus upon the following sub-categories (knowledge of assessments, students, curriculum and instructional strategies). In each subcategory I compared and contrasted data, in a time series manner, from different events, conversations, artifacts and descriptions to build an interpretation for each case. Part Three depicts the evidence supporting the prospect of transfer of pedagogical content knowledge from a high school instructional setting to a college/university instruction. Part Four is a compilation of potential sources (such as teaching experiences and research interventions) that may have influenced or affected the BGF's prior understanding or gain of PCK. In Chapter 5 each fellow's case will be compared and contrasted among them, while in Chapter 6 the implications of these findings will be discussed.

Table 4. Codes used when quoting data sources during case study interpretation and analyses.

Code	**Descriptor**	**Code**	**Descriptor**
Gen. Int.	General Interview (First interview)	Vig. Int.	Vignette interview
Video	Video of enactment	Vig. Wri.	Vignette written reflection
VSR	Video stimulated recall interview	Ref. Sta.	Reflection statement
LP	Lesson plan	Ref. Int.	Reflective interview
LN	Lesson notes	Tch. Sta..	Teaching statement
Grad.LP	Graduate lesson plan	#	Number of VSR, Vig. Int., etc

Chris

Background

Teaching and learning. Chris shared insightful descriptions and anecdotes about her experiences with regards to teaching and learning before her GK-12 involvement. Chris expressed that, as a student, she did not enjoy speaking in public or volunteering to answer questions. She also indicated that she liked being challenged and feeling that she had to work hard in order to get a good grade. Additionally she supported traditional, lecture-based classes and felt really comfortable reading textbooks in order to prepare for class (Gen. Int., Vig. Int.1). However, during the same interview when asked how she might change teaching at the university level, she stated "…I just don't know how effective lecturing is, I just know from my own personal experience that I didn't retain most of what I learned" (Gen. Int.). Thus recognizing that lecture might not be the most appropriate approach to teaching and learning. Moreover she indicated that one of the best classes she ever took was an intensive summer marine biology class, in which she did field work, wrote papers and worked in groups conducting different research projects while experts in the field guided them in their learning.

From a teaching perspective Chris stated several times that she "…did not know anything about teaching" and that she had never, in essence, taught a lesson. Moreover, in her pedagogical pre-assessment test she indicated that she was unable to answer the questions because she lacked the pedagogical knowledge. She also mentioned she could have guessed some of the answers, but felt this was not the point of the assessment. She previously mentioned she had been a TA for at least four semesters in different biology related classes (Gen. Int., VSR1). Chris explained that as a TA she taught by mimicking the professor, the senior TAs, or by remembering how the course was taught to her when she was a student and then asking advice from other TAs if a problem was encountered. She questioned the effectiveness of this method in preparing her for a future professoriate career.

> I am curious … it is funny that one of the main aspects of a professor's job is teaching and yet we've never had any formal training in it but we are supposed to be able to do it. So, it wouldn't be a bad idea for people to have to take a course in education… no one really tells you, you just learn from observing or talking to other TAs (Gen. Int.).

Motivation to join the program. Chris' motivation to join this particular program is summarized nicely in a comment she made during one of our interviews "[I would like] to make myself more well-rounded and to get myself comfortable in a role of a teacher and have to do it everyday. And so it was kind of for personal growth…" Gen. Int.. Another reason she gave for participating in this program was related to undergraduates and the need to understand where they are coming from in terms of preparation and past experiences. She said:

> Because we [Faculty and TA's] see them [undergraduate students] when they come here. We see what problems they have when they arrive at our doorstep. So it would help [to be part of the program] because if I do end up teaching at the university level, it would be helpful to understand where they are coming from during high school. What are they learning? What's going on in the high school level that is, (laughs) how do we get in this spot? What are we starting with? (Gen. Int.).

In essence, Chris joined the program to overcome personal challenges and be more "marketable" once she began the process of searching for a job. With regards to pedagogy, Chris' reflections and descriptions of a teaching and learning situation suggest a basic understanding of the different ways in which pedagogical knowledge is developed. In many instances, I noticed that Chris claimed not to know anything about teaching, but at the same time she talked about being exposed to teaching environments and she mimicked teaching practices from other "more experienced" teachers. Chris is a typical case of someone who has experienced a sink-or-swim approach to learning how to teach; an approach that many TAs continue to experience. This phenomenon has been documented by many researchers (Dobson, 2001; Elton, 2000; Norman, 1999; Nowlis, Clark & Rock, 1968; Park & Ramos, 2002; Wulff & Austin, 2004). Finally, it is evident that Chris is not a blank slate when it comes to understating of teaching and learning, which is the opposite of what she believes.

Pedagogical Content Knowledge

Assessment

Evidence suggests that Chris possessed basic knowledge of different types of assessment, in particular tools teachers use to evaluate student performance. She mentioned: multiple choice questions, short answer questions, essay questions, writing a research paper and end of topic tests. She also mentioned: hard tests given out by teachers just to fail the students, teachers being very hard on the grading, students being graded on a curve and also watching videos without an assessment in place. All this knowledge about types of assessments are, in one way or another, linked to her experiences as a learner and as a TA at the University (Gen. Int., Vig. Int.1 and Vig. Wri. Part #1).

Concurrently, Chris' understanding of uses of assessment was varied. Sometimes she was adamant regarding certain uses of assessment, like the use of essay questions to evaluate student learning. Other times she was scattered or unsure about the actual uses of an assessment, like in the case of diagnostic assessments and formative assessments.

For example, in terms of being adamant, when I asked Chris to elaborate on "fairness" or best ways to assess students, she had a consistent answer regardless of the data gathering instrument being used or timeframe. Essentially, she thought that a good science assessment should have the following two characteristics:

> (1) Students need to apply what they learn to new and familiar situations.
> …if they are able to apply what they've learn that means, for me it means that they can understand. If they can take a new situation and apply the concepts or, or, or if they are presented with some problem or question that they need to… it is just not regurgitating what I told them that… if they are able to figure out why something is happening, is happening like if you, if you eliminated… I don't know if some, if some species is not here or starts to decline and then you ask them, why might the bat [population] start to decline? What sorts of things [affect it]? Get them to try to sort of apply what they've learned. (Gen. Int.)

Similar evidence is observed in her first vignette interview and reflection where Chris talked about making students plot a logistic curve, and in her third interview and reflection where she talked about providing different examples and/or graphing activities for students to apply their knowledge in different contexts.

> (2) Students need to write things
> I think you can understand that you have a better understanding of what they understand when you get them to write things because you can see, you have more insight into their thought processes rather than a multiple choice that doesn't tell you very much either than, they really know it or they don't (Gen. Int.).

On another occasion, when talking about multiple choice exams, Chris stated that questions that made students provide explanations for answers were more likely to provide information on student learning.

> Well sometimes [in multiple choice exams] you can see why they may have picked that wrong answer, but if it is an essay question and they have to explain themselves when they pick the right answer, or they explain themselves when they say the wrong thing, then you get more information from that (Vig. Int.1).

Similarly in her second vignette interview Chris again emphasized the importance of testing students based on essay questions and her preference over multiple choice questions.

> …They have to explain what they are thinking so it gives me more information. So if they get it wrong it gives me more information about what they were thinking vs. the multiple choice question where if they pick the wrong one you are not really sure why they picked the wrong one. So… essay is much better. (Vig. Int. 2)

Finally during her third vignette interview, when I asked about what she believed to be a fair way to assess student knowledge she stated that essay-type questions would provide a greater insight to student reasoning and might provide the teacher with a better idea of what they had learned

> … I don't know. People, --it would be either essay tests or a take home test with one essay test that they took home. Well, because they are able to, I mean, if you just give them like a multiple choice home test, then if they get it wrong you don't know why. But if you make them write essays, then they have to explain their answers and you can see, you can follow their logic better, so, you know what they are thinking and you can give them like, maybe, another graph, or another example and ask them to explain … (Vig. Int. 3)

Chris also mentioned that using an essay or questions that require writing, gives people the ability to look into students' thought processes and allowed the teacher to determine what level of understanding of the concept has been achieved. When asked why she believed that this form of assessment is not the norm in college assessment, especially in undergraduate classes she expressed that, while multiple choice questions might be harder to come up with, grading them is an easier task.

> Because it is harder to grade? It takes more effort I guess. Multiple choice is so easy. It might be harder to come up with the questions but then, it's just, it is easier to standardize. So you can tell. Yes it's just so much easier [but] it's not as effective. (Vig. Int. 3)

This dialogue and previous ones, also showed that Chris is aware of some of the drawbacks an assessment instrument like this (essay) has.

Overall evidence suggests that Chris was inflexible in terms of what she believed was the best way to evaluate student understanding of biological concepts. Additionally, Chris' point of view regarding essays and writing is a good example of a concept (assessment knowledge) that is engrained. In this case it is engrained as the best way to assess student understanding.

Apparently, other types and uses of assessment are not as engrained in Chris' mind. They are more scattered. For example, when discussing the use of pre/post assessments, her knowledge was not as substantiated as with the use of essays. The following interviews and discussions about pre/post assessments and pre-quests[1] (pre-quests and pre/post assessment are both considered diagnostic assessments[2]), sheds some light into this claim.

> José: Do you think that [testing students in a Pre/Post manner] would be effective? (49:00)
> Chris: Well it might be an effective way… Because if you do [a] before and after [test] you will know exactly what they have, at least what they have … I guess you would know what they've learned. Well you can't test them over everything. But, I don't know. You'll have some idea of, if they learned anything at all. You have to assume that they would learn something going in (laughed/ smiling) as they were in [the class] very much. [On the other hand] I'm not sure that it is really that valuable of an exercise because of course they should've learned something during the class. Um, I think, I guess again it may be more important to see how much they have retained afterwards… (Gen. Int.)

Three weeks after the first interview, when we were discussing the first vignette about population biology, the following conversation transpired:

> José: Now L36-39. Do you think the pre-quest's where a good idea?
> Chris: --I think they can, they can be a good idea. I'm, I'm not sure how they were used, but Um.
> José: -Well, if, if they were used properly… First of all how would you use them properly? And why would that be a good idea?
> Chris: --Well when you are asking them questions about something you haven't taught them yet you could tailor your question so that you could see what they already understand mm, so you… to know. 'cause you're asking questions about things that they already, you already taught them the thing. You are asking before and after right? So before you start a chapter you could ask them questions that maybe are more general or more basic and um try to get a feel of what they are

[1] As described in the vignettes (L36-L40): [* Pre-quests' were questions about the last and the coming chapter that Dr. Thomas posted online. They needed to be answered and handed in before the beginning of every topic/ chapter. They were an important part of the grade.]
[2] A diagnostic assessment provides useful information about prior knowledge of learners.

> already understanding what they don't understand so you know where to start. At what level to start your lecture and then post questions you could use to gauge whether they understood what you just taught them or not (Vig. Int.1).

Almost 7 months later during her third vignette interview

> José: Let's go to line 36 to 39…What do think about that part in terms of teaching and learning?
> Chris: I think it's a good idea.
> José: Why?
> Chris: Because, it helped him to asses whether how well they understood the last lecture and then it helped them prepare for the pre quest. It helped them prepare for the topic that they are going to be. Because if they've already read a little bit about the topic then it might be easier for them to understand it… this would force them to at least look through it (Vig. Int.3).

Looking at the quotes from a chronological stance, I would like to point out how Chris' view of pre/post assessment changed from uncertain "…well it may be effective…" or a "I'm not sure that it is really that valuable of an exercise because of course they should've learned…", to a confident belief in its usefulness because it would help assess how well students understood the previous material or what their prior knowledge regarding the topic was.

Another example of uses of assessments that Chris was not as familiar with was the idea of formative assessment. The data provide insightful representations of Chris' understanding of uses of these types of assessments. For instance, during Chris' critique of the population biology vignette (Vig. Wri.1, Q2), she seldom addressed the importance of calling on pupils during class in order to see how well they understood "things." Moreover, during her first video-taped class and follow-up interview, little evidence was found of Chris using formative assessment in her practice. Interestingly, in the evolution vignette (Vig. Int.2, Vig. Wri.2), Chris' comments about what she liked regarding the class were centered on how well the teacher depicted addressed student questions and took the time to answer them.

> I liked how Dr. T. stopped to ask the class questions and to answer questions from the class. He also tried to get the class to explain some of the slides to him rather than just telling them what was on the slide. I liked the use of examples to illustrate the concepts he was trying to teach.

This characteristic of gauging student understanding using questions and answers is observed throughout her written and oral responses both in the second vignette interview and her third written reflection. It is worth mentioning that the vignette instruments (Vig. Int.1, 2 & 3) are identical in terms of portraying different pedagogical skills and practices. They only differ in the topic being discussed, which makes you wonder why Chris centered her discussion on this issue during the second and third vignette and not the first one. This suggests that her beliefs about formative assessment could have changed.

Further along the lines of formative assessment there are three other instances where Chris' understanding of this particular use of assessment is surfaced. The first one is during her videotaped classes. During the first videotaped class, while teaching a review class on population biology (Video1), she utilized questions and answers on few occasions to test students ongoing understanding of what was discussed. The main way she did this was by following an initiation, response and evaluation (IRE) strategy (Cazden, 2001). It was evident from watching the class video that Chris' formative assessment during this particular class was unusual and non-pervasive. On the other hand, during the second videotaped class (almost 6 months later), throughout the class it can be observed that Chris took more time to ask questions in order to gauge students' understanding at different levels and stages of the lesson (Video2). In addition she did not provide a yes/ no answer, but at times tried to guide students towards the answer. The following excerpt from the VSR2 depicts Chris' explanation of what was going on in her class in relation to this assessment practice:

> José: When you say they don't know what they're doing
> Chris: Well, they're doing they're going through these motions of maybe they're not understanding what they're doing.
> José: How do you know? I'm just curious really, how do you know?
> Chris: Well, I guess listening to their comments like today when they were doing their organic molecule slides. They're all doing it, you know, they're going through and they're doing it, but some of them, I don't know what's going on, you know, I don't know what I'm doing. I'm just adding this, I don't know why or whatever. So, they're busy, they're doing things, but they don't (VSR2).

These differences could well be because of the nature of the lesson where one (the first video taped lesson) was a review lecture-discussion lesson and the second one was an activity based lab with a 30 minute review component at the beginning of class. But other evidence suggests she was developing an understanding of and preference for formative assessment.

The second instance that sheds light on this particular issue of formative assessment occurred when I asked Chris for helpful pointers to teach a lecture class during our third vignette interview. She showed particular interest in the idea of assessing throughout the lecture.

> Chris: I would say --Don't lecture the whole time.
> José: Okay.
> Chris: At least stop (pause) and have some kind of question-response thing where the students (pause) can kind of (pause) absorb something of what's going on and you can see whether they are understanding hum try to see what they are understanding (Vig. Int.3).

Finally, when I asked Chris about the importance of having in mind this kind of assessment during the last portion of Vig. Int.3 she said:

> I think you should consciously, you should have it in mind [formative assessment] whether you do it when you are actually up there doing or not. I don't know but I think, it would be good to have it in mind when you are doing it.

A third instance was observed in Chris' lesson plans handed in at the end of the program. These required lesson plans had a portion in them that targeted informal checks for student understanding (i.e., formative assessment). Chris completed this section in a very comprehensive way.

In retrospect, evidence from the different dialogues combined with informal observations during the MOSTEP summer workshop suggests that Chris' basic conceptualization of assessment changed**.** In other words, Chris' concept of assessment was initially limited to the idea of assessment as a tool (i.e., test instrument) to inform teachers how much a student knew about a particular science concept in addition to how much s/he knew how to apply the concept. As time progressed and as Chris was "forced" to reflect on this particular aspect of PCK, ideas about looking into students thought processes and using this data to inform the teacher about student learning and teacher practices started transpiring. Her understanding of assessment seemed to have changed from a summative point of view to a more formative perspective.

Summary

In general, Chris showed fundamental knowledge about the different types (i.e., tools) of assessments used to evaluate student work. This knowledge, for the most part, is basic to individuals who have gone to school and college where exposure to multiple choice exams, short answer questions, true or false questions, essay questions, projects that include the scientific method, and writing papers are the main means of assessment. In the eyes of Grossman (1989), these experiences are powerful sources of PCK.

Concurrently, evidence suggests that Chris' understanding of uses of assessment was varied**.** It was varied because some ideas, such as using essay questions to understand student learning was well substantiated (engrained) and other ideas like formative assessment were not as well developed. In Chris' eyes essay questions and questions that required writing were the best way to assess student understanding. Her preference for essays may have limited her views of how other assessment tools could be used to yield information in more effective ways. Consequently, it seems as if Chris struggled with recognizing alternative ways of assessing student understanding of scientific concepts. For example assessments like: journals, self evaluations, peer evaluations or projects could have been overlooked or missed. Nevertheless, Chris appeared to reach a higher level of understanding of open-ended assessment.

In terms of change, evidence suggests that Chris' knowledge regarding formative assessment and diagnostic assessments, shifted in time. A change in her discourse, when referring to these assessments, was observed as the year progressed. Initially she did not seem to consider questioning students and informally assessing them during class as a valuable form of formative assessment. After reading this section of her case Chris claimed that no one in the program defined the word assessment for her, but that she had recognized the value of doing a question-answer discussion with students before joining MOSTEP. Nevertheless she believed MOSTEP helped her develop a deeper appreciation of this form of assessment. During follow up discussions she further supported the use of this type of assessment as a good, yet challenging, practice. Regarding pre/post assessment she mentioned that this approach could be an interesting idea but at the same time she was unsure of the value of using this type of assessment. Her views changed as she went through the MOSTEP program and at the end she acknowledged the value of this form of assessment to determine learners prior knowledge and/or advancement of knowledge, as well as a way to draw a knowledge baseline.

In her mentor's class, formative assessment was a very common daily practice. Most end of topic tests (summative in nature) distributed by the teacher where mainly multiple choice questions with some short answer questions embedded and, at times, tests contained a constructive response item. No pre/post assessment was used in the high school.

I would claim that, while Chris is familiar with different assessment instruments, (e.g., multiple choice and essays) she has not yet developed an understanding about the uses of assessment (e.g., using formative assessment to enhance student learning and inform teacher practice). Finally, Chris' conceptual understanding of assessment seemed to have shifted from an evaluative/summative stance to an instructive/formative perspective. In other words, assessment for her evolved from a "How well you perform on tests" to a "how do I [student or teacher] use this information to enhance learning or improve teaching, respectively".

Curriculum

Evidence suggests that Chris had a strong preference for classes that followed a logical content sequence. On several occasions Chris mentioned the importance of biological concepts following a logical order and building on top of each other. When discussing the first vignette (Vig. Int.1 & Vig. Wri.1) she mentioned that she liked the fact that "The information seemed to be presented in a logical order[3], and actual examples were given to illustrate various concepts." Later, during that same interview, she said: "Well, usually you are building on concepts they have already learnt…" In the third vignette (Vig. Int.3, also a PBV), almost 7 months later, she said: "…I mean, I only say that because, because these ideas do logically go together…" after commenting about changes she might make to the class portrayed in the vignette. During the video-taped classes (Video1 , VSR1 and LNDoc1) and lesson notes (i.e., population biology review class-LNDoc#1, scientific method class-LNDoc2, and the penguin taxonomy class- LP1), we can observe how Chris really focused on following a logical order to convey the

---

[3] Content sequence of vignette #1 and #3 (PBV1, PBV2): population growth curves (J- exponential vs. S-logistic), mathematical modeling and factors controlling populations (density dependent & density independent).

content being covered in each class. For example, in the population biology review class, she went from what she considered a basic and simple concept (i.e., base factors affecting population growth, e.g., birth, death rates and exponential growth) to a more complex one (i.e., logistic growth curves, density dependant factors and mathematical models). During the second vignette (Vig. Int.2), that is the evolutionary biology vignette (EBV), Chris commented that she liked the way the teacher (Dr. T.) approached evolution but she critiqued his initial focus on the evidence of evolution. She said that she would probably start with natural selection instead.

> Chris: [I would probably] start with natural selection.
> José: Why?
> Chris: Because that's the part that they'll have… I mean thinking about it from a controversial, evolutionary controversial point of view. Natural selection is something that they shouldn't have a problem with really. It is very intuitive, very… when we talk about… that there is a variation in a population and then some individuals are, will be better adapted than others and leave more offspring than others. I mean that's very… you can't argue with that… I think I would start with natural selection at the micro-evolution level and then from their evidence for the macro [evolution]. (Vig. Int.2)

Looking at the data, it seems like Chris does have a particular way of thinking about lessons and course organization in biology. She emphasized the logical flow of content, going from simple to more complex concepts, and she also acknowledged the importance of content building on top of previous content.

In terms of scope of content, Chris developed sensitivity as to how much content a teacher should cover during class. Throughout the first vignette Chris emphasized that the class in the Vignette did not cover enough content. She mentioned on a few occasions that she would "… deal with more details in the class if I were to teach the class.". On the other hand during the second vignette she claimed that the content covered was too much and that Dr. T. should not cover more content.

> José: You wrote down "I didn't like how much information he tried to cover in one class" (Vig. Wri.2), so what makes you think this from the vignette that there is a lot of information.
> Chris: Just from knowing, I mean, seeing how much he was trying to cover and knowing how complicated the material is, but also (reading) "Sarah said, I don't get it when he moves so quickly through the materials. So he needs to slow down…" (Vig. Int.2)

While it can be argued that the difference n perspective arises from a difference in Chris' knowledge of the content between vignettes (Vig. Int.1- population biology vs. Vig. Int.2- evolution), in the final vignette, which is a replica of the first, Chris again mentions the idea of content coverage being too much.

> I think, I wouldn't, there is no content that I would remove. It's just; my idea would be [to] take more class periods. That's it. There is nothing that I would really take out. (Vig. Int.3)

Chris' perspective regarding content coverage seemed to vary as a result of her experience with MOSTEP. Initially she talked about "adding content" at the beginning. Then she talked about the vignette class "covering too much information" and later considered leaving the information as is but "taking more class periods" to teach it. A reason for this shift could have been the fact that, in the bi-weekly meetings fellows had with the educational specialists in the MOSTEP group, the struggles teachers had in high school when dealing with depth over breadth issues were addressed constantly. Moreover, during various informal interactions with the high school teachers in the program, this theme was raised multiple times. Furthermore, before she taught a class, her mentor checked her lesson. These checks usually resulted in reduction of content and not addition of it. Hence it reinforced that idea of Chris considering a balance of depth vs. breadth when challenged with this notion.

In terms of knowledge about materials available for high school and undergraduate life science topics (such as labs, equipment and software), evidence suggests that Chris draws ideas mainly from her undergraduate teaching/student experience and her graduate work (research and courses). For instance in the development of lessons like: a) the osmosis experiment (LNDoc3, Video1 & VSR2); b) the penguin taxonomy (LP1) and PCR/Electrophoresis lessons; c) the review lesson on population biology (LNDoc1); and d) the Darwin Finches evolution plug-in, she used ideas from a variety of sources. Some of the sources she used were: a) college text books like Evolutionary Analysis (Freeman & Heron, 2003) and Biology 6th Ed. (Campbell & Reece, 1999), b) laboratory manuals for undergraduate biology (e.g., exploring osmosis lab), c) primary literature such as peer-reviewed journal articles (e.g., for the Soay Sheep, Galapagos finches example and penguin lesson), d) the internet (e.g., ENSI site, PBS site and Google) and e) her graduate classes (e.g., incorporating modeling programs for population biology or community ecology). In order to test for accuracy of content Chris compared what she found in different sources to a few well known foundational textbooks and her own content knowledge[4].

In terms of knowledge of goals and objectives about teaching and learning, evidence suggests that Chris' teaching goal was for students to develop a strong content knowledge by providing them with real life examples. She seemed to use this to guide her planning**.** The use of real life examples is emphasized in both high school and college reflections and while the important of content is highlighted only for college/university classes. For example, during the vignette analysis she mentioned several times the importance of linking the concepts to everyday life (i.e., conservation, population growth and economic/social implications).

> José: So, what do you think is the purpose of teaching this topic? Why do you think people should learn about it?
> Chris: Well I think it's…especially, you know, in conservation biology you are just in general really important that people understand um…Well, in general it is good to understand what control, you know why populations are the size that they are uh-huh- especially for people um to understand how human population grows you know I would show a picture of the geometric growth of the …exponential growth of the human population and try to get them to realize you know that we've seen this models here what do you think it's going to happen to human population um just try to make it more relevant to…to them. Bu…I think (Vig. Int.1)
> José:-What do you think is the purpose of teaching this topic? Why do you think people should learn about it?
> Chris:-Because evolution explains everything. (Laughter)
> José: Everything makes sense in light of evolution.
> Chris: That's right (smiles). It is the unifying theme of biology Umm. Really, I mean not to be glib about it is true.
> José: So if I'm an economist why would I need to learn about evolution?
> Chris:-well… I don't know. You'd mean needs to know about it, but, I mean it's the world around you and it just seems like there should be some inherent interest in understanding um and so many people struggle with where do we come from, and trying to understand why the world is the way it is, I mean, here's this theory that no knows about and no one understands, that explains a lot of it you know. I don't know. I think maybe for an economist it doesn't matter, although we can talk about social Darwinism and stuff like that. (Vig. Int.2)

---

[4] [Note: In many instances work done in undergraduate has been infused into high school classrooms as a way of increasing/"improving" the content.]

During the video-taped lessons it is also evident that she emphasized providing real life examples and raising students' awareness regarding the relevance of the content to society (LNDoc1, Video 1 and VSR1- throughout).

With regards to content, the following excerpt (Vig. Int.2) suggests that Chris is a strong advocate of using content to guide her in planning and developing a lesson.

> Chris: Because I think we all think about that and, like when I, if I have to make a lesson or something the content is the first thing I think about. Like what do I want them to know and make sure I have my facts right. I mean for me that is the first thing I think about… (Vig. Int.2)
> José: Would you do things differently to start the class?
> Chris: (pause) no I think it's fine. I mean it is nice to have a, I don't usually do this but when people do do this I like it so I'm not sure why I don't do it. But, having the, an opening outline slide that you talk about, you look the main points that you are going to get through, so you could see the big picture before you start and then it helps you put, it helps you know where you are during the lecture and where things fit in into this. (Vig. Int.2)

These comments point at content being the most important consideration in Chris' lesson planning. Further comments reinforced this notion in the section. Additionally her ideas are complemented further during the instructional strategy discussion.

Evidence suggests that Chris used personal experiences, past tests, past quizzes and textbooks (high school, college texts and research review books) to plan her lessons. Concurrently, evidence also suggests that Chris' views on how to plan a lesson changed. The first two high school lessons developed by Chris were a review lesson about population biology and a scientific method lesson (LNDoc#1, LNDoc#2). The lessons included a PowerPoint presentation, a handout. The lessons were delivered in a lecture format. Both lessons had classical, real life examples (such as the Soay Sheep for population growth and barnacles for scientific method). When I asked Chris how she came up with these lessons she basically said that her fellow teacher requested a topic and then she used textbooks, past tests, internet sources and journal articles to develop them (Video1, VSR1, Personal Communications, 2006). The next two lessons, almost 5 to 6 months later, were a penguin classification activity and an osmosis lab (LP#1, LNDoc#3). Both were delivered using an inquiry approach and hands-on activities with worksheets included. The same sources as the previous two lessons were used to gather information for the lessons.

From a holistic approach, taking a top-down look series of events in time and given that, while fellows were always encouraged to prepare an activity-based lesson, they were not forced to do so, I raised the following question: Why did she use a lecture format during the first two lessons and later (5-6 months) decided to make two inquiry lessons? Her explanation to this was that her selected approaches were driven by the nature of the content. However in her reflection, she said that if she could turn back time she would change the way she taught those first two lessons (Ref. Int.).

Another point to consider is that Chris disliked the lesson plan format provided by the lead educator of the project. On several occasions she showed her reluctance to using the plan one proposed for the project (see Appendix A). She complained about not being told how to develop a lesson plan, or what each category in the lesson plan meant. Nevertheless, at the end of the program Chris handed in two well written lesson plans (required by the project) with the categories filled out in a very coherent and logical way. She later explained to me that some of the objectives were revised by other fellows.

Summary

In general, evidence suggests that Chris' understanding of curriculum was superficial and only changed on certain levels through her participation in the MOSTEP project. Firstly, the notion of a logical sequence based on content, when planning a biology course or class, was prior knowledge Chris brought into the project. This was probably based on the constant exposure to rich content classes she as a student and her learning of this content.

In addition, evidence suggests that a cognitive shift, expressed in the form of developed sensitivity, occurred in regards to content coverage (*aka* scope). This was revealed during the vignette discussions.

Furthermore, evidence suggests that Chris already had an idea of where to get materials/resources to plan lessons. What was observed is that she scaled down undergraduate/ college materials to be used at a high school level. I have seen this trend before in science education when content enrichment is the goal of curriculum development.

Moreover, evidence suggests that Chris gave strong emphasis to content and had a tendency to use many real life examples when planning instruction. These ideas resonate with the ideas about teaching and learning that Chris had at the beginning of the program and were discussed in the background section (Gen. Int.).

Finally, with regards to lesson planning, evidence suggests that Chris' understanding of lesson planning shifted. For instance, she seemed to have changed from a lecture-based, teacher-centered planning approach to an activity-based, student-centered, inquiry and hands-on approach. Apparently she also seemed to have changed from not understanding the components of the lesson plan template to being able to complete a lesson plan using the template in an accurate way. However, after reading this section, Chris mentioned that she felt like she was guessing as to what was appropriate to write in each section of the lesson plan. Caution needs to be taken when interpreting this particular result.

Students

Learning theories. In terms of knowledge about theories of learning science, evidence suggests that Chris had no explicit knowledge about them or about the theorists who contributed to this knowledge base. For instance, during our first interview she said "…I did most of them [answered questions] except the ones that asked about Piaget or Maslow. I don't know who those people are or what the zone of whatever proximal development is (Gen. Int.)." Additionally, during our following conversations, Chris never used terms such as constructivist learning theory, or the learning cycle theory, or made reference to Piaget, Dewey or other theorists, except for this one time. However, evidence does suggest that Chris had implicit knowledge about student learning processes (such as students constructing knowledge or developing habits of minds) and factors affecting student learning (such as student's motivation, student's prior knowledge) as demonstrated through some of the topics that surfaced during our conversations. Evidence also suggests that part of this knowledge changed. Some of the topics discussed were: a) student engagement and motivation, b) linking concepts to everyday life, c) building concepts on top of previous concepts, d) pre-requisite knowledge, e) student prior knowledge and misconceptions and f) student diversity.

Chris showed basic understanding about getting students' attention (physically engaged) and, through her participation in MOSTEP, developed an understanding about the importance of keeping them intellectually engaged. The following conversations and discussions shed some light on this matter.

> José: So what do you think about that particular section L50 to 52?
> [Note: In L50-52: Dr T. turns on the projector and has a slide with an outline of what's going to be discussed during that class]
> Chris: Well … this is just at the beginning right?
> José: Yes
> Fellow#3: So he is saying very generally what [the] topic [is], [and] what they are going to be talking about. I think it was ok… He can probably think of better ways to start of the class but at least he is sort of centering them on the topic, the general topic and then starting with his lecture. […]
> José: How would you do things differently?
> Chris: Well, I was thinking about the bell ringers[5] they do in my mentors' class.
> José: And why would you do that?
> Chris: To get their attention. Or maybe something, make them think about, I kind of, they [bell ringers] seem to get the students, to sometimes think about things in a way that they wouldn't have thought about it… (Vig. Int.1)

In the above dialogue Chris recognizes the use of a visual tool to grab student's attention. She even elaborates on using a "new" tool, she just learned about (bell ringer), to improve the practice of this teacher. Towards the end of the project, almost 8 months after this interview, Chris actually used the bell ringer idea during the second videotaped lesson (Video2). Furthermore, during our first video interview, just 2 ½ months after the first vignette interview, she raised the idea of engagement and motivation again.

> José: Okay, so what do you think are the strengths and weaknesses of a strategy like this [lecture]?
> Chris: Well, the strength is that you get through the material you need to get through… And then the drawback is it's more boring. They [students] probably weren't real excited about it. Although, do they ever get excited about anything in that class?
> José: Why do you say that?
> Chris: I watch them sometimes like when my mentor's talking and they just, you know, they're doing everything except looking interested. You know, they're because they've got their heads on the table. They're drawing doodles. They're reading a book. They're just doing everything except looking like they're engaged, although they do seem to be listening. At least some of them are listening because some of them will, you know, answer when you ask a question. (VSR1)

---

[5] A bell ringer was an instrument used by Chris' mentor teacher. She used it as a way to start her class after the bell rang. They consisted of short questions, images, or other artifacts that helped the teacher engage the student in what they were going to learn that day.

From the above conversation, Chris seemed to recognize some of the drawbacks of students being disengaged in class. At the same time, she seemed to be unsure of how students could be mentally engaged (listening) while not showing interest in class (heads down).

Chris shared some further views regarding engagement. During the following excerpt (almost 4 months into the program), it seemed like Chris' discourse was more along the lines of students being mentally engaged.

> Chris: He built discussion by asking students to explain their answers and then asking more questions that built on those answers. This kind of interchange slows the class down a bit [but] gets the students thinking more about the material than they would if they were just taking notes the whole time.
> José: Why is that important?
> Chris: […] I think it helps them learn. I found when I'm just taking notes, I'm taking notes passively and I'm not really thinking about what's going on. I'm just taking notes. I may even not understand what I'm writing down. But, I don't know that I'm not understanding because I'm just taking notes. *(*Vig. Int.2*)*

Finally, during our last interview, Chris shared two related thoughts regarding engaging and motivating students. The first reflection was about changing the way she taught her first class (teacher-centered) and making it more engaging (activity-based). This change can be observed during the second videotaped class where she engaged students, from the start, by allowing them to explore the de-shelled egg. The second reflection was regarding the fact that "somehow" students learned using an activity-based teaching approach. She felt unfamiliar with this approach and thought that was more about having fun than learning. The following dialogue sheds some light on the latter.

> José: How would you describe the main teaching and learning environment in your classroom?
> Chris.: I would describe it as mostly activity-based. When I first started, I wasn't sure when, how they [students] were learning really. Because they don't take notes, they take notes every once in a while but it's not like I've been watching them constantly learning. They seemed to learn indirectly
> José: Osmosis?
> Chris.: Something! (laughs)… Just [the] activities they were doing, when they filled their study guides, they are reading the book and they're learning things that way and yeah, whatever activity they have. (Ref. Int.)

Although Chris does not demonstrate explicit knowledge of the underlying principles or theories about students learning, she does show a change in her understanding of how student get intellectually engaged. This change is reflected in comments like: "…they do seem to be listening…" or "… I think it helps them learn…" and finally "…they seem to learn indirectly". This is further supported by her actually implementing ideas to engage and motivate students to learn during her practice. Comments about students being mentally engaged do not emerge until the last two vignettes (i.e., 4 and 7 months after the program began). Further instances about engaging students are embedded in the following analysis about linking concepts to everyday life.

Evidence suggests that, for Chris, linking concepts to students' everyday lives helped students understand the content better. Chris always emphasized the use of conservation biology, a topic that lends to linking biology to everyday life, to engage students in learning. She highlighted, on multiple occasions, the use of a variety of real examples to clarify abstract concepts (like logistic growth curves) and engage students into meaningful conversations. For example, after watching an instance of her practice (Video1), I asked her why she addressed conservation and over-fishing when she was talking about population growth. She said: "Well, it just… maybe [it] makes them care more about what you're trying to tell them. Or maybe remember it more" (VSR1). Later, during a discussion we had with regards to using a variety of examples, this same idea emerged again.

> José: Why do you think more examples makes more sense?
> Chris: Because I think it helps. The more examples they have the more likely that at least one of them will make sense to them and […] They're real. It's not just like a, I mean if you just threw a bunch of these curves up here, it's just very abstract. I mean do they want to be able to relate that curve to the natural population without any examples? (VSR1)

Another example that showed Chris' partiality towards using multiple examples can be seen in a reflection Chris wrote during the third vignette exercise.

> Q: What did you like about the vignette?
> Liked: Dr. T. stops to ask the class questions and to answer questions; he spends pretty much time discussing rather than just lecturing; he uses a lot of examples which help the students to look at the material in different ways and understand it better (Vig. Wri.3)

Also later during the interview about this same vignette Chris shared the following insights:

> Chris: It seems if you don't, if you just use the equations and just like lift the assumptions it's too abstract and they won't be able to really understand it or see why it matters, unless you apply to a concrete example like the cranes something where they can better understand or they can relate to an other animal, so it's easier for them to understand it. (Vig. Int.3)

While Chris always showed a strong preference for using multiple real life examples, something that transpired toward the final stages of the program was how she related this to greater student learning/understanding.

This idea is clearly related to the use of everyday examples in teaching. Evidence suggests that Chris had some insight regarding the idea of students constructing knowledge. For example, Chris acknowledged the importance of helping students see the larger picture so that they could visualize how concepts fit together.

> José: Why will that be important? [Going over a pre-questionnaire (pre-quests) at the beginning of class]
> Chris: Well, usually you are building on concepts you have already learned or you know… [So] as you progress through your lectures, if it is something that is fundamental that they didn't get, you want to go back over.
> José: Why?
> Chris: So that (laughs), to make sure you understand. So when you build, you try to introduce some other topic that builds on that first one that they [should] have a good understanding of (Vig. Int.1)

Along these same lines, while talking about an advance organizer to show the logical flow of a topic being covered, as Dr. T. (our vignette teacher) portrayed, Chris commented:

> Chris: I think it helps them [students] understand how the parts are related, and also were they should [fit so] they have this construct of, of the topic in general where they add…, when they get information they are able to fit it into the puzzle more easily. (Vig. Int.1)

Moreover, during our first video interview she also talked about guiding students by using an outline slide.

> José: Yeah? You think this will help?
> Chris: I hope so. Because I had just gone through them [population biology concepts] I mean alternatively what I could have done, maybe should have done, was at the beginning have an outline slide where I say, "Okay. There's going to be three different types of population growth." So then they can see where we were going. Maybe that would have been better. I don't know. I just did it at the end and so that they could see how they all fit together I guess (VSR1).

Finally, in terms of how students are integrating knowledge to their prior schemas, the following statement made by Chris showed some interesting ideas:

> Chris: Well, I think if they are able to put it, you know when they learn a new concept, if they are able to put it into a framework or link it to things that they already understand, then it's easier for them to learn it (Vig. Wri.3).

Overall, the message that resonate the loudest, towards the end of the program, was how Chris talked more about students adding new concepts to their mental frameworks.

Concurrently, evidence suggests that Chris had some basic understanding of pre-requisite knowledge students need in order to understand concepts that would be addressed during class. Chris was able to recognize pre-requisites knowledge and skills (specific and broad) that students should have conceptualized in order to learn specific concepts such as population growth, evolution and osmosis (Vig. Int.1, Vig. Int.3, Vig. Int.2, and VSR2). For example, during the first vignette, she talked about the need for students to know about different animal interactions (e.g., predation and competition), in order to understand how these factors affected population growth and hence the type of growth curves (logistic or exponential) that they observe in class. A second example is seen during her teaching of the osmosis lab, where she showed awareness of students' lack of skills using a microscope and graphing. She responded to these needs by giving them some basic directions. This is something she had learned throughout the year from comments of her mentors and through direct observation.

Throughout the course of this study Chris's understanding changed slightly with respect to valuing how students' prior knowledge plays an important role in learning. In the past, Chris seemed not to realize that students came to class with ideas of their own, with their own baggage of pre-conceptions and misconceptions. This became apparent during our first interview, when I asked her about her most frustrating experience while teaching.

> And, see what else oh another thing. One other thing that happened to me that I, I really, I really was upset when it happened and I still regret was in the undergrad non major class we touched… they handle evolution a little weird in the lab. […] (Gen. Int.)
> I can't remember which lab we did after the video something I think really related and after I showed the video I asked them if they had any questions and I was completely unprepared for their complete lack of, lack of… they are just displeased with evolution. They just floored me. I was, I was not, I mean most of

> them are very quiet and there were a couple that, Um, that were vocal about how they just didn't believe in, and it didn't make any sense to them and they believed that Jesus was the one that, you know. They just completely didn't believe it and I was so taken aback by the situation that, I couldn't believe what was happening, that I didn't have responses for them. I just, I couldn't think of what to say because I was, I was so completely surprised by it. (Gen. Int.)

Later, it seemed like Chris became more sensitive about building on students' prior understanding of a concept. She actually addressed an important point regarding student prior knowledge in population biology and community interactions in the following dialogue:

> José: I noticed that you seem to emphasize the other form of competition [space, nest sites, etc]. […] Is there anything here?
> Chris: No, I guess for me, I mean whenever they think about competition they are always thinking about food. I think. I mean that's what we really emphasize is that it's food. When really I mean they probably are competing for food but there's also these other, you know, space issues, breeding sites, nest sites that we don't ever talk about at this level of class [at least]. I just thought it would be good to at least draw their attention to these other forms of competition. (VSR1)

Moreover, she used students' prior knowledge to tailor her teaching. She did this by trying to provide examples that were relevant to students' everyday life, or important to the human race.

> José: Why do you relate things back to humans?
> Chris: Because it's something that is easier for them to understand because they're humans and they have more experience with that. Maybe they don't have very much experience with rabbit populations or deer populations. So, it's something that they can more easily understand. Once they understand the concept as it relates to humans then they will be able to extrapolate to the natural population (VSR1).

Other instances in this same interview showed how Chris paid attention to students' prior knowledge in order to teach. This occurs when she talked about immigration (VSR1, ~5:30), when she elaborated on the phrase "growing indefinitely" when talking about an exponential growth (VSR1, ~21:00) and in the second interview when she acknowledged students previous experiences with Ziploc bags and osmosis before being exposed to osmosis in plants, eggs and dialysis tubing (VSR2). Overall Chris believed that MOSTEP allowed the concept of prior knowledge to be "formalized" in her mind.

Parallel to this, evidence suggests that Chris had a strong understanding of the main misconceptions people have in some life science topics, but she had little understanding of how to use misconceptions to her teaching advantage. For example, in evolution it is evident that Chris had a good handle of the potential misconceptions student could bring to class.

> José: What are the most common misconceptions in evolution?
> Chris: [That] humans evolve from monkey, Um like, how the general process works even.
> José: What do you mean?
> Chris: I think a lot of people say that it **just can't be random mutation**. I mean how can, I mean just random chances are not going to get you a human from an amoeba. (Gen. Int.)
> I would think they would have things like: it is only a theory like Pedro says. So you need to know, be prepare to explain that scientist see theory in a different way. Um, I guess the other thing … just the basic mechanism. People don't understand how macro evolution happens. (Vig. Int.2)
> On other instances when asked how she would approach teaching evolution, Because that's the part that they'll have. I mean thinking about it from an evolutionary controversial point of view, natural selection is something that they shouldn't have a problem with really. It is very intuitive. When we talk about, [that] there is a variation in a population and then some individuals are, will be, better adapted than others and leave more offspring than others. I mean that's very… you can't argue with that (Vig. Int.2)

Nevertheless, as she shared earlier during our first interview, she failed to use this knowledge to her advantage when she had to teach evolution to a non-major biology class. While Chris showed awareness of misconceptions, the evidence does not show that she would actually use this knowledge to help students understand biology concepts.

Student diversity. Evidence suggests that Chris' understanding of how student diversity affects teaching and learning in science classrooms changed throughout the program. Our conversations evolved from a dialogue about lack of interest, to one about different student perspectives, and finally to one about providing ideas regarding teacher readiness on how to deal with variety. In the beginning, during our background interview (before the program started), Chris shared one of her most frustrating experiences with regards to a college class she taught. In this dialogue we can appreciate Chris' aggravation with regards to what she described as a lack of student interest in the intrinsic value of the content delivered. She believed this was unacceptable.

> José: What was the most frustrating experience [you've had] when you taught?
> Chris: Frustrating some of the, well last semester dealing with, I shouldn't say dealing with… I guess more seeing the attitude of, you know because it seems to be two types of biology students. The evolution ecologist one and then the pre-med ones, and the pre-med students I find it more difficult to deal with because they don't care… they don't see the value in what, in what you are trying to teach them. I guess they are harder to teach because they, they really don't see the value. They just want to know, why do we need to know this? They just constantly question: Why do we care about this? Which I guess it's a good thing to question. But they just, I mean in general they often don't see the intrinsic value or the intrinsic interest of the subjects. They are more concerned about the grade! **(**Gen. Int.)

Later, during follow up interviews, Chris' points of view about different learners in a class seemed to shift. The following conversations, during three different time intervals (3 weeks, 4 months and 7 months later), shed some light on how Chris' views changed. Chris was asked the following question after reading and reflecting on the vignette instruments that portrayed a typical biology college class:

> Q: What can you tell me about the students? Do you think that having a diverse group of students' matters?

(3 weeks later…) (Vig. Int.1)

> Chris: Well I think it's good to have people from different backgrounds that um, that to bring in different perspectives. The people have different goals. Um I guess it is less advantageous…because… you might teach a student who wants to eventually go to graduate in ecology different from a student [that doesn't] […] So maybe the class can be less tailored when, when students have a variety of goals or variety of, of what they need from that class.

(4 months later…) (Vig. Int.2)

> Chris: Anyways, I think that it is good to have from diverse backgrounds because they will have different points of views and, so it just makes the discussion more interesting I guess, and it helps [you] think more about your point of view more if you hear someone else's point of view, maybe.

(7 months later…) (Vig. Int.3)

> Chris: (Laughter) Yeah, I was trying to remember what I answered last time. I think it was hum that they have different, they come with different backgrounds and different view points of what they are learning and so they can give different perspectives when you are doing the discussion part. But, I think it's also, sometimes more difficult when you have a large diversity of students because they're not on the same page necessarily, they don't all have the same body of knowledge, so, it maybe harder to pace the class, so it might be really slow for some students and really fast for others but, so I think it could go either way.

Comparing and contrasting these quotes, it is evident that Chris shows some recognition to the value behind having a diverse class. This is articulated in her comments on students having “different perspectives” or “different points of views” and making the discussion more interesting. She also recognized some of the inherent problems faculty face when teaching courses where some students might be majoring in ecology and others might just be fulfilling a requirement. Interestingly, in the second vignette she only focused on the positive outcomes of diversity. Nevertheless this focus could have been the consequence of her awareness of the heated educational debate on the topic taking place at the time. In her last remark, during her third vignettes interview, we can see how she elaborates on the fact that students not only come in with different prior knowledge but that there are differences that occur in teacher learning. Moreover this statement shows not only her awareness that students have different points of what they are learning, but that this information should be used to guide instruction. Chris seemed to be moving from a self-centered (teacher’s perspective only) understanding of diverse classrooms to a student-centered one. I believe the following quotes during her reflection interview sums up her change

[Beginning of program]

> José: What will you say is the best way for a student to learn something?
> Chris: Um the, I guess the more varied ways a concept can be presented the better the students could pick up. I mean for me I always liked, I this probably goes against what educators liked, because I, I liked having the textbook to read. I liked hearing it like in the lecture form from a teacher but then I think also having some kind of hands-on activity that maybe remember the concept more and you know, you are able to associate something fun. Yeah I don’t know, just having an activity that presented the concept in a different way too that maybe helps you remember it. (Gen. Int.)

[End of program]

> Chris.: Well I guess, the best way for a student to learn, with having activities that -- are, well, I kind of feeling that I’d probably say things I’ve heard other people say now, and I probably think they are right inquiry based...the kind of thing where
> José: Okay.
> Chris.: Where you don’t get the students to answer but you try to get them to work through something logically, solve problems logically in their heads and that they understand -- the end point better, rather than just telling them the end point.
> José: What’s the value in doing this?

> Chris.: Well, it makes it more if they go through the baby steps to figuring out themselves they'll feel good about figuring out, and they are more likely to really understand it. Really understand it because if you just memorize things you don't necessarily understand what you are doing you may think you do -- but if you have to go through the process of figuring something out then, you are more likely to really understand it. (Ref. Int.)

Summary

Overall, evidence suggests that, while some aspects of Chris' understanding of student learning theories, processes and factors affecting student learning changed throughout the MOSTEP program, others did not. For example, Chris' knowledge of student learning theories or theorists that contributed to this knowledge base is non-existent both at the beginning and at the end of the program. Nevertheless she has her own understanding on how learning takes place. In her case, this understanding is akin to constructivist learning theory since she believes that knowledge is constructed by relating new knowledge to prior knowledge and experiences. She talked about prior knowledge and using many and relevant examples (real life examples), to make sure students were able to link (fit) what was being taught/learned to their prior experiences. The change that takes place over time is evident as she develops an understanding of student learning and this influences her teaching practice.

Another situation where Chris' knowledge on learning is related to learning theory occurs when Chris mentioned the idea of mental schemas related to cognitive learning theory and mind maps: "…I think if they are able to put it, you know when they learn a new concept, if they are able to put it into a framework or link it to things that they already understand, then it's easier for them to learn it." While there is no evidence of Chris knowing about mental schemas theory, she still talks about the idea of linking concepts into a mental framework. Upon reading her case Chris said that one of the teacher's in MOSTEP made this comment and it made sense to her.

Chris brings to the table her own ideas about what is good to do, like using multiple and varied examples as shown in other occasions during our discussions about curriculum knowledge and instructional strategies. It changes because even though Chris may have ideas of her own, she conversed about how these ideas had implications for student learning and how these ideas changed her understanding of engagement and motivation with regards to students.

Although evidence about student learning and factors affecting student learning have been presented in a compartmentalized manner, we know these ideas fit together like a mosaic. Expert teachers juggle every day with multiple aspects of student learning theory: prior knowledge (using every day examples), misconceptions, motivating students and engaging them (e.g. bell ringers) and tailoring their class for differential instruction due to diverse learners. What is interesting is that Chris does not seem to show this integration of concepts clearly.

Another interesting idea that blossoms from this discussion on curriculum discussion and instructional strategies is how very much engrained in Chris is the idea of using, not only real life examples, but many of them to help students learn.

Finally, with regards to prior knowledge it is common for beginning teachers to assume that students shouldn't have problems understanding basic concepts being taught. They come unconsciously with the idea that what they know should be easy to understand. What they are not aware of is that students often do not have background knowledge, but the fact of the matter is that all students have their own baggage (NRC, 2000).

Instructional strategies

Activities and representations

From previous analyses, evidence suggests that Chris was fond of using real life examples in her lessons (Curriculum Analysis) to enhance student learning (Student Analysis). Further analysis, from an instructional strategy point of view, reinforces these views and suggests that Chris' understanding of the use of real life examples, in the form of representations and activities, was polished. For instance, Chris used real life examples and scenarios, in the form of analogies, to clarify ideas to students. She often times used human scenarios as examples. One way she did this was by using humans as an analogy, to help students understand concepts such as population dynamics and population density-dependant factors (Video1, ~2:10 & 17:30, VSR1). For example, during the first video-taped class (Video1), she used factors that affected human growth in St. Louis city as an analogy to factors that affect growth in other organisms. Something similar occurred with small pox and avian pox during the same class. A second way she helped clarify student's ideas was by tying conservation-related issues to particular biology concepts (e.g., density-independence) to make student learning more meaningful as conservation could be easily tied to their lives.

> [When asked what area in general ecology should not be excluded from the syllabus]
> Chris: …One thing I would really like to stress in if I were teaching an undergraduate ecology classes, is the conservation biology as to just how everything we do impacts, so many other species, at multiple levels. And then of course how do we impact the abiotic cycling and, so, I think that would be very important to include as well. *(*Gen. Int.*)*

Concurrently, when discussing issues related to college teaching, she always emphasized the use of classical examples and up-to-date examples. A classical example would be the Galapagos finches used in books to explain micro-evolution, and an up-to-date example would be something (related to an organism) that just came out in the literature that has not been used in textbooks before. The exposed arguments reinforce Chris' standpoint regarding her use of real life examples to enhance student learning as observed also during the student and curriculum analysis section.

I believe that at some level Chris' understanding of why it might be important to use real life examples to enhance student learning was not initially clear but seemed to become clearer as time went on. It seemed to change from something like "what works for me" to something more along the lines of "what works for them'. For example, at first Chris justified the use of real life examples in basic ways. She would mention that she would use a "real population with real data… so students could identify more [with it] than just a graph*"* (Vig. Int.1). Then, later **(**3 months**)**, she would talk about using real examples to enhance student understanding of population growth curves by bridging a theoretical graph with a natural classical example like the Soay sheep (VSR1, ~11:00 & ~75:00). Finally, looking at the following quote sheds some light on Chris' refinement of the importance of using real life examples (7 months later):

> Chris: It seems if you don't, if you just use the equations and just like lift the assumptions, it's too abstract and they won't be able to really understand it or see why it matters. Unless you apply a concrete example like the cranes, something where they can better understand, or they can relate to another animal, so it's easier for them to understand it (Vig. Int.3).

In retrospect if we look at these conversations from a chronological point of view, we can appreciate how Chris' views about the use of real-life examples changes from a rough, sometimes scattered description "…so students can identify more…" to a smooth and solid explanation using terms like "understanding an abstract concept" by using concrete example relevant to students' lives.

Interestingly, evidence also suggests that Chris had the ability to create (invent), useful representations to enhance student learning. This is substantiated in the lesson plan that she developed for classifying penguins. She really integrated, in a simple way, the idea of using morphological and genetic traits to classify penguins much like taxonomists do nowadays. She also introduced the idea of phylogenic tree in a simple and easy way for students to understand. This concept is often viewed as being complex and abstract. A similar example can be seen in her polymerase chain reaction (PCR) presentation and lesson notes.

Summary

Chris always held the idea that using natural examples (i.e., real and concrete) would help students understand population growth models (i.e., mathematical and abstract), or any other concept in ecology. What seemed to be rough was Chris' understanding of the pedagogical reasons behind the use of these examples, which towards the end of the program seemed to be polished/refined as observed in her reflections. Providing multiple real life examples is strongly related to Chris' ability to integrate activities and representations of biological concepts in effective ways to a life science classroom.

Major methods of instruction

Lecture. Evidence suggests that Chris' views about lecturing were challenged and changed. From the start, Chris had thoughts of her own with regards to lecture-based teaching and learning. She had heard that lecturing was not a good way to teach, she claimed that not everybody learned in lectures, she acknowledged that it was the main way professors taught at college (apparently this worked for her), and at various points she also said it was the most efficient way to cover material (Vig. Int.1, 2). At the same time, she described lecture-based learning as being "sheer memorization" and said that depending on the goal of the teacher "…if the point was for people to learn and to retain what they learned then the lecture course really, doesn't, wasn't cutting it really…". She also mentioned that it was probably the easiest way to teach: "I mean just standing up there and talking…I mean think of all the stuff you can get through in just 45 minutes." These last descriptions transpired from our first interview (Gen. Int.). Later, in the introductory interview, she was asked how she would teach the concept of food webs while being prompted with a diagram of a complex land food web (Appendix #X). Her response was the following:

> …I am afraid this is the way I learned. I'll just go through and explain what the different levels [are] (laughing) and you know (laughs) the basic things and then try to get them to apply it. So maybe give... you know this is an example while you are teaching them what all, you know what the arrows mean and all that and then give them another example where they have to try to like maybe give them a bunch of little animals and plants *(*Gen. Int.*)*

Chris' description can be classified as a teacher-centered lecturing approach.

How did her views change? How were they challenged? Three weeks later when she had to reflect on the first vignette, which portrayed a didactic lecture-based approach with a good mix of question/discussion, she described the teaching episode as a typical lecture-based university class. Furthermore, when asked what she disliked about the class, she said that Dr. T. "covered too much material". She also said that "[Dr. T.] Seemed to lecture a lot, whereas activities might [have] helped the students understand the concepts a little better" (Vig. Wri.1). Later, when asked to expand on what sort of activities she would implement, she was unable to mention any from the top of her head. However, during the follow-up Vig. Int.1 (after her written reflection #1) she did refer to her experiences as a TA and claimed that activities were not really doable in a lecture hall (Vig. Int.1). Thus, a mixed message is being sent by the fellow at this point, which could be evidence that her stance regarding lecturing is being challenged. Meanwhile, when asked about a specific instance in the vignette (Vig. Int.1, L50-52), where the professor (Dr. T.) engaged the students from the start of the class with a slide that has an outline of the course, Chris mentioned that she would have engaged students in a different way, by using bell-ringer's. Bell-ringer was a strategy, usually a small activity, used persistently (almost daily) in her mentor's classroom as shown by the following dialogue, and as discussed in the student learning processes section:

> José: Why would you do that [use a bell-ringer]?
> Chris: To get their attention. Or maybe, make them think about …It kind of… , they seem to … get the students to think about things in a way that they wouldn't have thought about it. By, by not giving them the whole story they start thinking about it, I can't really explain.
> José: -you are doing fine, since I know what a bell ringer is (laughs)
> Chris: You know what it is? (More laughter) But they don't, they don't know [what] they are answering until you tell them later what the whole point was. So they think about it in a different way than they would have if you just told them right away what they were learning (Vig. Int.1).

Interestingly, when Chris was asked to teach a class to be video-taped, she used a lecture-based approach for her first class but an "activity-based" approach for her second class (5 months later). While reflecting on the first enactment, she recognized that lecture allowed her to get through the materials needed, but it was more boring (VSR1). Similarly, at the end of the program, during the reflective interview, she said that the most frustrating experience she had was this first video-taped class.

> José: What was your most frustrating experience?
> Chris: With the general class, like there was like all lecturing and asking them a few questions that they just, they didn't care. I don't know. So, I didn't like that very much (Ref. Int.).

When reflecting upon the second vignette she described the instance as a lecture-base approach but seemed to emphasize a little more of the discussion side. She even mentioned the idea of incorporating a hands-on activity: "…It would be nice to incorporate some kind of hands-on activity in the class to demonstrate the principles, though it is difficult with the size of the class…" (Vig. Wri.2). In this same reflection, Chris shared an interesting notion about lecturing, triggered by a MOSTEP graduate fellow's comment during one of our biweekly meetings:

> José: Based on your previous answer which says "he tried to cover too much information in one class"
> Chris: Uh-huh (laughter)
> José: -Then you say "you can get through a lot of information while you do lecture um (laugher)". So, which is it?
> Chris: Yeah. Um (long pause). Well there is, you know, I mean you can do this and not do this much in one class.
> José: What do you mean?

> Chris:-I mean you can do mixture of lecture and discussion. This goes back to what Taylor (another graduate fellow) was talking about.
> José: What do you mean?
> Chris: At the MOSTEP meeting. Um where he feels like um all they do in their class is play games and that for him is a very slow way of, a very inefficient way of teaching. They may understand it more. They may understand the concept better, but you can only go through concepts very slowly when you do it that way. Whereas if it would be a straight lecture you can cover a lot but then the students might not pick it up that way. But I think having a mixture of the two, where you do some lecturing and stop and ask them questions and have some kind of discussion is sort of a happy medium. (Vig. Int.2)

I think Chris is undergoing internal deliberations with regards to what is a good approach to teaching, especially at the college level. On the one hand, she recognizes the coverage capabilities of lecturing. On the other hand she talks about incorporating learned strategies such as hands-on activities and bell-ringers to enhance learning. Further reflections about this matter transpired in the following conversations during Vig. Int.2, 4 months after starting the program:

> José: …Okay, the end of question 4. "this kind of interchange slows the class down a bit and gets the students thinking more about the material" (Pause). So again we are going back to, slowing down [or] moving fast, more material [or] less material, thinking more [or] thinking less. Am I making sense?
> Fellow: Yeah.
> José: What is your overall pitch here? From all the things we've talked about, how do you feel about these things?
> Chris: Well, I think there is a balance. I think there is some value to have some lecture and some discussion. I think if you just do lecture the whole time then you can fall into the trap were you are going too fast for them, and you don't know you are going to fast for them. You are giving them, I mean, you can say a lot in 45 minutes, or however long your class is, and so you are just talking the whole time. And that is a lot of information that they have to deal with, you know. But, at the same time that's by far the most efficient way to get through a lot of material, is just to say it. So, I think that if you stop and have little discussions, that slows it down, so that they have a chance to maybe internalize what they are saying and think about it and then, you get through less things because you stopped and did some discussing so you can't cover as much. But hopefully they'll understand better what they are trying to cover. Does that make any sense?
> [...]
> José: Well, I'm hearing that you rather have them internalize a few basic fundamental concepts than giving them everything. Is that correct?
> Chris: Well I think it's that, kind of battles the plain: Quantity versus quality.
> José: Ok. In your eyes what is it?

> Chris: Well I guess quantity doesn't matter if they don't get anything but you know… so I guess that I would try to reduce the quantity so that they learn maybe fewer things, more important things and then learn it better. (Vig. Int.2)

This same point of view is also reflected later in written and interview sections of Vignette #3. First when she was asked to describe Dr. T.'s approach and the improvements she would make to his teaching, she wrote:

> Dr. T.'s approach was a mixture of lecture and discussion. I think it is probably the most appropriate way to do it. Lecturing is an efficient way of presenting new material to the students, and breaking the lecturing up with some discussion helps to keep the students engaged. The discussion parts also allow Dr. T. to begin to assess how much the students are actually understanding. I think my approach would be pretty much the same. (Vig. Wri.3)

Later, when she was asked about what pointers would she give to someone who is going to lecture for the first time? Chris said: "Don't lecture the whole time… stop and have some kind of question-response "thing'… see if they are understanding… stop after a major chunk…"(Vig. Int.3).

Summary

It is evident that Chris has gone through a changing process in her understanding of didactic-based teaching and learning strategies (especially lecture). She seemed to recognize the value of lecturing to cover materials (breadth versus depth) and at the same time acknowledged the dullness behind the approach that can turn students off from learning. Moreover, Chris seemed to reconcile that a mixture of lecture, "good" discussion/questioning, and maybe some small activity could be a good recipe for a successful class, especially at the college level.

*Questioning/Discussion***.** Evidence suggests that Chris' views about questioning/discussion were challenged and perhaps changed. Although questioning/discussion is considered a major teaching strategy, for Chris learning through discussions occurred only in smaller classes, like a graduate class, or else it occurred as part of a section of a larger general class (Gen. Int.). For instance, in her experience as a TA, in a general biology class, she explained that her class was broken down into 4 parts: a lecture, a discussion, a recitation and a lab section. The latter three had smaller numbers of students. For Chris, discussions were associated strongly to a small "part" of a bigger class, but not necessarily a strategy that could be embedded within the larger class (lecture).

How Chris' view of discussion changed can be observed in her vignette reflections. For example, in the first vignette, Chris talked about Dr. T.'s questioning being very superficial. When asked to reflect on what she liked/disliked about the vignette she wrote: "He did pause to try to get students to answer his questions and discuss, but it was in a half-hearted way." During the interview part, she made further comments about Dr T's questioning approach:

> …I guess he just lectured to them about what the two curves are but he didn't go into that much detail and when Lisa asked a question, he said 'not exactly' and didn't answer her question. And I don't know he glossed over (laughs) your question, and he didn't ask if anybody had any questions. Maybe he could've stopped and asked, you know, does anybody have any questions about this or just stop right there and try to make them answer questions about an example or something (Vig. Int.1)

Although not much information about discussion/questioning is present in the dialogue, it is evident that for Chris it was important for the professor to stop and answer questions to clarify student's ideas. Interestingly, four months later, during our discussion of Vignette #2, Chris made the following comment when asked again what she liked/ disliked about the vignette:

> …I liked how the teacher tried to engage the students in discussion. He tried to get them to figure some of the concepts out themselves rather than just telling them all the information in a lecture format. He built discussion by asking students to explain their answers and then asking more questions that built on those answers. This kind of interchange slows the class down a bit and gets the students thinking more about the material than they would if they were just taking notes the whole time (Vig. Wri.2)

Knowing that Vignette #1 and Vignette #2 are similar in format but different in content (i.e., Population ecology vs. evolution), we could argue that Chris' views about the vignette being more interactive, in terms of discussion and questioning, could be due to the different topic (evolution). The fact of the matter is that she made similar comments during Vignette #3 almost 3 months after the discussion of Vignette #2's (Vig. Wri.3).

In the follow up interview of Vignette #2 we can find an instance where Chris might have found an example that would have changed her views.

> Chris: Well I put more value on the sort of stopping and asking questions. I put more value now, than I would have before MOSTEP started… Because I was used to, I mean, all my entire education was lecture based and so having seen how [her mentor teacher] handles this in class I [now] see the value of using this strategy more.
> José: Can you give me an example where you've seen that?
> Chris: No, (laughter) not specific. Well just everything we do, and you do too. Actually not just [her mentor teacher], but other teachers too]
> José: What do you mean by me too?
> Chris: Well, you place a much greater emphasis in not just telling them everything but trying to get them to tell you.
> José: When did you notice this?
> Chris: I don't know whenever you were teaching, the lessons that we did and when I was just observing [her mentor teacher] during classes. How she does it, and they don't take notes (surprised voice), they just [get it]… They basically learn the concept. (Vig. Int.2)

Summary

The above dialogues suggest that Chris' understanding of the value of discussion/questioning as a strategy for teaching changed. The communication analysis sheds some further light onto this matter, especially on the specifics about how and when to question students. Further analysis of questioning strategies is discussed in some of the following sections.

*Inquiry/hands-on and other strategies***.** Evidence suggests that Chris' knowledge about inquiry-based learning changed. At the beginning of the program Chris made the following comment: "I don't know anything about teaching and the words I keep hearing over[are] inquiry based or assessment based… this words keep flying around amongst high school teachers " (Gen. Int.). This was her first exposure to inquiry-based and other learning strategies. It happened during our summer workshop where fellows got to know the teachers involved in the program. Various conversations along the lines of these two concepts happened. It would be fair to say that not until Chris' reflection of Vignette #2 (4 months later), did I observe any evidence that suggests that Chris gained some understanding of inquiry. The following comment made by Chris when asked what she liked/disliked about the vignette reflects this notion a little better:

> ..He tried to get them to figure some of the concepts out themselves rather than just telling them all the information in a lecture format. He built discussion by asking students to explain their answers and then asking more questions that built on those answers. (Vig. Wri.2)

It is clear that Chris is articulating what is at the heart of inquiry (i.e., using questions to help students answer their own questions). In this case a form of guided inquiry, through a discussion section, is being used. The idea of building on top of concepts is another important underpinning to consider when we talk about inquiry. This notion of concept building is discussed previously at greater lengths in the student analysis section. Nevertheless, further evidence from the second video-taped class interview sheds light on how the concept of inquiry-based learning evolved in Chris. I asked Chris what teaching strategy she used for the lesson:

> Chris: I'm not sure like what strategy I used. I mean, we're just doing labs to try to demonstrate the concepts that they had learned the previous day and in a more sort of lectured kind of way.
> […]
> Chris: We wanted to make it a little bit more inquiry-based, but it didn't really come out that way.
> José: Inquiry-based?
> Chris: I don't even know what that really means. I know it's something that people like.
> José: …You don't really know what [inquiry is]?
> Chris: Well, they try to, they have to figure these out more for themselves (VSR2).

Evidence from the above dialogue suggests that Chris still is hesitant to use the word inquiry. It is important to note is that throughout the year she had been exposed to this strategy in her mentor's classroom. Interestingly, during the same interview Chris was asked what were some of the strengths and weaknesses of this approach to which she answered:

> José: Okay. What are some strengths and weaknesses of an inquiry-based class?
> Chris: Well, a weakness is it takes really long. You have to have a lot of time for them to come up with what they're doing. But I think it's more meaningful to them because it is more personal. They think about it more and they're forced to really think about it and try to understand the situation so that they can come up with a way to test something rather than they're more likely to remember that in some experiment (VSR2).

Being able to articulate some of the strengths and weaknesses of inquiry-based learning is evidence that somewhere in Chris' mind this concept is materializing and taking shape.

Evidence also suggests that Chris had basic knowledge of other teaching strategies such as summarizing and providing graphic organizers as a map for students to organize their thoughts. Other teaching strategies in terms of methods and techniques are discussed during our interactions but in a more tangential way. Some of these strategies were summarizing at the end of a class (Vig. Int.1, 3) focusing students at the beginning with graphic organizers (outline of where they are in the course) (Vig. Int.1, Vig. Int.3) and hands-on or activity-based learning as referred by Chris (Vig. Int.2). Chris really liked the way Dr T. used an outline slide to guide students, since it seemed logical to her and she argued it would help students tie concepts together. She also liked the summarizing part portrayed in all the vignettes. She argued this helped students bring the concepts together since during a linear talk (lecture) sometimes students would miss the bigger picture. This idea is also discussed during the curriculum analysis section. Although Chris does not know what a graphic organizer is per se she liked how people use them.

Summary

In summary, Chris' inquiry-based knowledge changed. Chris might not have enough experience with the application of inquiry but she understands some of the major underpinnings. Also it is evident that Chris is able to recognize and articulate ideas regarding other strategies such as hands-on and summarizing.

<u>Summary of major methods</u>

When asked how she believed the program had impacted her, the following reflection made by Chris:

> [The program] Opened my eyes up to other source of teaching methods that I had never really thought about before and it just made me think more about the process of teaching rather than… Or how to be more creative about it, rather than just going through the kind of the motions and the material like kind of spewing (vomiting out) it out, you know what I mean? *(*Ref. Int.*)*

I believe this statement sums up the change she underwent regarding her understanding of major instructional teaching strategies. When asked how she believed students learned best she answered:

> Chris: Well I guess, the best way for a student to learn, is with having activities that -- are, well, I kind of feeling that I'd probably say things I've heard other people say now, and I, I probably think they are right, inquiry based...the kind of thing where you don't get the students to answer but you try to get them to work through something logically, solve problems logically in their heads and that they understand the end point better, rather than just telling them the end point.
> José: What's the value in doing this?
> Chris.: Well, it makes it more if they go through the baby steps to figuring out themselves they'll feel good about figuring out, and they are more likely to really understand it. Really understand it because if you just memorize things you don't necessarily understand what you are doing you may think you do -- but if you have to go through the process of figuring something out then, you are more likely to really understand it. (Ref. Int.*)*

This last statement shows Chris' how an inquiry-based teaching approach is embedded in her teaching strategy framework despite her not using the terminology in her responses.

Communication techniques and strategies

The evidence suggests that Chris' understanding of communication techniques at different levels was, initially, superficial and changed as time went on. I believe that the following two quotes summarize nicely how Chris changed her views about communication techniques in general. During the following dialogue Chris was asked to describe what she believed were qualities of a good science teacher, she answered the following:

… (During our first week in the program)

> Chris: …You know really being enthusiastic about what they are teaching. Making it clear how it [what's being taught] relates to [life situations]… like why is it important, why I should care about it? (Gen. Int.)

… (9 Months later- same question)

> Chris: Well they have to be able to think on their feet. Good communication skills, patience, they have to know the material really well… I guess it's mostly communication, just being able to pay attention to what, how the students are, whether they are picking up what you are intending them to pick up and then, if they are not getting it, how to change what you are doing, adapt to the situation.
> José: Can you give me an example?
> Chris.: Like, my mentor is really good at leading them through something... when someone gives an answer and the answer is wrong she's really good about leading them to the right answer just by asking questions, without making anyone feeling bad about answering and being wrong. Just having a kind of environment where it's free enough for them to say something even if it's not right *(*Ref. Int.*)*

After 9 months Chris' views regarding teacher characteristics showed a greater emphasis on communication skills and strategies, than on the use of good examples or enthusiasm. She even talked about this happening multiple times in her mentor's class. The notion of teachers having good communication skills did not come up at any point during the first interview. Nonetheless, as time went on, the data from the different instruments used showed an increased emphasis on this topic. For instance, when discussing Vignette #1, Chris emphasized the lack of Dr. T.'s consideration towards answering student questions.

> Chris: I don't remember. I guess he just lectured to them about what the two curves are but he didn't go into that much detail. And when Lisa asked a question, he said "not exactly" and didn't answer her question. And I don't know, he glossed over (laughs) your question and he didn't ask if anybody had any questions about. Maybe he could've stopped and asked, you know, does anybody have any questions about this? Or just stop right there and try to make them answer questions about an example or something without [telling them the answer]. (Vig. Int.1)

Questioning strategies, verbal and non-verbal communication. Evidence suggests that Chris' understanding of questioning strategies changed in time. Towards the latter part of the program Chris mentioned more often the importance of using appropriate questioning techniques to enhance student learning. Her ideas of appropriateness included using questions to bring forth prior knowledge, explore student level of understanding of the covered concept, and encourage students to articulate their ideas further. For example, during a discussion of Dr. T.'s teachings, she stated that "Dr. T. should have told him [the student] that it was a good answer and then asked another question to get at what he had meant to ask the first time" (Vig. Wri.3). This comment reflects her position regarding the use of questions to guide students into further thinking. Moreover, the following quote sheds some further light on her ideas.

> José: So, lets look at a few lines here lines 50 to 52. What do you think about this particular section, -- in terms of teaching and learning?
> Chris: -- Hum, well, what he could've done -- is -- instead of just, -- he asked them a question but then, but then, and he pauses to see if they respond but -- when they don't he just tells them – so maybe what he could've done would be to, if no one answered just to call on somebody and ask them what do you think population growth is? and, try to get them talking. (Vig. Int.3)

Chris also mentioned the importance to encourage students to answer questions (Vig. Int.1**). S**ome of the strategies Chris proposes to encourage students to do this where: Tell the student that you will answer the question in a few minutes (Vig. Int.1 Line 67, Vig. Int.3); and get the students to explain things rather than [you] just explaining everything. This is shown in her practice as evidenced by the following quote:

> Chris: I was really nervous.
> José: Yeah? Well, that's --
> Chris: No, I was just trying to ask leading questions to get them to figure out what we were gonna do that day. [Osmosis Experiment]
> José: Yeah, so do you think you would do things differently if you had the chance to do it again? (VSR2)

Other ideas, more in relation to none verbal communication, were also shared by Chris. For example, she talked about the importance of tone of voice, **"…**Because this is a touchy subject [evolution] and um I guess it depends on its tone of voice" (Vig. Int.2). A similar point is raised during vignette interview three when discussing line 65 of the vignette:

> Chris: Well, I think for one I do that just to, yeah, it's probably not a good thing. I should probably make them think.
> José: Why is it not a good thing?
> Chris: Because the way I did it was they'll automatically know no. Okay. They're not gonna it's not gonna go that way because I sort of imply that to my tone. And then maybe they'll I'll be ready to say, "Forget about yes. Let's start thinking about why" (VSR#1).

Later, during vignette interview three Chris was asked to choose one of the three incomplete discussions from the vignette. Then she was asked to think how the discussion could have happened and was asked to write a dialogue about this. The following is the dialogue generated by Chris as a result of this exercise.

> Dr. T.: How about you Sarah? How would we know whether we have already counted a bird or not?
> Sarah: I guess we could mark the birds that we've counted.
> Dr. T.: That's exactly what biologists do. Does anybody know how we mark birds?
> Djuan: I think people put little colored bracelets on them. I saw it on National Geographic.
> Dr. T.: Yes, we call them bands, or rings if you're from Europe. These bands allow us to recognize individuals. How does this help us to census birds?

> Pedro: Well, you could just keep catching and banding every bird you can in a given area until you can't find any more unbanded birds. Then you'll know how many are there.
> Dr. T.: You're on the right track, Pedro, but usually biologists just catch a sub-sample of individuals in a given area and then calculate the total population size by comparing the ratio of banded birds to unbanded birds. If you know the number of birds you banded and what proportion of the population they represent, then you can calculate the total number of birds. We'll talk more about this later in the semester.
> Lisa: How do people catch the birds, Dr. T.?
> Dr. T.: That's a good question Lisa. There are a number of methods people use…. (Vig. Int.3)

In this proposed dialogue we can see evidence of enthusiasm, appropriate guidance by the professor (e.g., asking students to explain things), picking a student that is shy (e.g., Sarah), and paraphrasing at the beginning if compared to the vignettes L112 & 113. Being able to articulate (include) all these features in a dialogue provides evidence of Chris' awareness of the importance of each of these factors when questioning students during discussions.

Summary

In terms of communication strategies, and questioning strategies, Chris' understanding of both changed.

Transfer

Evidence suggests that some of the gained PCK seemed to have potential for transfer into a higher education setting. For example, the use of bell ringers for lecture-based courses is considered by Chris on several occasions during her first Vignette interview, as a viable strategy to enhance a lecture class in university. In addition, the consideration to use hands-on strategies in a college setting is mentioned by Chris during the second Vignette interview although difficulties in applying this approach are highlighted by Chris. During her reflective interview, she mentioned that the use of questioning strategies, the way they were exemplified to her during her high school teaching experience, were a viable option and something she would definitely try if teaching in academia. These are the most salient examples of potential for transfer from a high school to a higher education context. Additional evidence to support this potential for transfer is the fact that during Chris' classroom performance, she used bell-ringers and in some instances tried to not give away answers but instead guided students towards an answer. In a way more experience is needed to consolidate this idea.

Potential Sources for PCK

Using Grossman's (1989) frameworks for sources of PCK as a guide, I have narrowed the analysis, to two levels. One level corresponds to those instances outside MOSTEP that could have affected Chris' PCK. A second level corresponds to those instances within MOSTEP that could have influenced Chris' PCK. At each level evidence of the sources stated by Grossman's which include apprenticeship of observation, content knowledge, teacher education, and teaching experience could be appreciated.

External to MOSTEP

Outside MOSTEP the following experiences seemed to have influenced Chris development of PCK: a) scientific presentations; b) laboratory meetings; c) undergraduate/ graduate student classroom experience; d) TA experience; and e) reflection on her own learning.

Scientific presentations. In terms of scientific presentations Chris shared that she would prepare her speeches for a professional conference using a verbatim approach. A similar strategy of writing word for word was used by Chris when she planned her first video-taped lesson.

Laboratory meetings. When presenting at lab meetings, Chris had been advised not to read from her slides. This same idea appeared twice when discussing vignettes one and three.

Student experience. As a college student, Chris believed good teachers were enthusiastic, knowledgeable, challenging, with a good repertoire of good and classic examples regarding the science concept being taught. This description surfaced multiple times, as an important teaching strategy and was used oftentimes by Chris during her lesson enactments.

TA experience. In describing her TA experience Chris stated the following experiences in the form of comments: "…when I first starting TAing I realized how good it is to have an example" (Gen. Int.) or, "In my undergrad and other TA experience it's been the camouflage with tooth picks or paper clips. It is the same thing over and over" (Vig. Int.2) or, "…in my [TA] experience it seems that the non-majors just didn't care…" (Vig. Int.1).

Reflection on teaching. In reflecting on her own learning Chris said "lecture worked fine for me…but I am aware that sometimes I did not retain the information that much" (Vig. Int.2), or "At least for me I needed to apply this [learned concept] to a new situation" (Vig. Int.2 & 3), or "…the TA would ask a question and nobody would answer, it was like pulling teeth…" (Vig. Int.3).

Within MOSTEP

Within MOSTEP the following experiences seemed to have influenced Chris' PCK: other fellows; education specialists; MOSTEP mentors; the researcher.

Other fellows. Other fellows' comments of their experiences during our bi-weekly meetings prompted Chris with ideas that apparently affected her PCK. In one case a peer explained that she had problems teaching the concept of density-dependence to students in her class; they simply did not understand the concept. Chris used her peer's experience to change her practice when she taught the lesson herself (VSR1). In a second case a fellow's skepticism about the use of inquiry-based strategies versus lecturing strategies apparently challenged her views of the value behind these two strategies. In this case, her peer said that he felt like all they do in class was play games and that for him this was a very slow way, a very inefficient way of teaching. Chris added: "they may understand it more, or they may understand the concept better but you can only go through concepts very slowly when you do it that way. Whereas if it would be a straight lecture you can cover a lot but then the students might not pick it up that way." Then Chris adds to this reflection "I think having a mixture of the two, where you do some lecturing and stop and ask them questions and have some kind of discussion is sort of a happy medium." Working with other fellows, when developing the penguin activity, also helped in this (Chris worked with Alex).

Educational specialists. Education specialist talked about inquiry-based learning, and gave tips as to how to run some activities in class. Chris said that she made mental notes (personal communications, April, 2006) about these tips. For example, she said that something she remembered was when one of the educational specialist said that it was important to cover only one concept at a time.

High school mentor. When discussing her mentor, she commented about seeing him handle questions and interactions in class and saw the value of using this strategy. Like she said: “My mentor places a much greater emphasis on not just telling students everything, but trying to get them to tell you” (Vig. Int.2). In her final reflection she commented that she was shocked to see that students understood the content without taking notes.

Reflection due to research intervention. Evidence suggests the reflections that Chris had to make as a participant in this research process were important components for her development of PCK.

> But now that I’m in this situation where we are thinking about this kind of things, now I’m paying much more attention… it makes you think about, it makes you reflect more on, on what your are [actually] doing (Vig. Int.2)
> “…Well, when having to answer what you like about what Dr. T. did and what he didn’t do or whatever, it makes you think about how you would do it…” (Vig. Int.3)

Additionally, Chris commented how going through the motions of watching herself on video helped her view things from a different perspective. As a result she was able to decide on improvements to her teaching.

Summary

Overall, Chris asserts that she puts more value on stopping and asking questions as a result of her MOSTEP experience (Vig. Int.2). She also said that the program helped her think more about how to best construct an activity while having in mind what you want the student to learn. Moreover, she said that MOSTEP helped her understand how her future college students were coming prepared in terms of content knowledge (Ref. Int.). She reflects at the end “I understand now more the value of having this sort of activities that might drive a point home better, so incorporating that more into university level…should do good.” These examples are further evidence of the changes Chris underwent in the different areas of PCK.

Chris made this final reflection after reading her case:

> I realize that I did learn some new teaching techniques from MOSTEP, and I learned how to better approach teaching in general. I still feel like most of my

> knowledge has been gained by personal experience or by watching and mimicking others (knowing what they were doing but not necessarily why they were doing it). I learned a bit more during MOSTEP by listening to some of the jargon that was being tossed around ("assessment", "inquiry"), but I don't feel like we were formally taught what those things were or why it was better to use some techniques over others.

Tyler

Background

Teaching and learning. Before starting MOSTEP, Tyler shared some opinions, descriptions and anecdotes of his past experiences regarding teaching and learning. For example, Tyler said that "a college biology teacher should be more of an expert in the material and a high school biology teacher should be more of an expert in educational approaches" (Gen. Int.). From a student perspective**,** Tyler claimed to be very competent. He shared that many times during study groups he was usually the one that knew the most and when he explained the concepts to his group he felt like the concepts were further consolidated. He also said that he valued teachers that very strong content knowledge and encouraged him to ask questions in class. In addition, he commented that he liked being challenged, especially when professors implied to him that he would not be able to meet the expectations of the course or task. He described himself as a self-learner (Gen. Int.). He knew what his strengths and weaknesses were when embarking in learning.

From a teaching perspective, Tyler commented that he had taught before to diverse audiences from grade school to college students; to business people and to the public in general. Most of his teaching occurred in an informal setting. He also mentioned that he was in charge of developing a new education program at a zoo. He shared that to accomplish this task he modified learning programs from other zoos. He mentioned that he took a museum education course at a private university where he learned about "epistemology… learning theories and things like that" (Gen. Int.). He claimed he had no issues teaching controversial subjects, like evolution to religious people. He did say that he would be more hesitant to teach parts of biology he knew the least, like genetics or molecular biology. He also thought that the difference in age and his life experience (i.e., political, social and emotional) provided him with enough tools to handle difficult teaching situations. He added that he had a very strong opinion regarding people that were in college. He said that “by the time someone is in a college program… they should have learned how they learn… [they should know] what they need to do to assimilate that knowledge and not rely on a college professor to tailor his or her approach to every individual” (Gen. Int.). Part of this reflects the way he was taught when active in the Marine Corps. It also explains some of his answers during the research intervention. Tyler also had questions, as Chris did, regarding the teaching preparations a future professor should have. He commented “I always thought it was kind of ironic that you needn’t need to have teaching credentials to teach in college but you do in high school.” (Gen. Int.)

Motivation to join the program. Tyler’s had two main reasons to join the program**.** The first reason he indicated was the opportunity to test his abilities and skills at a different level. The second reason was the excellent support in the form of tuition and stipend offered by the program. Being released from funding concerns was a way for him to focus exclusively on his graduate program too (Ref. Sta.).

In summary, Tyler joined the program because he saw a challenge and an economical benefit. He saw pursuing a teaching career as distant to his interests but definitely a possibility. During our conversations, he indicated he would be very confident teaching anything in front of a classroom or group of people ready to learn. Additionally the most important thing he learned in high school was “…learning how to learn. Not learning a subject but learning what you had to do to approach that subject, to become a master of that subject…” (Gen. Int.). Moreover, in Tyler’s mind there were clear distinctions as to what and how people learned, or should learn during the different levels of the education continuum. For example, at the undergraduate level, he said: “…[it] is about regurgitation… being given the material, learning the material, memorizing the material, being able to recite the material.” At the graduate level he said: “…it is more, being presented with the existing evidence, discussing the strengths and weaknesses of that evidence using your own critical thinking (Gen. Int.).” What is portrayed through this description is the point of view of a person that has extensive life experience as Tyler is the oldest of the fellows.

Pedagogical Content Knowledge

Assessment

Tyler's knowledge of the different types of assessment teacher's use to evaluate student performance was basic. Throughout our conversations he mentioned, at least once, the following assessment tools when discussing different ways to evaluate student's performance in the classroom: a) multiple choice questions; b) essay questions (with variations); c) pre-evaluation; d) oral testing; e) fill in the blanks; and f) what he called an "amorphous mixed testing" approach. This notion of "amorphous mixed testing" was coined after being prompted with a hypothetical question as to how he would assess students if he had taught a class using a proposed food web (See Appendix for Food web). He said:

> I would foresee… an amorphous mixed [assessment] approach depending on the perceived capabilities of the individual, my relationship with the individual, so it may be some sort of question and answer reward points building thing for somebody. It maybe more of just a conversation about one-on-one of how does this relate to something in your life sort of thing [for others]. (Gen. Int.)

Tyler was trying to foresee how he would assess students in the near future if he were to teach food webs. In doing so he came up with the idea of using a battery of tools, such as one-on-one conversations and reward points, to learn how much students really understood the topic. Although an approach like this could be an appropriate way to assess students, it is unclear if Tyler understands how using these assessment approaches could help or hinder teaching or learning.

Evidence suggests that Tyler's understanding of uses of assessment was varied. Sometimes he was unyielding, as was the case with essay questions and multiple choice questions. He strongly believed that essay questions where the best way for students to show how much they knew or how much they had "assimilated" the concept taught (Gen. Int.). Furthermore, when evaluating the vignettes he expressed similar ideas when asked what he thought was a good way to assess students. He commented: "I think a blank sheet of paper… and all they've got to work with is what's in their heads. [This] is maybe a stronger way to demonstrate the actual knowledge." Comparable ideas transpired from the first video stimulated recall interview, and later on during the second vignette interview. One interesting difference was that during the latter he showed awareness of some of the difficulties behind using essay questions. In addition, he shared some strong opinions regarding students not being able to handle essay questions and his own dislike towards them as a student.

> You know this is the world that you live in, especially now [that] you're in college. If you can't write an essay question maybe you need to go back and take some English classes, some writing classes, and not just, you know, okay well I'm going to allow you to answer this question in interpretative dance and expect that that's how you're going to present your information at a scientific symposium someday. So there may be that argument that some people don't write essay questions well. You know if it's a language issue maybe find a way they can write it in their own language and have somebody translate it for you. From a student standpoint, yeah nobody likes them. You know it's a pain in the a... It's hard you know, it takes a lot of time. You actually have to think about it, yeah I hate them too because I hate writing by hand… So I pity whoever has to read my essay questions because a lot of the times there's scratch outs and errors pointing to this and that but… (Vig. Int.2)

Understanding the difficulties and hurdles one may encounter when using essay questions deter Tyler from believing essay questions were one of the best ways to assess student understanding. Rather, it gave him a deeper understanding of this type of assessment and its uses. Like he reiterates during the third vignette interview, "essay questions are better for assessing whether somebody gets it or not**.**"

With regards to multiple choice questions (MCQ), Tyler was very clear as to why he did not believe multiple choice questions were a good way of assessing students understanding. In his mind MCQ's did not really allow teachers to gauge if students grasped a concept or not (Vig. Int.3). Additionally, he believed that giving students options to a problem was not an accurate representation of real life as he expresses in the following quote:

> José: What do you mean by 'the multiple choice test will probably not allow him to gauge' [student understanding of a concept]?
> Tyler: [Well], does the student really get it or was he just able to rule out you know, choices A, B, and D? … I mean ruling out alternative hypothesis is one valid way of approaching science, but you know, very rarely in the real world are you going to be presented with a problem and there's only four possible choices. So you can't miss. You can't always rule out all 100 possibilities. I don't think multiple choice seems really an accurate way to gauge whether somebody really gets it (Vig. Int.3).

Moreover, he equated multiple choice to multiple guesses. He said that as a teacher you were not testing individual's knowledge but student's ability to guess. He also talked about teachers using multiple choice tests because they were easy to grade and demanded less effort. However, he said that this did not mean that it was a good way of assessing students (Gen. Int.). From a student perspective he did not like multiple choice because he believed sometimes MCQ's were ambiguous. He said that at times he had actually turned MCQ's into essay answers to make himself understood.

At times Tyler was scattered, as was the case with pre/post testing and other forms of formative assessments. Initially, Tyler was unsure of the value behind using pre/post assessments, but towards the end of the program he believed that using this kind of assessment had some value. For example, if we analyze this issue in a chronological order, he was first introduced to the notion of pre/post assessment during the pre-evaluation period of the project. Tyler commented that he was unsure of the reasons behind taking a pre/post test for the project. During his reflection Tyler pointed out that the reasons behind such test could be related to technicalities. Three weeks later, during his high school "duties" he was introduced to the idea of pre/post assessment again by another fellow. In this instance, it was introduced as an instrument to use in his high school classroom. This particular fellow was in her second year of the program and had teaching experience and training in pedagogy. Tyler explained that in this particular case they were trying to introduce a pre/post assessment into an activity-based exercise to:

> "… assess student's prior knowledge …We came up with the test and the exercise at the same time. [The test became] a monitoring tool. Did they do better on the second test, than the first test? Then it [became] a curriculum steering tool**.** [So] we know they're weak here. Let's make the lesson plan heavy in this area. (Vig. Int.1)

In Tyler's words they use this pre/post test as a tool to gauge student learning. This would allow him to focus on "filling the [knowledge] holes" (Vig. Int. 1), A few months later while reflecting on one of his video-taped classes ,Tyler shared how, at his mentor's request, he had implemented a pre/post assessment in a similar way to the one used in his beak evolution class. He implemented this test without much help from either his mentor or the other fellow. He also sounded more confident about what he did as compared to the first time we discussed pre/post assessments during the first vignette interview. The following excerpt of our conversation depicts part of Tyler's thought process when questioned about this instance.

> [I told the students] 'tell me in your words, your understanding of how natural selection affects the evolution of characters such as birds' beaks. As a hint try to use some of the following terms'… I use things like mutation, genetic inheritance, reproductive fitness, survival… and then just had them write a paragraph…and [the differences in understanding] were abysmal.
> José: You did this?
> Tyler: I did, I did that before, before doing any of this [teaching]. I did that to sort of get a feel for at what level I can teach this. (VSR1)

Initially, he thought he could teach them about reproductive isolation and the implications on genetic diversity in large and small populations, however after looking at the students' responses and making a diagnosis he realized he had to change his approach. Tyler used the assessment as a monitor/steering tool. When Tyler considered giving the post-test to students, he became hesitant and questioned the statistic validity of the approach. He stated that he had a "non-independent sample". Furthermore, he explained, the pre and post assessment was more a "repeated measurement" and "some power would have been lost and a generalization would have been harder to make." At this point Tyler seemed to be juggling back and forth with the value behind using pre/post testing based on his statistics dilemma. Nevertheless, during the second and third vignette interviews it became evident that he embraced the idea of using diagnostic tools to enhance teaching. He suggested the usage of pre/post assessments to guide and monitor students' understanding of scientific concepts. In essence, Tyler's view on pre/post assessment seemed to change; he went from not liking the test during the program evaluation period, to exploring its uses with a second fellow, to including the assessment as part of his class.

During both the third vignette interview and the reflective interview Tyler shared some further thoughts regarding uses of assessment to inform his instruction. For instance, he mentioned that he would use questions and answers (i.e., in class, assignments and tests) to prepare students according to the State science objectives and thus allowing the objectives to guide both his teaching and assessment (Vig. Int.3). Additionally, he talked about accommodating and developing assessments items according to the student level (such as AP versus a general life science class). Last, he shared that earlier in the program, while assessing students, he also felt frustrated with the results he was obtaining. In some of his tests student performance was so poor that he lowered his expectations, which in retrospect he believed he should have not done. The following quote sheds some light on this matter.

> I've learned that apathy can be contagious if you let it be…early disappointments in evaluation of the students on material I presented led me to expect less and ask for less…I think this was a mistake that I had to make in order to learn from, and I would guard against similar attitudes in the future. (Ref. Sta.)

I think that these reflections were important to form and expand Tyler's understanding of formative assessment, in particular the use of pre/post testing tools to accomplish this.

Summary

Overall, evidence suggests that some ideas Tyler had on assessment changed. Tyler's concept of essay questions, and multiple choice questions was maintained. In contrast, Tyler's concept of pre/post assessment changed. His elaboration of pre/post assessment as a tool to be used to evaluate student's prior knowledge is clear evidence of this. In addition, his description of this type of formative assessment as a "monitoring and steering tool" (Vig Int #3) to help plan and change a class shows further understanding of the benefits of diagnostic assessments. Finally, the concept of formative assessment knowledge, while not explicit, was noticeably prevalent towards the end of the program.

Curriculum

Evidence suggests that Tyler had a preference for classes that were structured in a logical sequence**.** This tendency transpired during multiple conversations. During the vignette interviews, Tyler said that Dr. T.'s class was "organized in a logical way" (Vig. Int.1). He also commented that one of the things he liked about Dr. T.'s class was that he had a "clear framework for material [concepts] to be covered" (Vig. Int.3). His idea of clear framework comprised the following two notions: 1) the organization of the population biology and evolution class content in the vignette and 2) the way the presentation was made using a "map" slide at the beginning of the talk and summarizing the class at the end. In examining his lesson plan outlines (LP1, 2 & 3) Tyler's proclivity towards a logical sequence became more evident. In his outlines, Tyler was very specific as to how you should move through the lessons; there was no room for diversion, everything was written down almost verbatim. For example, in the case of his "trophic cycling" lesson (LP#2) he wrote: a) Hand out pages of animal images… b) Instruct student to cut images… c) Use pencils to draw lines representing feeding relationships… e) [tell students] these arrows represent "trophic" relationships…h)Do you know where the nutrients to support all life forms comes from?... m) does a trophic interaction means that the eater kills the eaten…, etc. The specificity of what he wrote is not as important as the concept sequence that he used. All of Tyler's lesson plans seemed to follow a well thought content sequence. Moreover, when the lessons were enacted, these sequences became more evident (Video1 & 2).

Concurrently, Tyler mentioned that sometimes he felt like his mentor would teach in a "less objective driven [way], and more free flow and tangential [way]", giving the impression the he did favor such approach. What he probably meant was that his mentor would teach in a more conversational way and as things "popped up in his head" he would go in that direction, and if a student asked another question he would go in another direction. He felt like for certain concepts and ideas this would not work. Tyler wanted, a little more control in an almost military fashion. For instance, he wanted to make sure that "…[concepts] were said and presented in a particular order that would make sense". Additionally he felt that concepts needed to be "stacked on other concepts". He summed this up by saying: "I tend to take a little more [of a] directional approach…" (VSR2). From the above quotes, it is clear that teaching with a content sequence where concepts build on top of other concept, is a preferred strategy for Tyler.

Another idea that Tyler emphasized was the idea that lessons had to be synchronous to the goals and objectives behind a class. As an example he said that an undergraduate ecology class could either be geared towards "understanding wild life dynamics" or else towards understanding the "human ecology and impacts of humans on the environment" (Vig. Int.1). He added that the teaching approach would be different depending if it was a "wildlife biology program or if it was an environmental health [program] Vig. Int.1", respectively. During the "Trophic cycling" lesson interview (VSR1) the idea of goals guiding lesson planning was also brought forth. When asked why he used this "cycling" approach when teaching trophic levels, he said that he wanted to have a common theme "cycles" that would interconnect feeding relationships with life cycles and nutrient cycling. One of his big goals was to make this relationship visible to the student through the idea of cycles. Moreover, when asked in what ways he believed he met the goals of his class he added: "I think they are familiar with the content…and some technical aspect…Like I said…when I sent them out [to the field] I wanted them to think about connections between animals, plants and themselves… I think I succeeded… I am working on the follow up test." When challenged as to why during the first video-taped class, he did not elaborate the notion of animals stealing food and competing for the resources with other animals when the issue was brought up by students, he emphasized that he did not do this, because even though it was rich and lent itself to do so, it was not the objective of the lesson. He said: "The objective of this lesson was to prove that, to show that, the shearing beak had the advantage and it was the one to reap the reward of that advantage…not competition…" (VSR1).

For Tyler, not only did the goals and objectives inform the sequence of a lesson or unit, but they were important components of the lesson per se that helped him guide students to achieve a better understanding of the concepts. As an example, Tyler pursued some affective objective during most of his lessons. This unconscious drive was partly a product of his own passion for wildlife. The following excerpt sheds some light on this matter.

> José: What did you want the students to get out of it?
> Tyler**:** Well the interconnectedness of things, how an effect on one thing might affect something else… the strength (2:00) of the unpredictability of those interactions is very much a contentious issue among ecologists… Scientific accuracy aside, I also wanted to… incite the, sort of, the feeling in students that, you know, yeah this is this is, these systems are interesting and things can throw them off and it's best to take cautious approach when messing with things in nature and hopefully instilling some of my fascination with those things (VSR2).

Tyler showed some reluctance and skepticism with regards to the efficiency of state tests in measuring students "real" understanding. For Tyler a clarification of the goals and objectives behind testing needed to occur. For him it was like: "…if your objective is for the child to score well [in the state test] then rote [learning will do]… I'm spewing it to you. You absorb it as best you can and shoot it back out to me just as I gave it to you when you take the test." On the other hand he argued that "If your objective is to build a healthy mature adult who is comfortable with taking on a part of the world… becoming confident with taking on new material and … tying…with everything else within their world…" (Vig. Int.3). Getting to this level of discussion where assessment is used as a guide for curriculum development and lesson planning indirectly speaks about Tyler's awareness towards the role of objectives and goals in the curriculum.

In terms of knowledge about materials available for high school and undergraduate life science classes, evidence suggests that Tyler draws ideas mainly from textbooks, the internet, his graduate work and his creativity. For example, when he was asked how he came up with the evolution of beak lesson, he explained he used a grade school activity and then did a web-search to look for further information. As a result of this search he came by many lessons, none of which really satisfied him. Therefore, he took bits and pieces and developed what I considered a very innovative and a complete lesson. The lesson included: a pre/post assessment, a visual PowerPoint "beak diversity" slide show, a activity-base, hands-on and inquiry lab, a concise discussion, and a consolidation of the concept using a self-made story to pull the concepts together (Video1, LPN1, VSR1). In contrast, he mentioned the use of computer simulations to target evolution concepts and population growth (Vig. Int.3). He gave an example of how a simulation could help answer questions like: "What happens when you increase environmental stochasticity into a very stable environment or a very volatile environment? What happens if there's heterozygote advantage to this allele?" He claimed that "those sorts of things [effects on populations] can be fairly easily demonstrated in computer labs." Nevertheless he agreed that simulations could take away "the real life experience, hands-on sort of feeling about it." Recognizing potential resources to develop lessons, and being cognizant of the advantages and disadvantages of such tools and resources is a sign of being knowledgeable regarding curriculum materials.

In terms of lesson planning, evidence suggests that Tyler's understanding of lesson planning changed. While looking at Tyler's lessons (i.e., evolution of beak, life cycle, food cycle, nutrient cycle and evolution of mammals) it is evident that Tyler felt more comfortable writing up everything that was going to happen and what was going to be said in his class. His planning flowed as follows: a) He started with a topic. b) He then checked the topic in a textbook and looked up the examples in the text. c) Then he put together an outline and wrote down step by step what was going to happen during class, while he developed the materials (i.e., a PowerPoint, a story or an activity). This strategy of lesson planning is consistent throughout his lessons. Additionally, Tyler did not embrace the lesson plan format proposed by the project. At some point he said: "I'm not gonna teach off the lesson plan (referring to the proposed LP)… let me make what I want to teach [his outline] and then readapt it to fit the lesson plan (VSR1)." For Tyler it seemed like the proposed format did not fit his teaching style. Nevertheless, if we look at the teaching sequence of his video-taped classes they seem to follow the proposed lesson plan format. Tyler goes from an anticipatory set and exploration phase to an explanation phase and extension phase while evaluating students along the class using questions. During the final interview Tyler seemed surprised to realize he was using unconsciously the lesson plan format when teaching his taped lessons.

From the point of view of scope and coverage it seemed that Tyler, at the beginning of the program, tried to cover too much information. He acknowledged this in the second video stimulated recall interview: "I know I tend to cram too much stuff into my lessons and presentations". He said that this was because he wanted to make sure he did not miss anything important. Additionally, this is not only seen in his lessons, but also in some of the slides for his presentations where too much material is placed on the slide so that enough props are available to the instructor. His first lessons for example, took 1 hour more than anticipated. However, during the following lessons he seemed to control his timing a little better (Personal communication, April, 2006). Most of Tyler's lessons, while intended for two periods ended lasting three or four class periods.

Tyler perceived that he had changed regarding lesson planning. The following excerpt summarizes how he believed he had changed mainly with regards to lesson planning.

> José: …Is this the way you always plan your class?
> Tyler: It's it seems to me illogical to do it [plan a lesson] any other way. I just, if I'm writing, I'm going to … constantly get the background… as well as the best way to do it. What are they going to get out of it? What's it gonna take? What's it gonna give? What's s/he gonna take away? I'm probably a lot different at it now than I may have been in some of the earlier lesson plans. Maybe a little bit better at anticipating where things are gonna get held up and when they're gonna go smoothly, or what. Maybe my priorities are a little bit different now than they were in the beginning, and thinking more about connecting things, but also now I've got a base on which to build, because of the earlier lesson plans I've given to classes. (VSR2)

Summary

In general, evidence suggests that Tyler's understanding of curriculum was superficial and changed throughout his participation in the program. First, it is evident that Tyler preferred highly structured and well thought and sequenced classes as opposed to un-guided approaches. He did have some differences with his mentor's approach in this area. Second, he acknowledged the importance of goals and objectives in guiding a class' sequence and lesson planning. Third, evidence suggests that Tyler draws from different sources to plan for a class, especially the internet. Also, a strong reliance on PowerPoint presentations for his teaching was observed. Nevertheless a good combination of inquiry-based activities and alternative strategies was used with the PowerPoint presentations during his high school interventions.

Finally, with regards to lesson planning, it is evident that Tyler was very detailed at preparing his lessons. Despite not being comfortable with the proposed lesson plan format, he managed to put together a comprehensive plan. In addition, he claimed to have improved in anticipating problems during teaching and thinking about connecting things when developing lessons.

Students

Learning theories. Tyler had no explicit knowledge about education theorists who contributed to the knowledge on student learning but he did show declarative knowledge of some of their proposed theories. Tyler seemed to have been exposed to some learning theories during his work at different zoo's and museums. After many years away from this job he still remembered some of them though not necessarily in detail. During the first interview when conversing about his prior educational experiences, he talked about learning during a museum education class something about an "axis with four quadrants" with an intellectual (thinking) and an emotional (feeling) component. [He was probably referring to Kolb's learning styles[6] (See figure below).] He also mentioned a "personality

[6] *"David Kolb and Roger Fry argue that effective learning entails the possession of four different preferred manners of dealing with information processing: concrete experience, reflective observation, abstract conceptualization and active experimentation. As a result they developed a learning style inventory (Kolb 1976) which was designed to place people on a line between concrete experience and abstract conceptualization; and active experimentation and reflective observation. Using this Kolb and Fry*

inventory", probably referring to the Myers Briggs Type Indicator (MBTI)[7]. Finally, he also mentioned people being kinesthetic, tactile or visual learners[8], probably making reference to the multiple intelligence theory proposed by Howard Gardner (Gen. Int.). Some references to these ways of learning were made by Tyler during our conversations. For instance, when we were discussing Dr. T.'s teaching approach, he mentioned that "some people just aren't capable of being the person who can be intimately attuned to ten different personalities in a classroom and treat them all as individuals" (Vig. Int.1). Later, during the same conversation, he mentioned the idea of students being better at listening than at observing (i.e., auditory vs. visual learning). He even discussed some situations in which people were over-stimulated causing what he called "short circuits" in their understanding of the content (Vig. Int.1). In the third vignette interview he talked about people not being verbally strong, that is they were not able to articulate their ides appropriately when speaking and some when writing. Also, during the video stimulated recall interviews, ideas such as students being "manually confident" (VSR1) or understanding better a concept when manipulating materials, surfaced. These instances, where Tyler shares insights regarding the application of some of the previously mentioned theories in a practical way, provides evidence of his level of understanding regarding some of the theories.

Evidence suggests that Tyler's understanding of learning processes changed at certain levels and in certain topics regarding student knowledge. Among the topics that surfaced and some of the changes discussed were: a) metacognition, b) building concepts on top of previous concepts, c) student prior knowledge and misconceptions., d) linking concepts to everyday life, and e) pre-requisite knowledge and motivation

Tyler talked about metacognition without "really" understanding what metacognition was and its implications in teaching and learning**.** Nevertheless, it seemed to be something that made sense to him. For example, during our first interview when discussing what were the best ways for a student to learn, he said that it depended on the individual. He said that students need to "identify what works for them and what doesn't

---

proceeded to identify four basic types of learners: Convergers, Divergers, Assimilators, and Accommodators." (URL: https://www.cs.tcd.ie/crite/lpr/teaching/kolb.html)

[7] The Myers and Briggs Foundation URL http://www.myersbriggs.org

[8] Gardner, Howard. Frames of Mind: The Theory of Multiple Intelligences (10th Anniversary Edition). NY: Basic Books, 1993.

work for them" and that the teacher should know "what's best for the individual [student]" to do, in order to learn about the concept at stake (Gen. Int.). These two ideas lie at the heart of metacognition. However, it seemed like Tyler considered these ideas more a self-directed learning approach than a teacher facilitated approach; hence the idea of knowing what works for you. This reflection seemed to be consistent with previous comments Tyler made about his own learning. During the second vignette discussion, he said that for him it was important to think how he learned best; to understand his "own personal epistemology" (Vig. Int.2). He claimed that this thought process allowed him to construct a better internal model of the concept being discussed by knowing how he best learned. Clearly, a metacognitive approach to learning is being portrayed by Tyler. Even though he might not be familiar with the term per se, the notion of reflecting on what works best for one is a critical component in teaching and learning. No direct or explicit evidence of Tyler considering metacognition in his classes is observed. In spite of this, Tyler was the only fellow that mentioned this idea as an important tenet for learning. He claimed that he had learned this throughout his learning ontology combined with his exposure to zoo learners and educators as well as museum education courses.

Evidence suggests that Tyler had some prior knowledge regarding the idea of students constructing knowledge**.** From the beginning of MOSTEP Tyler seemed to understand the idea of knowledge being constructed. Tyler said that, for him, real learning was about making connections. He provided the following analogy to explain the process of building knowledge: "I think [learning works] more [like] an erector set [where] you put a girder in place here and you connect it to this, and you connect it to this [other], and the bigger your armature is the more things you can stick on to it in different places." He added that "loose concepts that do not have interrelation might help in Trivial Pursuit (game) but they would not help you recognize how something fits into the larger framework of the world" (Gen. Int.). Later, during the same interview, when we were discussing ideas of how to teach food webs, Tyler mentioned similar ideas (~55:00) of concept formation for this topic. Moreover, during the second vignette interview he highlighted that the concepts that Dr. T. dealt with in class were cumulative in nature, and if someone did not feel comfortable with the preceding material it was going to be hard for them to build on the following ideas. Similar claims of building knowledge are made throughout this and the following vignette discussions (Vig. Int.3).

Furthermore, during the reflective interview he emphasized that “the best way [for someone] to learn is to find those [familiar concepts] that will help you plug that [new information] into your framework in a way that it will stick with you (Ref. Int.).” This idea is discussed further in the prior knowledge section but, from our previous discussion, we could argue that to an extent, a constructivist approach is preferred by Tyler. Although explicit knowledge of such learning theory or philosophy was not presented, Tyler’s descriptions seemed to portray constructivism.

Finally, the idea of mental models and using schemas to build knowledge seemed to be part of Tyler’s prior understanding of how students internalize information. Although at times he referred to students “absorbing” information instead of constructing knowledge (VSR2), he favored using the idea of a framework or armature to which new knowledge was connected to.

Further evidence suggests Tyler’s understanding of how students prior knowledge plays an important role in learning changed. The idea of using prior knowledge to build concepts is implied by Tyler in his analogy of the connectors and erector presented during the discussion described in the previous paragraph (Gen. Int.). Even though he mentioned the necessity of building on top of this initial framework in this first intervention, little evidence is provided with regards to knowing about the importance of using this knowledge of student’s prior knowledge as a teaching tool. For example, during the general interview, when Tyler was asked what considerations he would take when teaching food webs to an undergraduate biology class he said: “I think… pre requisites… You have to make certain assumptions of a certain base knowledge of the students…” (Gen. Int.). This answer indicates that Tyler, instead of gauging and learning about what they actually knew, he was making the assumption that students had a similar knowledge-base. The importance of knowing about prior knowledge seemed to emerge first during his evolution of bird beak activity de-briefing when we were discussing the fact that students had a very discrete (i.e., black or white) ideas (VSR1). For example, he said that his students either thought organisms where generalists or specialists. He said that he had noticed that this was happening also when his mentor taught a previous class on birds and was talking about birds being either precocial or altricial[9]. Consequently, he decided to tailor part of his bird-beak activity to hit this particular misconception based on his reflection of the prior knowledge he expected students to come to his class with regarding the concepts he would teach (e.g., generalist vs. specialist). Additionally, he tried to use familiar objects to run the bird feeding activity to exemplify the bird's diets (such as marshmallows and cereals) and bill shapes (such as pliers and pincers). Using familiar objects implies an indirect consideration of students prior knowledge when planning a lesson. However, it can be argued that this idea (i.e., using pliers, cereals and such) was initially part of an activity he found in the internet.

During his second video stimulated recall interview other examples, where he acknowledges prior knowledge, transpired. For instance, when discussing the photosynthesis equation in the food cycling lesson, he was asked why he tried to get students to come up with the components. He explained that he did this because students had already done this in previous lessons and he was trying to draw from their prior knowledge (VSR2). Also, when asked about the use of calculator in that same class, he said that most students where not able to perform the calculation he showed without a calculator. This is something he noticed during previous classes. Again he showed consideration regarding student prior knowledge to tailor his class and accommodate learning so that he did not lose the main goal of the lesson. When asked if he tried to acknowledge prior knowledge often in his teaching, he answered

> Tyler: I try to do it often, but I don't know if I do it often enough…I think [it] is important… especially when I'm about to use a word that I know they've heard before, because we've done it, you know, previously. That's when I'll often do like this, ask them to try and give me that [information] back instead *(*VSR2*)*

Finally**,** Tyler shared that one of his main roadblocks was the incongruence between what he knew and his understanding of what students came with. He reflected: **"**I am teaching what they [concepts] mean to me and then trying to make that mean the same thing to somebody who's got a completely different worldview [prior knowledge] than [what] I have" *(*Ref. Int.). Recognizing this roadblock is further evidence to support the idea of Tyler struggled and dealt with this particular pedagogical concept of prior

---

[9] Precocial refers to species in which the young are relatively mature and mobile from the moment of birth or hatching, altricial is the opposite)

knowledge that resulted in changes. The following comment sheds further light on how Tyler embraced the idea of prior knowledge despite his struggles. When asked: How would you say it's the best way for a student to learn something?, he said:

> [Finding] a way to make the connection from whatever is being presented to them to something that they already have, that they already know... Find out how, what that thing [is],[it] takes a little thought but somehow, someway that thing is going to be somehow [be] connected to what [they] are interested in so the best way to learn is to find those and that it will help [them] plug that into [their] framework in a way that it will stick with you **(**Ref. Int.**).**

The integration of building concepts, using examples and working with prior knowledge shows a change in understanding of learning processes. Prior knowledge has been also discussed from the perspective of assessment in the assessment section.

Evidence suggests that, for Tyler, linking concepts to students' everyday lives and taking into consideration their context, helped students understand the content better. Tyler always emphasized that linking concepts to the human side, like to environmental impacts, population explosion and the pressures it generates on the globe, was important to get students motivated (Gen. Int.). Although not explicitly identified as a link to prior knowledge, Tyler's examples were important in terms of their relevance to the student's current and future lives. Tyler emphasized the importance of using these examples, not in terms of numbers, but in terms of presenting examples in controversial ways where the NOS was demonstrated. He thought that this approach would be very productive and enlightening to the student, especially in a college setting. The following conversation sheds some light on this issue.

> José: So, what would be your teaching approach, how would you teach this [energy transfer across food webs]?...
> Tyler: I would say examples would be an aspect but probably, I mean, I wouldn't just say yeah, bla bla bla bla bla bla. Probably at the same time you're showing examples, you might want to show the fact that they are contradictory, conflicting examples, and somebody shows this but then somebody shows this and you know, sort of the whole uncertainty of science and the context dependency of things. (Gen. Int.)

Furthermore Tyler shared an innovative way of teaching about mutation and evolution using examples familiar to students. The following is an excerpt of what he said in his lesson to students when introducing the concept of mutation.

> Yeah mutation is usually bad but have you ever done anything accidentally and then found out that it worked? And then you do it, you know you used it. Well that's sort of how mutation can work. It's an accident that, most accidents are bad but sometimes it accidentally, you accidentally do something that's actually even better that you were trying to do… *(*Video1).

The slide show that went along with this conversation further highlights the connection Tyler tried to make. For example, during mutation he used an image of Ninja Turtles and X-Men (movie characters) to springboard into his conversation about mutation with the students. In other words he worked with student's prior knowledge to enhance his lesson. Similar application of familiar examples were used in his trophic cycle lesson and when putting together the organisms for the food web (Video2, VSR2). For instance, in the first case he talked about "grossology" items, like mentioning "poop" or "crap" instead of feces when addressing the way in which organisms get rid of their waste products. In the second case he said he tried to pull examples that students could have seen or would seen in their every day lives.

> Q: So, where did you get the examples you used for your food web instruction and for the food chain decisions, and how did you choose chose the examples?
> Tyler: I think I saw the grass, grasshopper, mouse, hawk thing in one of the books, so I just thought, oh yeah, it's simple. It happens right here, you know, in your 'nature area', we see hawks all the time. There are mice and grasshoppers here. So, yeah, it's a good starting point (VSR2).

In retrospect the fact that Tyler used these examples, like X-Men, "poop" and considering their nature, shows a practical inclination towards considering students prior knowledge when planning his lessons.

Parallel to this, evidence suggests that Tyler had a strong understanding of the main misconceptions people have in some life sciences topics. He also developed a better understanding of how to use misconceptions to his advantage when teaching. For example, in terms of identifying misconceptions, Tyler was able to point at main misconceptions in evolution. He talked about the Lamarckian versus Darwinian evolution misconception. He added the idea that "… if I work out and get big muscles, then maybe some day my kid will…I think in the early days of discussion of evolution that was still a stumbling point for some people" (Gen. Int.1). He also mentioned the creationists point of view and its discrepancies regarding evolution. He highlighted the idea of evolution just being a theory (Vig. Int.2) and that mutations were always seen as bad (VSR1). Likewise, during the third Vignette interview he pointed out misrepresentations or oversimplifications of the population growth formula. He mentioned that Dr. T. was missing immigration and emigration as an important factor in determining population growth. Tyler was the only fellow that picked up on this issue. Clearly, Tyler's strong content background allowed him to talk comfortably and extensively when discussing misconceptions. In contrast to other fellows Tyler seemed to exploit this knowledge on misconceptions to plan his lessons. A good example of how he did this was when he tried to make students understand that birds where not specialist or generalist, but that there was a continuum, "there were in betweens" (VSR1, Video1, LP1). In addition he emphasized this continuum idea during the second video taped class, when talking about organisms being primary consumers, secondary consumers or organisms being omnivores, carnivores and herbivores. He argued to students that there were degrees of "omnivory" and organisms do not necessarily fall under one trophic category. It became evident from our conversations that part of his teaching goals was to challenge these misconceptions and change them if possible (VSR2, Video2, LP2). Other misconceptions regarding food webs and nutrient cycle are also targeted by Tyler during this second video intervention. At the end, Tyler made an interesting reflection regarding misconceptions: "I think if you just take, if there's, these misconceptions and you just say what it is without specifically addressing why those misconceptions are misconceptions. They may still keep them *(*Vig. Int.2*)*."

Overall, the idea of misconceptions is not brought into our conversations that often until the first video interview. The fact that Tyler used misconceptions to address content in his follow classes is interesting. According to Tyler this happened after he recognized that his mentor was giving discrete (i.e., black or white) ideas to students when in reality things in science at times looked more like a continuum, like was the case with precocial vs. altricial and generalist vs. specialist organisms. This inclusion of misconceptions as an objective in his classes could be interpreted as a change in his teaching practice due to his understanding of student's prior knowledge in this area and him observing his mentor's oversimplification of biological phenomena. Nevertheless, upon further reflection, Tyler explains he believed that, at least for evolution, the changes in laws and debates that went on were indications that you "Cannot teach evolution without taking misconceptions head-on".

In terms of engaging students, Tyler developed certain sensitivity, in terms of maneuvering teaching, to accommodate learning styles and motivate students, but kept a strong inflexible point of student self-discipline and commitment to learning. For Tyler motivation changed as one matured. He believed college students should not be pampered and should be able to adapt to the different teaching styles different professors have (Gen. Int.). The idea of what worked for him should work for others seemed to be maintained all along. In his reflection interview, towards the end of the program, he said "a lot of the stuff that you learn in the university is not going to be terribly engaging unless you are intrinsically motivated. That you want to learn that" (Ref. Int.). Moreover, during our first conversations, Tyler expressed frustration at students (college and high school) for not caring to learn, or else frustration towards teachers that had to "play games" with students to keep them motivated. Interestingly after sharing this frustration, in one of his reflections he also mentioned that every now and then an occasional "fun" thing would not hurt to keep students engaged (Ref. Int.).

Furthermore, in his written reflection he said: "I've learned that I much prefer to teach in smaller, more intimate groups… and that I'm distracted by the inattention exhibited by some students" later he added "I've learned that apathy can be contagious if you let it be…early disappointments in evaluation of the students on material I presented led me to expect less and ask for less…I think this was a mistake that I had to make in order to learn from (Ref. Sta.)." Nevertheless, it seemed like Tyler regretted lowering his expectations for the students. Finally, the following quote provides us with Tyler's perspective on schooling:

> I think,[during my time there was] a little more of an intrinsic motivation to go to college whereas more and more it seems like, it's just what everybody does and it's high school stage two 'cause there's this increasing perception that you have to have a college degree to get a decent job so it's become almost in some senses, almost a little bit high-schoolish (Ref. Int.).

Towards the end of MOSTEP, he acknowledged that some of the activity based learning might be needed to enhance learning. Nevertheless he held a strong position towards students being more self-directed and self motivated learners.

Overall, Tyler's position regarding student engagement and motivation seemed to have been changed throughout the program. Although he kept a strong point of view regarding self-directed learning, he did acknowledge the fact that when he saw a lack of motivation in his students he should have not lowered his expectations. He also seemed to understand better about the type of learning environments he might be interested in teaching in the near future. Finally he acknowledged that sometimes to engage students doing a "fun" thing may not be as bad as he initially thought. However, upon further reflection Tyler said that he felt that "fun/humor was a great way to liven up a classroom, just not a crutch students should learn to lean on." In the end he said that he felt that more fun activities may mean a little more subject matter retention but questioned the cost in preparing students for the realities of a life after school, when the only thing they may get to prepare themselves was a manual.

Student diversity. In terms of having a diverse population in class in Tyler's believed that "there were benefits to having a diverse group [and] there are benefits to having a more homogenous group" *(*Vig. Int.1*)*. For instance, he mentioned that if you had a heterogeneous group in an ecology class, where individual experiences might help students deal with diverse perspectives, it would be beneficial since it will portray what happens in real life. However, he argued that having a homogeneous group would allow a teacher to deal with content gaps easier and have a better understanding of the students' background knowledge: "..if all get this [concept] and none of them get this [other concept], well it's pretty clear what you're going to focus on(Vig. Int.1)." Furthermore in the second vignette interview he also made some comments regarding diverse learners in classrooms. He said: "You know if they're all the same then they're all … moving at the same pace, maybe you can be a lot more efficient at hitting what you want to hit and not have to worry about getting to everybody who's got a very disparate background" (Vig. Int.2). In the other hand he mentioned "…diversity in the class may bring in some things, different experiences, different viewpoints, different opinions that may strengthen it as well (Vig. Int.2)." Tyler also mentioned that if you are taking "a single straightforward approach to teaching in a diverse group, you may lose a lot of people" (Vig. Int.2). Tyler seemed to be reflecting more, as the year progressed, on how to teach a diverse group rather than describing the group per se. Consequently, in the third vignette interview, during a discussion of the implications of diversity, he said "…who the audience is, is gonna sort of dictate what [teaching] approach you're going to take [in class]". These comments provide evidence of Tyler's considerations as to how diversity affects the teaching and learning processes in a classroom.

Summary

In general, Tyler's understanding of student learning theories, processes and factors affecting student learning was varied. For instance, he knew about theories (such as multiple intelligences and Kolb learning styles) and used this knowledge to discuss issues in different interviews. Concurrently, he had an interesting point of view regarding metacognition and knowledge construction. He strongly believed that the best skill a student can develop is an understanding of how he best learns. Additionally, for him it is logical that new knowledge gets added to an existing knowledge framework. Thus, he seemed to have learned (during the program) that understanding the particulars of student's prior knowledge is an important piece of information teachers should have to guide their practice and guide students towards better learning. This was shown by his fixation in correcting students misconceptions regarding concepts in biology that where not black or white but shades of gray. Furthermore, it seems that Tyler's understanding of motivation and classroom engagement is translated in an increase tolerance and acceptance of having "fun" in a class and providing activity based lessons to enhance students participation. In terms of diversity, at least at the level of undergraduate education, it seemed that Tyler considered altering his teaching approaches based on the audience whenever possible. The idea of not diluting the content, and meeting objectives was stressed further upon his final reflection.

Instructional Strategies

Activities and representations

Evidence suggests that Tyler was skillful at creating and modifying practical science activities and representations to enhance student learning. This attribute was observed in many of the lessons he developed: the life cycle lesson, the trophic cycle lesson, the nutrient cycle lesson and the evolution of beak form and function lesson. For instance, in the latter (VSR1), Tyler used household utensils/tools and foods such as:

pliers and peanuts, scissors and cardboard in the form of a carcass, strainers and beans, droppers and colored water, and a nut-cracker and nuts to represent the different beak forms and function within the bird taxa. The shapes of the simulated beaks (tools) were equated to their function such as pulling food (woodpecker), cutting food (carcass eaters), cracking food (parrots) or drinking food (hummingbirds). Another useful representation Tyler used was the example of the "telegraph game" to portray how errors occur as information gets passed on. He used this example as an analogy to how gene mutation can occur when DNA replication happens. In Tyler's words "…that [the telegraph game] was sort of a demonstration of mutation and accidents in replication, and how what you end up with might be something totally different than what you started off with (VSR1)." Tying "errors" during information transfer to variations within a population due to gene mutation and then adding to the mix natural selection was something that Tyler orchestrated successfully. Although some of the activities were not created from scratch, the modifications made to the activities and most of the representations were unique. Also, the connections made to generalist and specialist species based on stomach content, and a supplemental story book activity developed from scratch, were very innovative. Tyler's following comment, when questioned further about the activities, sheds some light on this matter of creativity.

> …things like, you know, looking at the stomach contents, dumping them out on the plate, arranging them in the pie graph, and generalist vs. specialist; that was sort of my twist..." (VSR1*)*

Towards the end of our discussion Tyler shared that: "The point of the activity was to demonstrate: mutation, natural selection, evolution, and speciation" (VSR1). In addition the simulations, representations and examples targeted some critical misconceptions in evolution like the ideas of: populations evolving versus species evolving, mutation being always detrimental and individuals adapting to the environment. Other misconceptions, not related to evolution, were also targeted: like defining a species as generalist or specialist in a discrete (yes or no) manner instead as opposed to a continuous one. Similarly, in the food web activity (VSR2), some of Tyler's creative skills can be further appreciated. For example, he discussed the feeding relationship between organisms with students, and tackled some misconceptions regarding the different trophic classifications and the requirements of resources in relation to animal size.

> I specifically chose that example, where the animal that needed the larger resource base was actually smaller than the animal that needed less…to show that, just because you see something in nature… well, [like] a three pound bird, how much, you know, how much habitat can it really take to support a three pound bird? Well, it can take, you know, a thousand times as much habitat as it does to support a six pound rabbit *(*VSR2*)*

In addition, Tyler simulated a scenario where a top predator, within the discussed food web, was threatened due to habitat loss caused by human intervention. Setting this scenario for the students, questioning them and making them perform calculations while developing an understanding of the implications was a very creative way of integrating what was learned throughout the class.

Summary

Although no change in understanding with regards to activities and representations is evidenced, it is clear that Tyler was able to come up with very creative ways of representing information to high school learners. He not only showed the ability to create innovative and useful activities and representation, but he also showed a level of understanding of the use of such activities. He was able to discuss some of the weaknesses and strengths of such activities as they were encountered in his classroom practices and later when questioned during the interview.

Major methods of instruction

Lecture. Tyler's views about lecturing were apparently changed. For Tyler, lecturing seemed to be a relatively good pedagogical approach where teachers would have the "most hope for impact with the less amount of effort" (Gen. Int.). His experience as a former marine corporal probably had a voice on this view. At one point when he was commenting about Dr. T.'s teaching approach he said:

> …In some ways you come in, clock starts, the lesson starts, you get information all the way through, little bit of discussion and all the way up until the class period is over… and that's the way to do it, and it's up to the student if they're feeling that they're not getting something or feeling that they're missing something to speak up (Vig. Int.1).

He believed that as far as the ground rules are set-up from the beginning of class, teaching in a lecture form should be appropriate.

> As long as the rules are explained, you know, you start the semester and you say hi this is me, this is who I am. This is how I teach. This is what I expect of you. This is what I expect you to do if you're not getting what you need, don't expect me to individually, constantly feel you out for how you're doing (Vig. Int.1).

This comment relates more closely with a teacher-center model than a student-centered one. Furthermore, during a discussion about how Dr T. handled an instance in the vignette, where student were struggling with the idea of counting a population using censuses, he mentioned that, "instead of trying and trying in vain to build them up to something maybe give it [answer] to them up front and have them work back towards [could work]" (Vig. Int.1). The lack of control as to where a discussion might be heading is something that apparently Tyler fears. However, when reflecting towards the end of the vignette (Vig. Int.1) Tyler added that if he had to change the class he would probably start with an example or demonstration where a population plummets or peaks instead of starting with the theory and then investigating the types of curves. In other words, he would use a more deductive approach than a didactic one. Tyler seemed to be sending one message "give them the answer" at the beginning of the vignette and another "make them explore" towards the end of the vignette. When Tyler was asked this same question 7 months later his answer was a little more elaborated.

> Tyler: Maybe he could have started [with] some real live examples, population patterns and asked the students to sort of anticipate the mechanism that might have led them to observe a pattern.
> José: Why do you think this is a good idea?
> Tyler: Just keep harping on inquiry and the MOSTEP stuff… it's been, you know, we've had good discussions, [that] showed how it may be more meaningful, you know, like [the education specialist] says,… [it] helps if you can ask the question first as opposed to just build up from all this boring and inane stuff. And try to get up to where the interesting stuff is. You know, probably not as good an approach as you know, here's something that we see in nature, think about it… And I think it may be [more] rewarding to somebody who's personal guess at how it occurred is close to the truth. So that may be reinforcing for them. You know, hey I was smart enough to sort of anticipate that. And that may make them take some ownership of it and feel like they're good in the area. Somebody who had the wrong idea may feel like 'oh gees I'm an idiot' but they'll have maybe anticipated some previous conceptions of scientists of how this thing had gone about and then being shown how further evidence changed the viewpoint to this [one] instead of their viewpoint... Maybe by them starting with the basics of this, you know, at least they got an impression of why it's this way and they'll understand better

> why it's not that way. And maybe it'll make it stick better. So, I think there's some value to an inquiry-based approach (Vig. Int.3).

First he seemed to be okay with lecturing as far as the ground rules were in place, then he seemed to debate how Dr. T. should interact with his class "tell or till", and finally he was considering inquiry "I think there's some value to an inquiry-based approach". Another change that was noticed was in the video-taped classes. Tyler in his first class started with a 20 minute lecture and then engaged in an activity (VSR1) whereas in the second video-taped class he started with an exploration activity and built the class on top of that, at the same time he reduced the amount of lecturing time (VSR2). When asked why he did this, he said that he wanted to try out a more "inquiring" approach. This is an approach he decided to take based on the recommendations made by other fellows and faculty in MOSTEP during one of the bi-weekly meetings previous to his classroom enactment.

Summary

It is evident that Tyler has gone through change in his understanding of didactic-based teaching as a learning strategy. Some of these changes can be further appreciated when I asked Tyler to give me some pointers during the third vignette interview of how to teach a lecture. In his answer he basically integrated different strategies discussed previously in several of our interviews. Some of the strategies were probably gained during MOSTEP.

> So, what pointers would you give me if I have to teach a lecture?
> Tyler: … For efficiency sake come up with an outline on maybe how it's approached in a textbook… sort of get a framework. Decide for yourself if you think that the progression in which the information is presented is the best progression. If you think of other things should come first or whatever. Try to come up with some examples that complement [the content] and maybe in some ways contrast the examples that are used in the text… Try to think about how you can engage the class more in the process through discussion but also through, I wouldn't necessarily say make your entire college lecture an inquiry-based lecture but maybe try to… put forth some examples of some observed patterns and have the students try to figure out how they would approach [that] figuring out what's causing those patterns. Communicate. Don't let the non-talkers just slide through without participating in the class. Maybe let the students know that this may not just be a lecture thing… that if they want a class where they're going to have the opportunity to be engaged and have a lot of discussion that they need to come to the class prepared... If they're not doing the reading and they're only basing their learning on what happens in your 50 minutes class period well you can't spend a

> whole lot of the 50 minutes just going off on tangents. So if they like the tangents and they benefit from the tangents well they have to do the reading. (Vig. Int.3)

Finally, during the reflection interview Tyler was asked about what practices he thought someone should avoid when teaching. He answered "Lecture, lecture, lecture" he was then asked why:

> Tyler: [Be]cause they [students] zone out, tune out and start thinking about other things. You've got to have the occasional hook, you know something that's supposed to grab them and drive their attention in, um (Ref. Int.)

Questioning/Discussion. Tyler's understanding of discussion strategies can be best appreciated in a three stage process**.** During the first stage Tyler described some of his prior knowledge regarding discussion. For instance, he showed awareness of the fact that not all students participate in the same way. He also said that: "some people aren't talkers and aren't engaged in class participation and if they were forced to be so it would be detrimental to them" (Gen. Int.). He also explained that in smaller classes discussion could be more prolonged, more in depth and even more conducive to learning than larger classes (e.g., graduate vs. undergraduate classes, Gen. Int.). During the second stage we observe Tyler making sense of discussion instances during the analysis of the first two vignettes. For instance, in the first vignette Tyler said that one of the aspects he liked of Dr. T.'s class was how he engaged students in discussions (Vig. Wri.1). No further details in any respect were provided by Tyler when probed further. However, in the second vignette, he became more critical of specific interactions that occurred within the vignette's discussion. Some of the interactions he described as "not conducive". He also expanded and critiqued the idea of students (such as Pedro) monopolizing the discussion, and about Sarah (another student) not speaking up when she had an issue. He criticized some of Dr. T.'s responses to students as being somewhat inadequate to foster a discussion (Vig. Wri.2). Finally in the second vignette he said: "I'm not sure he did a good job of spreading the discussion around to students of different levels but discussion can help to approach an issue from several angles, hopefully "hitting" it in a way that each student will "get it" (Vig. Wri.2). It seemed like Tyler had more things to say during the second vignette than during the first one. The fact that Tyler discussed in more detail certain aspects of the discussion sections could be interpreted as an increase in his understanding of discussion. He showed awareness of some problems in the discussion section that he did not pick up in the first vignette discussion. In the final stage, we can appreciate how Tyler not only critiqued specific sections of the vignette, much like in second vignette, but proposed interesting solutions to correct the flaws he identified.

> So I don't know I would just take that opportunity,[but] instead of looking at her like thinking well "duh," you know it explains itself. You know, he might say repeat the question, [what] does it mean, well what do you think? Do you think the population could grow indefinitely? And then what would be the consequences if that was the case? (Vig. Int.3)

In addition, Tyler said that his recent learning experiences in the classroom had been valuable in shaping his views regarding discussions (Vig. Int.3)

Tyler's three stage reflection process shows an increase in understanding of discussion strategies. This is observed in how his thoughts and solutions regarding the vignette analyses become deeper and more thoughtful towards the end of the MOSTEP program. Caution needs to be taken with this assumption since being exposed several times to the same stimulus could have given the same result.

Inquiry learning and other teaching strategies. Evidence suggests that Tyler's knowledge about inquiry-based learning changed. Tyler is one of the fellows that expressed early concerns, during one of our bi-weekly meetings, about students "playing" in class instead of learning the content. This comment was made while a discussion about inquiry was being held. It is interesting to note that inquiry or inquiry-based instruction is not mentioned at all by Tyler during the first interview interventions (Gen. Int.1, Vig. Int.1). The first time inquiry was mentioned in one of our interviews was in the form of a hurdle. Tyler had difficulties accepting inquiry as a good strategy because it seemed like he had little or no control of what was learned. He said during one of our discussions that inquiry was not an advantage because he was not 100% certain that "his point was getting across and assimilated". He added: "[so you] kind of having a little bit of faith in osmosis… in that you just put enough stuff out there and they're absorbing it whether they know they are or not as long as they're awake they're hearing it (VSR1).". However, in looking at the lesson he prepared for this first class it was evident that Tyler tried to incorporate inquiry based activities into it. Yet during the lesson he reverted to providing answers to students rather than fostering inquiry.

In his second class, (Video2) Tyler also included some inquiry-rich activities. The difference was that this time he seemed to be more conscious as to how he was asking the questions in order to avoid telling students the answer. Although in practice the process was not seamless, one could observe the changes occurring. The following reflection sheds some light as to how Tyler's thought process of implementing inquiry in the second video-taped class occurred:

> Tyler: It's sort of building in that inquiry piece,[that] is the main reason I did it. I sort of started to put it together in just a way that was logical for me, and that went right into introducing the food chains and stuff. And then I thought about [the] discussion about the bird beak evolution thing that we had done before, and in one of the MOSTEP meetings, it sort of described what how it went. And then on of the PI's said, "Well, don't you think maybe it would have been better if you had done the beak exercise (Video1) thing first, and then had them develop the questions in their head, and then gone to… the information to explain why there are those differences and how they affect things, to make it more of an inquiry based thing?" So, I sort of echoed [that] in my head when I was starting to do this. So, okay, well, how about taking the interactive part of it and trying to put it in first? So, this was sort of my concession to making it inquiry-based, as to sort of instead of giving them all the information and then having them do what they should with it, give them just some stuff… and then maybe some questions will pop up in their head while they're doing it, and maybe that'll make it a little more sticky up here [in head] *(*VSR2*)*.

Tyler's reflections related to inquiry as described in this comment seemed to have allowed him to come up with a framework and lesson that was more inquiry oriented than the first one.

In other stages of our conversations some interesting aspects of inquiry were further discussed by Tyler. He discussed the issue of coverage and knowledge retention as related to inquiry and lecturing approaches.

> I think there's a lot of value if it can be done in a way that you're still able to cover the material you need to cover. It seems like the inquiry-based stuff, you know if you've got 100 units of material that you've got to squeeze in and you can barely do it within the class period. When you've laid it out very clearly, objectively and outlined boom, boom, these are the points. An inquiry-based approach is going to be a lot more scattered and not as efficient, and not as focused. And while it may, what you do cover, may stick a lot better with the individual you may not have the time to cover the amount of material you would cover if you took a straight forward, here it is approach. So, I think there's a bit of a trade off there in how much information you're going to get across and how well the information is going to stick. (Vig. Int.3)

Additionally, seven months later, Tyler commented again on this topic.

> If your objective is to build a healthy mature adult who is comfortable with taking on a part of the world, that has no experience with, and becoming confident … and find ways to amass knowledge without being just spoon fed and everything, then inquiry-based is a better way to go. *(*Vig. Int.3)

In a way this perspective on inquiry, of students becoming more confident and looking for ways to learn without being "spoon fed", is in correspondence with what Tyler claimed should be the objective of student formation in high school. More interesting, is the fact that Tyler seemed to have been struggling towards implementing and learning as much as he could about inquiry. The following quote sheds further light on this matter.

> …So while I do try to get a lot of information across, and try to do it in a way that's more, I can't say I've really been great at coming up with inquiry based approaches to things, I've tried to do it at least in a more engaging and holistic manner as opposed to just getting people to memorize terminology. (Vig. Int.3)

In retrospect being able to articulate some of the strengths and weaknesses of inquiry-based learning, contrast the strategies advantages and disadvantages against other strategies (like lecture), and at the same time showing predisposition towards implementing inquiry in his practice shows a higher level of understanding about inquiry and lecturing.

Summary

In summary, Tyler perception on inquiry-based instruction changed. Initially he believed it was an abstract, "not-so-useful" teaching strategy. Towards the end of the program he considered it a strategy that would help develop individuals' thinking capacity in multiple ways and prevail longer in their cognitive schemas. However, he believed that inquiry-based approaches were more time-consuming and could limit how much information a teacher could convey to his students.

<u>Summary of Major Methods</u>

I think that the following two reflection made by Tyler provide further evidence of his overall change regarding the different major teaching and learning strategies. In relation to inquiry and lecture Tyler said:

> "… some of the stuff that I started out with was sort of little bit lectury with then more activity based and then I tried the lecture stuff again and go back more

> towards the activity stuff so you know, maybe, maybe my, one of my changes might be to recognize both approaches [inquiry and lecture] are important at [any level] Ref. Int.)

In relation to critical thinking and discussion, Tyler said that one thing he wanted to achieve towards the end is to have "the kids to actually critically analyze what's being said and told to them…and if they don't agree with something to say so and get the discussion going…" (Ref. Int.).

Communication techniques and strategies

From the beginning Tyler highlighted that one of the most important qualities of a good teacher was being able to communicate at an 'appropriate' level. In Tyler's words, a teacher should be able to convey information in a way that does "not fly over everybody's head" (Gen. Int.). In both video-taped lessons it can be observed that Tyler was consistent with this notion. He tried to take students step-by-step through a logical flow of the concepts, while he read from his notes. The enactment of the lessons (Video1, Video2) and the lesson plans (LP1, LP2) showed clarity in the delivery of information to the students and most important, the material was presented at a level appropriate for audience.

Questioning strategies, verbal and non-verbal communication. In terms of questioning strategies, Tyler was fond of asking questions that he believed encouraged critical thinking. The questions that he would raise would be related to controversies in the subject area like challenging definitions such as specialist or generalist. For instance, while reflecting on one of the vignettes (Vig. Int.1), Tyler mentioned that if he were to teach an ecology class similar to Dr T's, he would focus on "even more discussion time… to really build the concepts". Additionally he said he would ask questions like:

> How would you build an experiment to test this? Or what other things [variables] do you think make this work? [or], what other concepts do you think might negate this [hypothesis]? You know, okay we've got this, what about competitive exclusion principle? (Vig. Int.1).

The kind of questions raised in this conversation are not necessarily specific to a biology content area, but they are questions that invite the audience to challenge the information being delivered or the information they already have in critical ways. On other occasions, like in the second video-taped class, Tyler challenged students by questioning them about trophic level classifications. He asked questions like: "Are we primary consumers or secondary?" and "Where do humans fit as an omnivore (secondary, primary consumer)?" He also used this approach when he talked about species being generalists or specialists (VSR2). During past enactments limited evidence was found about Tyler trying out this questioning approach, for instance in the mutation and telegraph game error analogy (VSR1), he explained the relationship but did not ask students questions to help them come up with an explanation. Finally, a similar idea of asking controversial questions was observed while discussing species interactions:

> And being able to say you know okay in this situation this comes on, this goes on and this goes on. Is this is mutualism? You know is this always a mutualism? Is it, you know are there any cases in which it wouldn't be, being able to answer that sort of question is more to do with understanding" (Vig. Int.3).

Overall it seemed like some of Tyler's questioning strategies were tightly related to creating critical thinking moments for students. At a more specific level of understanding of questioning strategies, evidence suggests that Tyler had some knowledge about certain practices and about certain non-verbal and verbal cues as related to questioning strategies. These ideas have been grouped, and relevant quotes have been added to each group as evidence of Tyler's claim:

Guiding students to an answer through questioning. For example, he talked about guiding students towards the understanding of mutation as a beneficial error. In reality he told them about this, but he did have the idea of guiding them.

> And things like when you hit a scientific name and you know… hey [in this case] where have you seen these, parts of this word [mutation] before? What word do you know that maybe sounds like that? What do you think that words means then based upon that or you know have you ever done this and like talk about mutation? Yeah mutation is usually bad but have you ever done anything accidentally and then found out that it worked? … Well that's sort of how mutation can work. It's an accident that, most accidents are bad but sometimes… you accidentally do something that's actually even better that you were trying to do (Vig. Int.2)

He does something similar during VSR2 when talking about animal diets and trophic levels.

> Sometimes, people will ask just a really inane question, that the answer to that question is really meaningless. But if you can find some way to use that answer to get into something that is meaningful, you know, what does this animal eat? It

> eats this. Okay. Now I know what that animal eats. That means nothing. But this animal eats this, which is specialized to this sort of habitat, and that's why it's got these adaptations to get that, and that's why this animal is endangered, because that food resource is, you know, so sort of try to twist their questions to what I want them to know, and not just what they wanted to know (VSR2).

Although Tyler does not explicitly mention the use of questions in the above quote, this notion is implied. Guiding students towards understanding is something Tyler talks about, but it is evident that it is not always clear cut for him how to do this (VSR 2)

*Encourage students to answer questions***.** In terms of encouragement, Tyler argued that Dr. T. did not communicate effectively. He said that he actually discouraged Pedro during the census sampling discussion in the third vignette. He stated that Dr. T. did not explore Pedro's thinking, instead he said "no that's not it, boom". So for Tyler's Dr. T. could have gone back and said "…what Pedro said about this [is a] representative sample... And… while it wasn't what I was looking for at that time it was an important thing to understand about how a sampling is done and you know that sort of thing" (Vig. Int.3). This sort of approach is more inviting for participation. A similar problem is explored during the discussion of exponential growth being indefinite in previous yet it is not discussed by Tyler during the first two vignettes.

Using questions to bringing forth prior knowledge and help students articulate their ideas. In this case he tried to bring ideas from the beak activity to acknowledge a few points about food resources and feeding. When asked if he did this often Tyler responded:

> I try to do it often, but I don't know if I do it often enough. It's something that I think is important. Especially when I'm coming up to I'm about to use a word that I know they've heard before, because we've done it, you know, previously. (VSR2)

Tone of voice. When discussing some of the non-verbal cues Dr. T. was sending. Tyler made the following comment.

> Tyler: A lot of things I think… are nuanced, you know just the inflection in a voice when a question is asked, is it playful? Is it demanding? Is it you know, is it friendly, or is it confrontational?
> José: Do you think that's important in a teaching learning environment?
> Tyler: To a degree. I mean I think you've got to not do things in such a way that they're going to get people to shut down and be afraid or feel too much pressure, or something. (Vig. Int.1)

How things are said. Tyler acknowledged that Dr. T. was "combative" in his evolution approach when communicating with his class (Vig. Int.2). He wrote in his first reflection:

> Disliked: "Like it or not" comment, without framing the arguments and addressing the differences in scientific and spiritual approaches…prompting Pedro's last comment… It seems like a pretty brusk and insensitive way of approaching a topic which has been sort of something we've been discussing a lot. (Vig. Wri.2)

Non verbal cues. He seemed to use this as a form of formative assessment to determine if students are getting the information or not. In this case he talked about giggles.

> But, the fact that they did giggle a little bit when I said the mating thing, you know, I figure that might bring, bring some giggle from high school students. So, you know, that might be evidence that they were listening, but aside from that I really have no (VSR1)

Or in the form of blank stares,

> Quote: Tyler: Well, obviously I looked around and nothing but blank stares and no nobody even thinking about answering, so kept it moving on. And, you know, I didn't feel like I'd given them any sort of background or basis to give me the right answer either. (VSR2)

Or in the form of in-activity as in the beak activity when students that simulated specialist animals were waiting for the right resource.

> Tyler**:** Well, I'm keeping in mind the points that I wanna make and, you know sometimes, I judged which feed I was going to do next based on the looks of disappointment on the face of the poor animals that had a beak that was useless for anything else and sitting there with an empty stomachs. So, I was like, okay, I'm going to bring out the cheerios now so that the strainer beak can feel okay, you know. (VSR1)

Many of the non-verbal cues were described by Tyler as a type of formative assessment. The majority of these reflections occurred after 3 months in the program.

Summary

In terms of communication strategies, the following reflections provide evidence of Tyler's change in level of understanding of the importance of communication and how the experience may have altered his own personal skills. He perceived that "the experience helped him, as a scientist, to be able to better communicate with non-scientists" (Ref. Int.).

Transfer

Evidence suggests that at a very basic level some of the gained knowledge of PCK had potential to transfer to a higher education setting. For example, when Tyler was asked if he could use his beak evolution activity in an undergraduate setting, an interesting conversation developed. Among the things we talked about were: student maturity level and the appropriateness of using activities, like the beak lesson, with college students (the activity being viewed as fun by Tyler). We also talked about the fact that college students seemed to behave more like high school students and that some only wanted to bargain a grade to be accepted into pre-med later on. To this Tyler added "I guess I am digging my heels in a little bit in having old expectations of a college education." At the end he added that, if a game were to be involved "maybe this game needed to be on the lines of a math-oriented game or something a little more thinking and analytical than fishing for cheerios out of a fish tank" (VSR1). When asked how he would teach his second video-taped ecology class (i.e., trophic cycling lesson) in an undergraduate setting, he seemed to be more convinced that it could be done but offered a few additions.

> Probably not very much different, with the exception that I'll expect them to be coming in with more, I'll probably ask for a little more anticipation from the class, and not shy away from technical terminology and more advanced concepts. Maybe expect them to, you know, project consequences of changes further down the road (VSR2).

Being reluctant at the beginning with his first class and then a little bit more open with his second class could be an indication that Tyler is willing to accept that some ideas regarding teaching and learning could be transferable to another context. However, it could be argued that his inclination towards adopting one activity or the other could be more related to the degree of similarity among the tasks done in each activity and what he expects from students at a college setting.

When asked how he would teach the topics of natural selection and evolution, one of the first things Tyler commented was that he would find it "…hard to put together a lesson plan on the spot." Then he added

> I guess I might do it like I did it [in high school class] … I think broadly, find out what the knowledge is, find out what the misconceptions about the subject matter are. I think if you just take, these misconceptions and you just say what it is without specifically addressing why those misconceptions are misconceptions. They may still keep them. (Vig. Int. 2)

While is not a final indication of what Tyler would do when teaching evolution at an undergraduate level. It can be argued that he is drawing from his experiences in the high school environment to consider alternatives about teaching a future college class.

Furthermore, when discussing some of the teaching dynamics in Dr. T.'s class Tyler was asked why he had focused more on the specific questioning parts of the vignette, given that he had not focused in these sections before.

> Probably just because of my recent experiences in the classroom and you know knowing that it's, when, it's sort of a disequilibrium between this [college setting, Dr. T.'s class] and what goes, what I got experience in the last several months too… But… maybe some of the college students… are still basically just high school students. … Maybe some undergraduate students do need to be treated a little more like high school students to a degree but I think they need to be weaned of that pretty quickly though (Vig. Int.3).

Again we observe Tyler making comparisons between high school and college by pointing at the fact that college students nowadays seem to be more high "schoolish" than in the past.

Later I asked Tyler if he paid more attention in his graduate classes as to how the instructor teaches.

> … I do pay a little more attention now to, you know, how is this information coming across? Is it being spewed out to be transcribed onto notebook paper and taken home to read and memorize. Or is it being, you know is it more engaging and asking you to you know predict certain things and stuff. And so I think I do take a little more look at that sort of thing. (Vig. Int.3)

Finally, another interesting moment of transfer can be appreciated in Tyler's comment regarding pointers he would give me if I were to be teaching my first lecture.

> …Maybe come up with some, try to think about how you can engage the class more and in the process through discussion but also through, I wouldn't necessarily say make your entire college lecture an inquiry-based lecture but maybe try to like I said, in the response maybe put forth some examples of some observed patterns and have the students try to figure out how they would approach figuring out what's causing those patterns. Communicate. Don't let the non-talkers just slide through without participating in the class. (Vig. Int.3)

Considering the potential to include inquiry-based strategies, or the idea of managing a conversation and guiding students to an answer, shows that some of the ideas commented previously by Tyler seemed to be now considered as options if he were to teach in a college setting. The potential for transfer of some of the teaching and learning concepts is present.

Summary

Tyler had a very strong feeling that university teaching should be more content oriented and less about motivating students. He believed students needed to be the ones responsible for their own learning. This is a message that he constantly sends when engaged in discussions with me. He also said that one can do this while engaging students but that "a lot of the stuff that you learn in the university is not going to be terribly engaging unless the student was intrinsically motivated" (Ref. Int.). When asked a direct question as to the applicability of what he learned to an undergraduate/ college setting he said:

> I think, you know, I think [that with] university students, it probably wouldn't hurt anything to do the occasional fun thing, to, you know, engage and take a break from the, from the powerpoint and do something that you know, involves some interaction. I don't know what it would be and how you would do it in what class but… *(*Ref. Int.*)*.

Even towards the end Tyler does not seem convinced of the potential applications of some of strategies the learned in the program. In summary, as Tyler concludes when asked if he thinks teaching looks different in university than a high school, he said:

> Well, from the standpoint of knowing your class, knowing what they need, knowing how to get through to them, interpreting the dynamics between the classroom and the teacher and making, having the flexibility to make the changes necessary to see that what you are trying to do gets across to the student from that standpoint I'd say they look the same but in the inside, if you are looking at the mechanics of it. From the outside how you go about doing those things might look different because, theoretically at least, the university students are going to be a different type of student than the high school… I think, if we are saying that the good teaching is knowing your classroom, knowing what they need and knowing how too get it to them and having the flexibility to do so then, from that stand point I'd say it's the same. (Ref. Int.)

Potential Sources for PCK

In this section I offer examples of instances that provide explicit and implicit information of sources for Tyler's development of pedagogical content knowledge. Again I rely on Grossman's (Grossman et al. 1989) frameworks for sources of PCK as a guide and narrowed the analysis, for convenience purposes, to two levels. One level corresponds to those instances outside MOSTEP that could have affected Tyler's PCK, and a second level corresponds to those instances within MOSTEP that could have influenced Tyler's PCK. At each level evidence of using Grossman's outline: apprenticeship of observation, content knowledge, teacher education, and teaching experience could be appreciated.

External to MOSTEP

Outside MOSTEP. The following experiences seemed to have influenced Tyler's development of PCK: a) undergraduate/ graduate student classroom experience; b) Military experience; c) reflection on his own learning; d) teaching in informal settings and; e) intuition. I have outlined a few examples on each of the area to support these claims.

As a college student, Study groups, teachers in undergraduate setting and graduate setting seem to have influenced Tyler's understanding of teaching and learning. For example, Tyler shared that an ecology professor said to him that high school was suppose to teach someone how to learn, college (undergraduate) the basic knowledge and graduate school to think critically about this. Evidence throughout the different sections shows this stance clearly. Other examples that seemed to have an effect on Tyler's approaches regarding communication effectiveness and motivation strategies probably came from three different college professors. Two of the professors, according to Tyler, were able to communicate clearly, precisely and in simple ways very complex concepts. In retrospect this is similar to how Tyler approached breaking down complex concepts for his students when teaching trophic cycles and evolution of beaks (Gen. Int. ~13:00).

Experience in the military. Many times Tyler quotes his experience in the military to provide ideas like: "students should be responsible of their own learning" and if something is not understood "it is their responsibility to do something about it" (Vig. Int.1, 2 & 3). He says at some point during: "the rock hard ex-Marine in me wants to say, you give the information, you give the exam and if they didn't get it before the exam, it's their fault." (Vig. Int.1).

Reflection on his own learning. Games from his childhood allowed Tyler to put together an activity of mutation similar to the telegraph game (VSR1). Self reflection as how he learns best also seemed to be a source of PCK. He shared: "…as a student, when I'm learning something, if I'm given a new piece of information and that I, by connecting that to something else that I already know makes it stick. You know as opposed to just working on it (Vig. Int.2 and 3).

Teaching informally. The idea of learning styles and multiple intelligences was presented to Tyler through his museum courses and zoo educational program implementations (Gen. Int.).

Intuition. Sometimes when I asked Tyler where did he get some of his ideas about teaching and learning? he said that he suddenly recognized that something worked in a particular way and that he also had ideas of his own. For example, he said "I don't recall ever hearing anybody espouse a theory of you know this is how examples are effective and not effective and then I've taken that idea as my own" (Vig. Int.2). He also talked about teaching things in a certain way because for him it just seemed "illogical not to" (VSR2). He called it "Personal introspection and observation." (VSR2).

With in MOSTEP

Within MOSTEP. The following experiences seemed to have influenced Tyler's PCK: a) other fellows; b) education specialist; c) MOSTEP mentors; d) the researcher, and; e) teaching in MOSTEP

Other fellow's. Tyler commented that he worked very closely with one fellow that was in his second year and he learned from this fellow some strategies like pre/post assessment and prior knowledge considerations. Another instance was when a fellow talked about teaching evolution: "I do like, I think it was a fellow who pointed out how you can say yes it's a theory but point out that it is an almost unanimously consistent theory which has been supported by the greatest minds in the last thirty years in science (Vig. Int.2)."

Educational specialists. Tyler mentioned that part of the fact he tried changing his approach when teaching the evolution of beaks came from a comment one of the scientist made about teaching the class in reverse order to what he proposed (VSR2). In another conversation, previous to this one, he acknowledged the proposed lesson plan for the project but not understanding the theory it. He also talked about how to improve on Dr. T.'s teaching by using some of the strategies the teaching specialists shared with them (Vig. Int.3)

High school mentor. He points out that his mentor debriefed with him at the end of his classes "he points out what he thinks works well and where, you know, maybe where some points were lost… usually 75% good things and 25% things to improve" (VSR1). He also encouraged him to do less talk-chalk and to add some activities; hence he produced the inquiry lesson. In addition his mentor seemed to encourage him to use a pre-test to evaluate prior knowledge (VSR1). He also said that his mentor helped him to change the feeling that "Oh my God it doesn't seem like everybody in this class is learning everything I'm trying to teach and, and I'm a failure and this is useless" (Ref. Int.). Finally the following reflection depicts Tyler's feeling about the impact his mentor made: "My [mentor] provided guidance without interfering with my autonomy. He allowed me to teach to my interests, and provided prompt and constructive feedback. He steered me away from some pitfalls, and allowed me to experience others. He shared his wealth of experience freely; he commiserated with me when I hit the bumps in the road, and helped to guide me more smoothly over them" (Ref. Sta.).

Reflections as a result of the research process. Tyler shared that the fact that he had to reflect and then communicate both verbally and in written form his thoughts about the different instruments and video instances helped him to develop understanding of aspects of teaching and learning (Vig. Int.3). Other times, Tyler, asked for my opinion on certain teaching and learning matters. Most of the times, I shared my views at the end of our interview if reminded (VSR1). Similarly he acknowledged that talking about his own teaching helped him understand things about teaching and learning a little better (VSR2).

Teaching in MOSTEP. He was asked if he drew some of his answers from his high school experience when talking and debriefing about the vignette. He said that he did a little bit (Vig. Int.1)

Summary

Overall, Tyler perceived himself as someone with more refined tools to teach. He makes the following analogy: "I just kind of went in and sink or swim and I did the dog paddle and became a little bit strong swimmer" (Ref. Int.).

Alex

Background

Teaching and learning. Alex shared some insightful opinions and anecdotes of his past experiences regarding teaching and learning. Alex, unlike Chris and Tyler, was already involved for a year in MOSTEP before the main data collection for this study was gathered. It is thus expected that his level of understanding regarding pedagogy was different. This was evidenced by some of the conversations we had during our initial interview. It is pertinent for the reader to take into consideration this fact. The descriptions provided in this particular section account for the time before Alex joined the MOSTEP program. The idea was to generate a plausible baseline with regards to Alex's initial understanding of teaching and learning.

From a student perspective Alex mentioned that, when he was a student, he liked teachers that engaged his interest in the subject by helping him ask questions (even if he had none) rather than being told what to ask. He also appreciated a well structured and organized lecture (Gen. Int.).

From a teaching perspective, Alex began his teaching career as an assistant teacher in a park education program. Additionally, his teaching experience with MOSTEP was the first time he taught in a formal school setting (Gen. Int.). Moreover, he said that he "always had the patience and desire to teach others about topics that he was interested in" (Gen. Int.). When asked which areas in biology he would not feel comfortable teaching, he explained that he could teach any area if provided with enough time to prepare (Gen. Int.).

Motivation to join the program. Alex joined the program because he liked the opportunity of being part of a multi-level collaborative program (i.e., University teachers, high school teachers, graduate/ undergraduate and high school students). He also emphasized the idea that for people to have a better understanding of how a public school system works, they should work in one. He added: "I think it will be a real eye-opener for people to see what students and teachers [do], and how public education is being carried out (Gen. Int.)." Interestingly, when asked about the potential of teaching, Alex embraced the idea of teaching in academia but mentioned that it would be very unlikely for him to teach at a public high school.

Pedagogical Content Knowledge

Assessment

Alex showed advanced knowledge of the different types of assessment teachers use to evaluate student performance. Beyond the typical assessment instruments- multiple choice questions, short answer questions, essay questions, writing research papers and end of topic tests- Alex described other forms of assessments. Some of these forms were in class questions (e.g., informal checks, such as group or class questions and one-on-one questions) (Gen. Int., Vig. Int.1, Ref. Int., VSR1, VSR2), pre/post assessments, hands-on assessment (e.g., making students do a transect as part of demonstrating understanding of the process of making one, (Gen. Int., VSR1, VSR2)), small group projects, homework assignments and journaling (VSR2). Most of these assessments were mentioned within a high school context. Alex also used words such as formal assessment, (Vig. Int.3), and a student-based assessment (VSR2).

Furthermore, Alex's understanding of the various types and uses of assessment was firm. Regarding the topic of questioning, at a one-on-one level, Alex said this kind of questioning "…can tell you how much they [students] know,…which students are doing fine and which students are really going to need a lot of help (Gen. Int.)." Additionally he explained he used informal assessment, specifically group questioning to "check for student understanding" (VSR1 and VSR2) on the concept being taught. Two examples of this type of questioning were observed. The first occurrence was when he questioned students to check their understanding regarding the concepts of sugar classification (i.e., mono-, di- and polysaccharide, VSR1). In the second occurrence, Alex used the same method to question students about endemic and invasive species (VSR2).

Similarly, Alex used the idea of 'checking for understanding' to criticize Dr. T., the teacher in the vignette exercises, for not taking "more time to assess student's understanding before moving to the next topic" (Vig. Wri.1 and Vig. Int.1). He explained that Dr. T. should have questioned students more often during the class instead of putting the burden on the students. In the same way he pointed at his lack of action. "I think that he [the teacher] should begin by having students tell him what they covered. This will allow Dr. T. to assess how much students remember from the day before" (Vig Int 3). This 'check for understanding' using one-on-one and group questions seemed to be an important and valuable idea for Alex.

Moreover, Alex mentioned that he used these types of informal assessments to gauge prior knowledge, and simultaneously engage students in the current discussion topic. For example, he mentioned giving students a set of questions at the beginning of class. When asked to elaborate on this he said: "It wasn't really a test. It was just kind of a few questions to see what they knew… it was just interesting questions about, how long is DNA or which of these organisms have DNA…" (Gen. Int.). He also mentioned using in-class questioning "to level up students and bring them up to speed in terms of the concept that was going to be dealt in class" (VSR1).

Additionally, he used these same approaches to challenge students' prior knowledge. For example, after the penguin classification lesson when Alex was asked to comment on his classroom dynamics, he said:

> They were all going to be grouping [penguins] based on how they looked. I already knew that … but I wanted to readdress the point, 'Okay, so let's look at it a little more closely. How [do] they look, well, what do you mean by how they look? Why is this group different from this group? Why aren't you putting this penguin in that group? (VSR2).

The different ways Alex uses this particular one-on-one/group questioning assessment strategy to determine or challenge students' prior knowledge, shows advanced understanding of assessment. Moreover, recognizing that he is doing this purposefully is further evidence for this change in understanding.

Despite the fact that the previous analyses focus exclusively on how to use in-class questions to understand student learning, Alex also acknowledged how he used this type of assessment to evaluate his own teaching. For example, he evaluated his effectiveness in communicating with the students and used what he observed (student responses) to guide his teaching (Ref. Int.). Although Alex was not familiar with the term formative assessment he did show articulate knowledge of the value behind this form of assessment as shown by the above dialogues and his multiple perspectives on how to use this type of assessment.

Alex seemed to also be familiar with pre/post assessment. Although he did not seem to use this strategy often, he shared how he had used it in the past. He explained that he used it to learn how much students gained from an activity, like the penguin classification lesson (video#2). In this particular activity students were asked to classify penguins at the beginning, using their prior knowledge and ideas; re-classify at the middle using morphological traits; and then at the end using DNA sequences. A second way he used pre-questions was to get students working on something while he was handing out the materials. This was usually a set of questions that focused and introduced the topic that was to be discussed during class. Later he used similar questions to see how much students had learned. This idea complements the idea of engaging students discussed earlier (VSR1). Finally, when discussing pre-questions, Alex's points of view corroborated his understanding of how to use and why to use this type of pre/post assessment instrument (Vig. Int.1, Vig. Int.2 and Vig. Int.3).

Alex also mentioned journaling as a way of assessing student learning. Alex had his first experience with journaling when he graded students' journals for his mentor. He seemed very comfortable discussing the dynamics behind journaling, the importance of providing feedback to students using the journal, and making sure they knew what was expected of them through the use of rubrics (VSR2). In addition, he mentioned that a bigger goal behind journaling was "for students to achieve better writing skills" (VSR2).

Finally, Alex was also the only fellow that provided rubrics in his lesson plans as part of an appendix component (LP#1-#4). Alex used it quite a bit and later he explained that it was completely his mentor's influence (Personal communications, April, 2006).

Beyond the understanding of types and uses of assessment, Alex demonstrated a level of integration between assessment, the context and the student. Some of the following discussions shed light on this matter. For instance, Alex was questioned during his class on invasive species why he showed the students how to graph the population of goats and hawks instead of letting students figure out the scale and learn from their mistakes. He answered: "I really wanted them to be able to do it. I wasn't testing them on graphing. I was testing them on being able to interpret this information and come to these conclusions which they can't do if they don't do the graph right" (VSR1). Alex had a very clear goal of what was intended of the student and how the assessment would provide that information to the teacher. Additionally, when talking about homework assignments, he was well aware that in his particular context it would be rare for a student to complete work at home.

He acknowledged that one of the hardest things to do was develop assessments for his students that "would keep their attention during the assessment." He added "… when you put a [number of] pages of questions in front of them often times they are just going to get spooked and stop thinking" (Gen. Int.). Finally, when asked how he would assess student understanding during a food web lesson, a case question during our general interview, he shared a variety of ways that he would do this.

> I think it will be good to do some sort of activity were they have to make their own food chain and food web Um either with given different organisms and what their relationships would be and also by being able to identify what is the primary consumer, secondary consumer, third, you know, top level predator you know things like that.- So being able to apply the terms that they have just learned. What does it mean that, you know, which ways will the arrows point and things like that. Or what does that mean [pointing at multiple arrows directed to one organism] what does the arrow refer to (Gen. Int.).

Being able to articulate answers like the one above, or showing sensitivity towards the complexities behind the actual delivery of an assessment exemplifies a good level of understanding about assessment.

Finally, Alex talked of assessments as an intricate and very important guide for curriculum development. The curriculum development model adopted by Alex's mentor and in general his school district (UBD, Wiggins and McTighe) followed a backward design model which started with goals and the development of the assessment items. This in itself is something that Alex learned by his experience in the allocated school.

Summary

Although data for Alex's first year was not collected, follow up conversations with him corroborated that he knew very little about the diversity and specific uses of assessment before MOSTEP. He also acknowledged that, initially, for him assessment was basically an end of unit test and a grade. Yet given the evidence I would argue that Alex's overall conceptualization of assessment changed.

In general, knowing about the different types of assessment is basic knowledge for most people. But, knowing how to use the different types of assessment, knowing about the problems you might run in while using different types of assessment and how these assessments interact with the context they are being implemented in, demonstrates expert knowledge about assessment. This level of understanding was shown by Alex and transpired from our different interviews and artifacts. Moreover, the change in the frequency of 'informal checks' (formative assessment) as well as his in-depth explanations as to why he would use one type of assessment, is further evidence of his understanding of assessment. This expertise is further reflected in his knowledge of how assessment was affecting his teaching and student learning at the same time.

Curriculum

Alex's knowledge about curriculum changed. At the beginning of the program he believed that a curriculum was the content to be covered in a particular subject. After his first year, and towards the middle of the second year, this notion seemed to have changed and fine-tuned to a more elaborate one. During one of our conversations about methods of teaching, Alex mentioned that he understood a little better the Understanding by Design (UBD) model used by his mentor to develop curriculum and lessons. He also mentioned that he was aware that assessment was an important component of it and that the UBD model was based on a "sort of a backward design [curriculum development] model that helped them put together the lessons and/or the units in his class" (Vig. Int.2). The idea behind UBD and backward design was completely embraced by Alex. As a matter of fact, the lessons he developed for the project were made first by using the UBD format and then were transferred to the project's proposed format. The following excerpt highlights the degree of understanding regarding this curriculum building model for Alex.

> I am more familiar with that method [UBD] than [any other]… So much is intuitive for me now, that I don't really look at it and say I would choose this over doing this a different way because… if I want to get a point across, to teach a lesson, it just seems that there is a toolbox in my head… that there is appropriate ways of doing it and appropriate ways of not doing it… (Vig. Int.2).

Evidence suggests that Alex had a good grip of the importance for classes to follow a logical content sequence. On several occasions, when challenged as to how he would teach a certain class, or change something taught by someone else, Alex shared thoughtful comments of how to do it. Most of his comments had a rationale, and showed logical steps towards achieving his goals. For example, when asked how he would teach an ecology class in an undergraduate setting, he said that he would start with a good definition of ecology, then move into application of ecology and finally link the topic to environmental problems (Gen Int). When challenged again he added to his initial remark that he would take into account the students' prior knowledge. One way he said he would do this was by brainstorming with the class, then asking students questions, while considering the importance of ecology (Vig Int 1 & 3). A second example that sheds light on this matter occurred when challenged as to how he would teach an evolution class. He shared that if the unit was evolution, he would start with the history of evolution and the scientists behind it (Darwin, Lamarck, Wallace). He would then move to the evidence, then natural selection, diversity and differences in organisms. Alex claimed that this previous approach was probably driven by how his mentor taught the actual evolution class (Vig. Int.1). Alex also believed that evolution had to be integrated into the entire curriculum, be it a high school or a college curriculum.

> I think you almost have to teach them evolution before they know they are learning about evolution, and I think evolution would have to come out later [as a unit] in any sort of curriculum. They [students] have to have some basics in genetics, molecular biology, ecology and things like that, before tackling evolution as a concept. And I think you have to integrate evolution into all your [entire] curriculum. Whether you are teaching about cells or you are teaching about organisms, you have to integrate parts of evolution. So for instance when you are in molecular biology you would talk about… adaptations among bacteria and how antibiotics resistant strains are coming out. You don't have to call [it] evolution but you talk about that concept [while you] study the organisms (Gen. Int.).

In addition Alex led a group of fellows into the development of evolution plug-ins[10]. Developing the idea of such a tool provided further evidence of Alex's

[10] Evolution plug-ins were basically short activities that were meant to be 'plugged into' a life science curriculum to make the link to evolution visible to the student and the teacher.

understanding of content relationships throughout the curriculum at least for the topics discussed.

In terms of content scope, Alex developed some sensitivity as to the amount of content one should cover during class. Oftentimes Alex mentioned that the first two classes he taught in his high school served as a gauge to realize how much content/material needed to be cut off the lesson (VSR1, VSR2). Alex said that at the beginning of the program cutting materials seemed to be more prevalent than towards the end of the program (Personal communications, 2006). Alex seemed to become better at gauging how much he should cover in a particular lesson as the program advanced. This sensitivity towards too much content trickled to his analysis of vignettes. During the vignettes he argued that Dr. T. covered too much material in one class. Alex mainly argued about this coverage issue during the last two vignettes. He said things like: “A lot of difficult content... It is inconceivable that he was able to cover it [all]” (Vig. Int.2) or “He covered a lot... And he never goes into how this relates to the previous day” (Vig. Int.3). Not only did Alex critique coverage issues, but also linkage issues between concepts within a curriculum.

In terms of knowledge of goals and objectives about teaching and learning, Alex always had a goal and objectives in mind when teaching and planning each lesson. For example, during the lesson on invasive species (LP1, Video1), one of his main goals was for students to learn how to analyze data in the form of graphs. “I wanted them to get practice looking at data, just raw data, and then putting it into a more readable form such as they graph out the data and then to think critically about the data” (VSR1). This is exactly what he did in the class and most aspects of his teaching reflected this goal. This idea also appeared in a vignette analysis when asked what tips he would give to someone that is teaching a lecture.

> Alex: I would tell you to really think about the core things that you want to pull out, that you want students to understand when they leave the class. You know, what to do is it just something broad; I want them to understand population growth.
> José: Well, what about population growth do you want them to understand?
> Alex: So, maybe get some four or five bulleted points of things you want students to understand. And then think about, well, how are you gonna present this topic to them so that they understand these things (Vig. Int.3).

It is interesting to see that, when analyzing teaching instances at the college level, Alex brings forth the goals and objectives of a class as an integral and very important part of planning and teaching a lesson. These ideas Alex shared provided further evidence of his understanding of curricular goals in guiding teaching practices.

Finally, Alex became familiar with the National Science Education Standards and the state's standards and emphasized the use of multiple scientist perspectives to guide his planning too. This particular idea of embedding a scientist perspective was adopted from his mentor's model, since that was the way his mentor designed his instruction. His lesson and plans always referred back to these standards in a very comprehensive way.

From these analyses it is clear that Alex guided his planning having specific goals and objectives in mind. At the high school level these goals were strongly linked to the State's science standards, as can be seen in his lesson plans. At the college level the goals and objective seemed to follow a more logical and rational model.

In terms of knowledge about materials available for high school and undergraduate life science topics Alex draws ideas from multiple sources. Common sources for Alex were the internet (PBS learning, United streaming, ENSI site), the classroom text book (Miller & Levin, 2004), primary science research journals, and his own personal experiences in the field. This is seen in the invasive species lesson and the Galapagos penguin lesson (LP(D), LP(E), VideoA, VideoB). The first three sources were sources Alex learned during the MOSTEP program and the rest were just experience and through his graduate program.

In terms of lesson planning, evidence suggests that Alex's understanding of lesson planning changed. This change was strongly related to the fact that Alex adopted a curriculum model (UBD) that guided his lesson plan development practices, not present previous to MOSTEP since he did not teach formally at any institution. It is important to point out that most of Alex's lesson plans were reviewed by his mentor before handing them in. In fact they were revised multiple times before being used in his mentor's class. Usually the number of classes exposed to any particular lesson were between 4 and 5, hence the document was revised 3 to 4 times. For example, one time during the lesson on invasive species in the enchanted islands (LP1), Alex improved his graphing of the area. He added a scale to the area after realizing during class (video1, VSR1) that students were getting confused. He also changed some of the questions that guided the lesson to reflect what the lesson covered. Finally he changed the arrangement of the pages in the worksheet to support a more logical flow of events.

Most of Alex's lessons included a PowerPoint presentation (five out of six), all of them had a worksheet for students to complete, many had a graphic organizer (four out of six), all had a strong inquiry component, and all had an activity component after a presentation. They all had the following sequence: 1) they started with a section that engaged the students; 2) the following sections had an exploration and explanation phase in the form of questions and evidence presentation; 3) the last section was an extension of the activity. Evaluation was done throughout the lesson in an informal way through teacher prompted questions and during the lesson in a formal way by having students fill in the worksheet. The logic between the parts of the lessons presented and video taped, seemed to follow some form of the 5E learning cycle model.

Alex also used a combination of lessons from those that had real life examples (i.e., penguin lesson and invasive species lesson), to simulation lessons (i.e., with apples to represent the earth or clip birds and micro-evolution). The variety of lessons prepared by Alex demonstrated, in one way or another, his added expertise in lesson plan development and indirectly his understanding of curriculum. Unlike Tyler or Chris, Alex claimed that he does not write notes to teach a class but does a lot of mental work at home (VSR2).

Finally, Alex disliked the lesson plan model from the program. Nevertheless, when asked to put his lessons in this format, he would transfer his lesson, which followed a UBD design, into that of Madeleine's Hunter format with no problem. Moreover, he frequently left some sections of his first lesson plans in the form of the worksheet for the following one.

Summary

I believe that the following statement summarizes the degree of curriculum and lesson planning Alex had.

> I think that you have to be very forward thinking and you have to be a good designer. You wanna teach a concept, how are you gonna design what you're teaching? How are you gonna effectively teach it? So you've gotta think about [how] you're gonna structure your lesson: are you gonna talk? Are you gonna

> give activities? Are you gonna have them work in groups… you've gotta really think through how you're gonna structure each day, I think you have to be very you have to be a good planner and then to be able to work with and to adjust things, to change things, not just plan it one way do it the same every time, but be ready to adjust and change things and maybe even at the moment if something's not gonna work out, be ready to instead of doing an activity for 20 minutes, well it only took the students 10, all right, we've gotta do something else with that extra 10 minutes (Ref. Int.).

Students

Learning theories. In terms of knowledge about theories of learning science, evidence suggests that Alex had no explicit knowledge about them or about the theorists who contributed to this knowledge base. However, one of the things that seemed to be important for him was the idea of getting students more involved and exposed to the Nature of Science (NOS). This idea blossomed during our discussions in different forms. For instance, Alex talked about "getting [students] involved in the scientific process [because it] runs farther in [their] head, to think like a scientist, rather than just learning about science" (Gen. Int.). In addition, he used his field and research experiences as tools to develop lessons to show students how science was done *in vivo* (Video1, Video2, LP1, LP3). As an example, during the penguin classification activity (VSR2), he wanted students to experience how difficult and subjective classification of organisms could be. He also wanted them to see that scientists, even with specialized tools, still had questions about classifying those organisms correctly. In that same class, he tried to explain a little of the history behind classification to help students realize that as we "invent" new ways to classify organisms, our ability to scrutinize gets enhanced but is not determinant.

Another piece of evidence that supports the notion of Alex focusing on the use of NOS as a way to enhance student learning is the evolution plug-in group Alex spearheaded. Throughout the plug-in sessions, NOS was always embedded as a major goal in the development of the instrument. Furthermore, during the vignette exercises similar ideas about the NOS and its importance in the classroom transpired, especially when discussing Dr. T.'s teaching strategies.

Concurrently, Alex also talked about developing students' critical thinking skills. For instance, during his invasive species class (LP1, Video1, VSR1) when I asked him if he met the goals of his lesson he answered:

> I think we got them to think critically…we got them to think of the steps of the problem and… to answer any question [that] required drawing on a lot of different, you know data and examples and things they've learned already. So I think we did a very good job in getting them to think critically." (VSR1).

Moreover, during the penguin lesson (VSR2), critical thinking seemed to be an important component integrated into the class when students were engaged in determining how to classify penguins (video2). The focus on critical thinking was something that his mentor had been tossing around during the last MOSTEP year (2^{nd} year) as part of a leadership group in the school to enhance its implementation school wide. These were the instances where the notion of critical thinking was brought up by Alex. The fact that Alex is cognizant about the need to teach students about NOS and critical thinking could be interpreted as an inherent understanding of what might be missing in students' science education. Understanding of this gap is a reflection of knowledge about students' needs and the theories behind student learning. In addition, Alex's comment after reading this section was: "I remember that I used to think that the goal of the science teacher, when I began, was to teach scientific facts and details, rather than a way of thinking" (personal communication, July, 2007).

Evidence also suggests that Alex had some knowledge about student learning processes such as students constructing knowledge. Likewise he showed knowledge of factors affecting student learning such as students' motivation, and students' prior knowledge. Evidence also suggests that part of this knowledge changed. Some of the topics discussed with Alex were: a) knowledge construction or building concepts; b) prior knowledge; c) misconceptions; d) the use of real examples; e) pre-requisite knowledge and concepts student might have problems with; and f) motivation and engagement.

Alex had some insights regarding the idea of students constructing knowledge. He constantly mentioned the idea of reviewing concepts addressed in previous lessons as a way to bring forth prior knowledge and help students build new concepts on top of those (VSR1, VSR2). Additionally, he talked about breaking complex concepts and processes, like food webs and graph interpretation, down in order to ease student construction of knowledge (Gen. Int., Vig. Int.1 & 2). For example, in our first interview when asked how he would teach food webs, he explained that he would start talking about food chains to help student see that as they add more connections to other organisms it becomes a complex mess or food web (Gen. Int.). He believed that this was a good way for student to start constructing knowledge. The idea of constructing knowledge seemed to be implicitly embedded throughout Alex's discussion of using, for example, reviews as a way to bring forth prior knowledge (VSR1 & 2). The same is true for his use of misconceptions to challenge and later build new knowledge on top (VSR1 & 2). It is hard to tell how many of these ideas were owned by Alex prior to the program and how many were learned during the first year in the program. Additional conversations with Alex lead me to believe that MOSTEP, at the very least, reinforced this knowledge.

Alex's understanding of how student prior knowledge played an important role in learning changed. This change occurred not at the level of knowing what prior knowledge is, but rather at the level of how to use prior knowledge to enhance student learning. In our first interview, for instance, Alex mentioned that during his first year, in some of the lessons he taught, he used some form of a test first to "see what the [students] knew" (Gen. Int.) about the new topic, or remembered about a previous topic. During a discussion in the second vignette, I asked Alex if he discussed teaching methods with his mentor. He mentioned that one of the things they discussed, and was emphasized a lot, was "assessing [student's] prior knowledge" (Vig. Int.2). This relates closely to his use of the UBD model. It is evident that knowing about student prior knowledge was important in Alex's high school teaching environment to plan a lesson. The following examples, and quotes, shed further light on to how Alex thought student prior knowledge should be used and how he used it to enhance his teaching.

> José: You mentioned something like summarizing the previous lesson… as an approach to start [Dr. T.'s] class. So why would you do that if you were a professor?
> Alex: Well because the kids are taking other classes … and their lives are going to be just as busy as anyone's. I don't expect them to necessarily have thought about ecology all night…so knowing about what they retained (Vig. Int.1).

Additionally, during the same vignette he talked about putting himself in the mindset of a student before teaching. Indirectly he was trying to foresee students' prior knowledge to inform his teaching "…you have to get into the mindset of a student that hasn't seen this before or like how are they going to process these ideas and what are the questions they are going to generate so you just have to go through the natural process of learning something new" *(*Vig. Int.1*)*. Moreover, when we were discussing his teaching approaches in the first and second video interviews, Alex made further reference to the use of questions to review what kind of information students maintained from previous classes to bring that up and help students build connections. "I think it's important to review because if you just assume that they're going to remember everything you did and all the main points that you want … I think that's a wrong assumption (VSR1)." He also mentioned using this review to

> … jog students' memory … So, you gotta start jogging their memory. … Well, remember we were genetic counselors. … Oh yeah, we did that thing. … Well, what was that thing? … and so, you get into a, sort of, discussion about what we did and what was important about it and so, it's really jogging their memory (Vig. Int.3).

It is evident that Alex used his understanding of students' prior knowledge to help plan his teaching by predicting difficulties in content where students might struggle. Understanding prior knowledge, at this level, could be considered a substantial change, from awareness of the fact that students have prior knowledge to using this idea of prior knowledge to his advantage, in the way Alex did.

Parallel to this, evidence suggests that Alex had an enhanced understanding of how to use misconceptions to his teaching advantage. Alex was knowledgeable of different misconceptions students could have for areas in life science that were probed in the study (i.e., evolution, organism interactions and population biology). For example, he was able to point out typical misconceptions in evolution, like the idea of evolution "just being a theory", or the fact that "we descended from monkeys" instead of sharing an ancestor with them. He also mentioned social Darwinism and the idea of survival of the fittest mentality (Vig. Int.2) as being an important misconception to address. Additionally he used misconceptions to guide his teaching, much like he did with prior knowledge. For example, he talked about using misconceptions students had about inanimate objects having DNA. He used this knowledge to spark a discussion and increase student motivation during a class. The following quote sheds some light on this matter. Alex was recreating how one of his past classes in genetics went.

> …which of these… things have DNA: like a rock, plant, bee, tree. Things like that and just to get them thinking about it because then it was a good jumping point to discuss like the next day how much they actually know (Gen. Int.).

Misconceptions were further discussed in certain contexts like the case studies (Vig. Int.1&2). Alex did not bring up the idea of misconceptions too often during the video stimulated recall interviews or our last interview. It is worth noting that he used typical misconceptions in evolution as guides to develop evolution plug-ins. It is evident that, at some level, addressing misconceptions is an important component that Alex uses to plan his lessons.

Evidence suggests that, for Alex, linking concepts to students' everyday lives helped students understand the content better. Alex often emphasized that, when he taught, he focused on ideas and examples that students would be really interested in (Gen. Int.) to help them understand the concept in biology being dealt with. For instance, Alex asserted that he liked how Dr. T. brought up an anthropogenic link to his class. He said: "…I think that introducing these ideas of limiting factors and controls for population growth, and then relating it to human population growth is a very good introduction…" (Vig Int 1). I further asked Alex why he thought this was important and he replied:

> Well [when] you can talk about animals, any anyone can think about predator-prey with animals and everyone thinks this applies to animals [only] and I don't know if people make the connection in their head about human population growth. What's keeping our numbers in check? Or are we just growing uncontrollably forever? (Vig. Int.1).

Apparently for Alex making the connection to humans via examples is necessary because, he believes, students do not make the connection at all. This point of view is apparent not only from his discussions but also from his teaching. For instance, during his first video taped class on invasive species, when asked what one of his goals for the class was, he said. "[To learn]…to visually see and connect in their own minds the sort of effect that invasive species can have, and what are the things that sort of humans can do, you know, to try to turn back the clock" (VSR1). Additionally, during the second video taped class when asked again what his main goal was he said:

> I wanted to get into some of the specifics of classification and how do we organize living things as scientists. And so I wanted to just start them thinking about, 'Well, how do you organize things in your everyday life, whether it's your sock drawer or you homework' and things like that. Think about how we organize and categorize things (VSR2).

Trying to link classroom content to examples known by students is the way Alex tried to help students understand better the material being discussed in the classroom

Evidence suggests that Alex had some understanding of concepts in life science that might be complicated for students. Even though this area was probed superficially, Alex showed a certain level of awareness regarding this area. For instance, during the general interview, he said the following when talking about problem areas that might be encountered while teaching food webs and energy transfer:

> …that's [energy is] also a difficult concept especially for an introductory biology student… to really realize about energy being lost. But it is a very difficult thing to try to get students to come to that conclusion on their own. Like it almost has to be presented factually as energy is lost and this is kind of the relationship you see (Gen. Int.).

Additionally, in the first vignette he mentioned that dealing with J and S population growth curves could be hard for students. He shared that this was hard for him too and he still had to remind himself by going back to a book. Something similar happened with concepts like density-dependent and density-independent factors related to population growth. He believed that these concepts were hard to grasp at the beginning. Furthermore, he highlighted the idea that speciation and species was also a hard concept to grasp. He said: "Students have problems with this. When is something a species? What is a new species, what is a different species? All are valid questions and these questions are something that science is still dealing with" (Vig Int 2). Finally, he emphasized many times the idea that students, when dealing with graphs, really needed assistance at the beginning. It was his belief that graphs needed to be broken down and explained slowly (Vig. Int.1 & 2, VSR1). They needed to be separated into different slides if possible (Vig. Int.2) and equations, that explained graphs, need to be dealt with extreme care to facilitate students' learning (Vig. Int.3). Awareness of concepts that might present a challenge to students demonstrates enhanced understanding of student knowledge.

Alex demonstrated certain sensitivity regarding student motivation. His final reflection provided an interesting perspective regarding this matter. When asked, what were the challenges he encountered in MOSTEP he said:

> The usual challenges of when a student is not motivated and is not paying attention or is being distracting just for if it's one day, you know, trying to deal with that. So the usual, you know, teacher challenges (Ref. Int.).

In addition when asked what he thought was the best way for a student to learn he said:

> One to do their homework, two to actively be engaged in learning… If they're not interested in something, you know, you can understand that not every student is interested in biology, but if they put in an effort, you can get an A in biology (Ref. Int.).

Clearly motivation was a problem Alex identified in high school students. The ways in which Alex tried to deal with this problem can be observed in his teaching and his patience while teaching (Video1, Video2). For instance, he would show a lot of enthusiasm when teaching. Likewise he would make sure that he made the content relevant, whenever possible, to the students (VideoA, VideoB). Another comment Alex made was that he had learned to look for the source of the problem as a result of MOSTEP. For example, he said that if a student was not on task or motivated today, he would ask questions like: why is that? Are they tired? Were my instructions inadequate? Are they sitting with the wrong group of people? Are they easily distracted? Can the problem be remedied today, rather than writing it off as that student is lazy? (Ref. Int.).

Moving away from knowledge about learning processes, evidence suggests that Alex' understanding of how student diversity affects teaching and learning in science classrooms, was well defined. For example, during our first interview, when asked what one of his most frustrating experiences during the past MOSTEP year had been, he said:

> …Running anything [a lesson] for the first time… So that was pretty frustrating and it's frustrating too because you always have to adapt to whatever attitude the students are bringing in. So if [in] the first class they are all tired, they are a little bit cranky, they are coming in late slowly and I mean you just got to work with it and so that could be frustrating too. Days that you didn't have their attention and you need to constantly keep fighting to keep them on task, I mean, all those things (Gen. Int.).

The fact that Alex recognized variability among his classes during a day, especially in regards to student attitudes, is one step towards understanding the implications of student diversity. Proposing alternative approaches to deal with such issues is a second step. For instance stated:

> One thing that you learn right away is that you have to try to remember what it was like being a 15 year old in high school. What things are important to you? How you view the world. Different attitudes and things and experiences you can

> bring to the classroom. You have to work your hardest to try to remember what was like being at that time. I mean you really do (Gen. Int.).

Additionally, in the video-taped classes we can also appreciate different ways in which Alex dealt with diversity issues in his class. For example, during the penguin lesson (video #2) while describing one of his students' attitude he said:

> She's fiercely independent, very smart but you can't push her. So I wasn't going to, "Oh, I want an answer." I wasn't going to keep pushing her, but I wanted to make sure - I was trying to get an answer of some sort and try to resolve it (VSR2)

He would use similar strategies to get the best out of his students during class (Video A, B, 1 & 2). As a supplemental note, Alex shared that last year he talked with his mentor quite a bit about differentiated instruction and the fact that one needs to adapt one's science lesson to fit the audience (Gen. Int.).

Student diversity. Concurrently, Alex's sensitivity towards diversity was also reflected in his comments during our vignette discussions. Alex queried "…how in depth one wants to go to cover census in an ecology class having such a diverse group of students (doctors, computer science, sports, scientists) but if it were a biology majors group it will be different" (Vig. Int.1). He also questioned the value of having learners with diverse backgrounds:

> It is great to have variety because they will bring different experiences to the table. But in a way they are the same[too] because they are all taking similar freshman classes, some might be more active other ask more questions…there is always going to be people like me that do not chime in regardless of the opportunities [too] (Vig. Int.2).

Alex mentioned how having diverse learners can help **e**nhance the learning experience by having people bring forth their backgrounds to reflect upon the content being covered (Vig Int 3). Overall, evidence suggests that what Alex learned about the implications of student diversity in a classroom during his first year at MOSTEP and was most likely reinforced during the second year. He then extrapolated this to an undergraduate context via reflection.

Summary

Evidence suggests that Alex's understanding of student learning theories was minimal. Two exceptions might be that of critical thinking and the role of NOS in planning and teaching. Additionally, Alex' conversations during the interviews focus quite a bit on the students, and helping students get around their problems. The following reflection sheds some further light on this matter.

> You have to always care about the students is ultimately what I'm trying to say. So when they're when you feel that they should be performing at a level better than they are, then don't give up on them. Don't treat them dismissively or as less of an individual or anything like that. Try to bring them, try to address that. Don't think of students as being stupid I guess is what I'm trying to say. Because I've seen that too, and I think that it definitely has an effect how the students treat you and how they're gonna act in your class. So show that you care (Ref. Int.).

Finally, when discussing ideas such as prior knowledge, misconceptions, and diversity in a classroom, it is interesting to observe how Alex's understanding does not limit itself to just knowing about the existence of such ideas but the application of them as well. Alex understanding of these ideas changed.

Instructional Strategies

Activities and representations

Evidence suggests that Alex's understanding of activities and representations was well defined and, in general, changed. From previous analyses we know that Alex used 'real life' examples and investigations in his lesson planning to help students understand the content presented 'better' by making it relevant to their lives. Hence, it is no surprise that Alex' activities and representations bear at their core some of these qualities too. Many of the representations I observed Alex use involved providing students with an everyday object or idea (e.g., a clip or an apple) that symbolized a biological concept or process (e.g., beak evolution or Earth/land availability). The following examples will shed some further light on this matter. For instance, in the beak evolution activity, Alex broke down the concept of evolution into its particulars (e.g., beak shape and size, food shape, abundance and size, and vicariance events). Then by working with these components and using an inductive approach he helped students understand the broader concept of change with modification.

> So… as the condition changes in the two groups, and by condition changing I mean food size, you know big seeds over here, little seeds over there that certain variations…well which variations (middle, little, big size beaks) in a population, you know change over time because of different conditions. Then you see

> differences in the population growth. And once they see that, you know, [it] went a few rounds, and see how the populations change, you know in different sides of, you know the mountain, the geographic barrier, you kind of have a better idea … because I originally used the Galapagos finch example of how all this different species arise how did all this different beak sizes arise, well do we see how that could happen now? (Vig. Int.2, ~14:00)

Similar inductive approaches and uses of representations were seen in some of the video-taped classes and in other lessons we discussed (Video1, Video2, LP(C), LP(D)). Another analogy Alex mentioned was the idea of using human population growth to equate it to population growth in other organisms (Vig. Int.1, Vig. Int.3). In this particular discussion he seemed to use a deductive approach, that is, he went from a population level, to understanding the patterns of growth of the population, to understanding the role different variables played in defining such a curve. Thus, when using examples about human beings to help students understand population growth patterns, Alex was asked why he thought using this example was important. He explained that it allowed students not only to link what was being studied with their own social structure, but at the same time ask deeper questions like: "What's keeping our numbers in check?, Are we just growing uncontrollably forever? What about other limiting factors, like in animals, with food. Because it is easy to think like in winter time there is no more food so animals have to migrate and they go into hibernation… what do we do? Why not?" ... (Vig. Int.1).

One last example of a representation discussed by Alex was the use of food chains. Alex said that a food chain was a simplified representation of a food web. Hence teaching food webs by adopting a food chain approach, he believed, helped break down a complex concept of organism interrelatedness to ease students understanding of such concepts (Gen. Int.).

Alex was also able to identify and discuss knowledgeably different representations and examples used by Dr. T. in his class. He would credit those examples he thought were good in Dr. T.'s class and provided changes to those that he thought needed improvement. For instance, he discussed the appropriateness of Dr. T.'s teaching sequence and example regarding the natural selection section.

> I believe that his use of Power Point was appropriate to lead the discussion and to provide examples. He explained a concept, such as the different types of selection, and then provided a new example with which students had to explain

> using the new concept just learned. This occurred with the example of natural selection and the pepper moths (lines 219-249). I would, however, change his approach to reviewing content (Vig. Wri.2).

He also highlighted the idea of using real examples and research as a plus to Dr. T.'s teaching approach (Vig. Int.2).

At a more specific level, Alex discussed strategies that he thought should be used by someone who teaches graphs or equations like the population growth equations presented. Multiple times in the vignette interviews (1, 2 & 3), and also during his first video-taped class, he would say that one should break down the graph for students to understand (VID1). Afterwards he added that one should complement this process with other examples or activities where students had to interpret a new graph or calculate a new value using the equation learned to further their understanding. Graphical dissection is a major thing for Alex.

> Well, first you have to look at one graph and say 'well what is this graph saying'? All right the next graph is set up in the same way but with new information. 'well I can use the experience from the first graph, you know, to dissect the second graph and so on' so, I mean, you have to take it in steps you can't, it's just not, if not implicit, it's not you can't look at it and understand immediately what's going on. (Vig. Int.2)

Being able to address and discuss weakness and strengths of activities, and at the same time being able to come up with such creative representations, could be interpreted as signs of well developed understanding of activities and representations as is the case of Alex.

Alex demonstrated inventiveness when planning new activities and modifying old ones. For instance, in an invasive species activity that he developed from scratch (LP1), he managed to integrate the themes of population growth, conservation, invasive species and graphing in a very comprehensive and student friendly way. Furthermore, students seemed to respond well to the activity. Most of them participated at least once (Video1). The high level of engagement was evident and question/answer interchanges seemed appropriate. In addition, during this investigation-based activity Alex incorporated his most recent field research experience (i.e., goats, Galapagos and hawks), with powerful images and examples of habitat degradation and linked the activity to ecosystem fragility and proneness to human impact (LP1, Video1). The framework was set so students analyzed, deconstructed and worked with the particular characteristics of the scenario that eventually involved decision-making processes, in this case the decision to eradicate and control for an invasive organism by considering and interpreting the outlined data presented. Alex explained that he "wanted them to feel that they were doing something important that everyday people (biologists) do as a job and experience what it means to make decisions based on real data" (VSR1).

Another creative activity/concept coined by Alex was the evolution plug-ins. An evolution plug-in was an activity designed to be used in other topics in the biology curriculum to help the teacher hit on evolution while teaching other units. Alex's evolution plug-in integrated phylogeny and evolution to the molecular biology unit of DNA and inheritance.

Finally, the modifications he made to Chris' penguin classification lesson (LP3) demonstrated his ability to change an activity around to suit his classroom and teaching needs. For instance, he started with a few guiding questions: What characteristics do each of these organisms share? What make them different? How would you group them? Then he defined the term taxonomy and asked the students if they organized anything (like their clothes), or something else familiar at home (i.e., he used a real life analogy). Then he talked a little bit about the history of classification; he talked about Carolus Linnaeus and the about Aristotle classification of organism. At the end of this previous practice Alex added the activity of classifying penguins. When Chris developed the lesson the guidelines did not provide the details portrayed in this discussion. In summary Alex wanted to achieve the following with the activity:

> So to carry that further, I wanted to go through the idea of classification, the sort of history, and not just teach them about it, but get them thinking about it - how to organize, and what would be good ways versus what would be not so good ways. And then to have them do an activity that involves it, a real world example, and using different ways, and then to, at the end, assess and enforce (VSR2).

He finally worked on what he perceived were weaknesses in the activity and corrected for them. The ability to modify and reflect on the weaknesses and strengths of activities showed that Alex had certain skills and level of understanding with regards to topic-specific instructional strategies.

Summary

Based on the knowledge that Alex never taught a class before joining MOSTEP, and looking at the ease in which he teaches different activity-based lessons, suggests a change in Alex's understanding of activities and the appropriate representations in teaching and learning. This is further supported by his ability to discuss the pros and cons about the lessons used.

Major methods of instruction

Lecture. Evidence suggests that Alex was fairly knowledgeable about lecturing. He could correctly identify lecturing instances in the vignettes, was able to propose alternative ways to modify or improve the approach. His views of how a lecture class could be improved surfaced while discussing strengths, weaknesses and goals for Dr. T.'s class. When asked what he believed should be "the" major goal for a lecturing faculty member? Alex replied:

> I think their goal is to be able to teach them something.…To engage [students] in a lecture, the way you ask questions is going to have to be very careful and you are going to have to be very patience if you want them to come onto the concepts on their own in their own heads through questioning you an answering on a dialogue. It's gonna have to be … You would have to constantly adjust what your are teaching and what you are asking and things like that, so if you want the students to connect the concepts in their heads and you want one verification of that, one way would be in your questions and dialogues in the lecture rather, than just throwing the content at them and then waiting for the test to see if they understood it. (Vig. Int.1)

This said, Alex shared an example of how he would do this based on the population biology vignette (#1).

> Well one way will be just in this lesson…is when he is talking about what are limiting factors? Why won't a population grow out of control? Brainstorm with the class. So then they get to see what are some other things that might be affecting it? What maybe will keep J curve from being a J curve and turning more into an S curve. What will keep this population at a certain size? Brainstorming with the class before even introducing the ideas and that might even generate more discussion about a certain topic or maybe they are going to miss something so then depending on what you are trying to get out of them you would adjust kind of how you would ask it or … I don't know but something along those lines would help. (Vig. Int.1)

Many of the improvements proposed by Alex involved discussion management and question and answer strategies. As he mentioned in one of the quotes: "just throwing the content at them and then waiting is not going to make them understand" (Vig. Int. 2&3). Alex proposed similar improvements to Dr. T.'s lecture class in the follow-up vignettes. Basically, these improvements hit on the idea of engaging students through appropriate questioning techniques described many times as a Socratic approach by Alex.

We can see that in all the classes selected by Alex to be taped he stayed true to his point of view with regards to lecturing. When he lectured, which usually was a short time, he tried constantly to interact with students through open-ended questions, guiding questions and at times not answering questions at all (Video1-Video4).

Finally, Alex was asked to share some pointers to someone that was going to lecture for the first time. He recommended: 1) know your material; 2) know the key concepts and focus on a few points; 3) include an activity whenever possible; 4) break complex concepts like mathematical equations and graphs and; 5) listen carefully and rephrase answers and students' questions to further the discussion (Vig. Int.3, ~49:00)

Summary

Overall, being able to identify a lecture approach, discuss its weaknesses, strengths and potential ways of improving the lecture, using multiple examples to show the point and finally implementing these strategies during your own practice is a measure of the level of understanding Alex has with regards to lecturing. In this case it seems to be an appropriate level of understanding.

Questioning/Discussion. Evidence suggests that Alex's understanding of questioning/discussion approaches changed and was fine-tuned further during his last MOSTEP year. Alex said that his most rewarding experience during his first year in MOSTEP was when his students were completely engaged during a genetics/DNA class he taught. He particularly enjoyed his students' eagerness to contribute to the discussion (Gen. Int.). This comment highlights the importance of a good discussion to Alex.

Parallel to this, when talking about bad qualities in a teacher, Alex expressed that not being able to guide a student towards answers was not good. He said:

> I think it comes down to that control issue. I think that if you are trying to get students to understand a concept, and they are not understanding it, you tend to just give them answers… I think you really want them to try to get there [to the

> right answer] on their own. So while it's easier just to give them an answer you rather do sort of like with the Socratic method, just sort of like leading them with questions that they form and answer so they get to where they should be rather than you just telling them how it is (Gen. Int.)

The notion of a well-guided discussion underlies Alex's comments. For him, maintaining a certain level of engagement through participation was important. These ideas were complemented and critiqued further during other discussions we had. For instance, during Alex's critique of Dr. T.'s discussion strategy he wrote that the aspect he disliked the most was the discussion sections.

> …There seemed little room for student engagement. At several times he asked broad, vague questions about difficult topics. When no one would answer he would just answer himself. A better way may have been to rephrase the questions and encourage student involvement. There is more than one way to ask a question, especially if your goal is student understanding. Allow students time to generate answers, listen to a response, and adjust or elaborate on their answer. (Vig. Wri.1)

Part of Alex's dislikes seemed to be associated with the fact that Dr. T. asked vague questions, answered his own questions, and did not leave enough time for students to answer questions. Alex felt very comfortable discussing the trade-offs of some of Dr. T.'s discussion/questioning approach. The following excerpt during our discussion sheds some further light on this matter.

> …there seems to be a big difference between you just asking what is population growth? Population growth is this. And to just actually think what is population growth. OK if a population grows … (disorientation) numbers are growing bigger. OK so what are factors that can control that? You know and then asking the questions in their heads and trying to generate answers on their own. But that might take them more time. **(**Vig. Int.1**)**

Moving students from a definition to a more elaborate answer seemed to be a preferred approach for Alex. However, he seemed to be aware of the implications regarding time when leaning towards this more open-ended approach.

During follow-up vignettes, the same arguments towards Dr. T.'s lack of discussion skills transpired. In vignette #2, for example, Alex said: "…Dr. T. jumps into new material each class period and question-and-answer time gets neglected". Alex referred back to specific lines of the vignette when arguing his case about Dr. T.'s lack of discussion skills. This level of detail in his analysis reinforces the idea of Alex having a good grasp with regards to this particular teaching and learning strategy. Alex further elaborated on Dr. T.'s teaching approach, "Dr. T. needs to work on his Socratic method, asking questions that generate answers that generate more questions, and to answer less of his own questions himself (Vig. Int.3)." In addition, he suggested improving Dr. T.'s questioning as follows:

> Well what might restrict the ability, of a population, to grow?" And then that will lead into the equation, "Well, how does a population grow? What are some of the things that would inhibit that or excel it, population growth?" So, it was sort of that. Before that I mean I think these are good questions, you know, "What are some assumptions of this model?" I think he just hit it too fast. I think he needed to go about it in a different way. So, you gotta start jogging their memory. "Well, remember we were genetic counselors." "Oh yeah, we did that thing." "Well, what was that thing?" (Vig. Int.3)

Furthermore, Alex showed he was capable of critiquing a discussion approach by demonstrating how he used this approach in his practice (*Video1-Video4*). For instance, when challenged to discuss the reasons behind some of his discussion interactions he stated the following.

> José: So why did you ask this question?
> Alex: Because I want them thinking again, go back to the food web and how relationships between different species will be affected. So her argument was that the goat will do fine because there'd be plenty of other food to eat. But I wanted her to think back, "Well, what do those prey species eat?" Well, you know they eat, you know like the rice rat and, you know other insects and that. Well what do they eat? They eat grass. Well what else is eating the grass? The goat. So even though there's more prey species, could the hawk still be hurt? So she had that as an answer, but I wanted her to look at it from a different, you know is that, "Well if there's other things to eat then the hawk will be fine." Well it's a little more complicated than that. (VSR1)

Similar discussions regarding questioning strategies are shared by Alex during his second video-taped class.

> Alex: And I started thinking, like, "Well, okay. Let's look at - our how are we going to classify?" "Well, we can look at similarities." "Well, what similarities?" "Well, let's look at this is how people covered it in the past and talk about it and then critique it. "Well, is this a good method? Is this helpful? Is this not helpful? What are some drawbacks of using this?" And then kind of moving up to what the accepted method today. So I think it is important because it also kind of goes along our line of thinking, "Well, how would we classify? Well, maybe walking versus flying organisms would be a great idea. Let's classify them that way. Well, that might be what we think of at first, but let's look at it a little more critically.

> Maybe that's not such a good method. What are other ways we could do it instead" (VSR2)

Alex showed he was capable of describing the discussion/questioning strategy and outlining the major problems in it. He was also able to recommend suitable ways of handling such an approach. In addition, he showed practical applications of how this could be accomplished (VSR1 & VSR2). This could be interpreted as change in Alex understanding of this instructional strategy.

An important thing to highlight is that Alex mentioned the Socratic Method several times during our discussions. He described it as a back and forth dialogue between the classroom and the instructor. He claimed to have heard about this method before MOSTEP (i.e., during some of his philosophy courses in college), but not discussed it or practiced it as far as he remembered. He also said that what he learned in his mentor’s class gave him more tools to succeed using this method (Personal Communications, May, 2006). The Socratic Method is a dialectic method of inquiry. This approach, mainly a mixture of inquiry and discussion, was an approach Alex fancied very much. Every time we talked about the discussion strategy he would mention the Socratic Method. In a way many of his former comments fell under the definition of this concept. Finally, he added that he had learned from his mentor how to rephrase some of his questions to get students to think about their responses and feel comfortable with opening up in the classroom (Personal Communications, May, 2006/ after reflecting interview).

Summary

Overall the following ideas are central in Alex’s case: 1) rephrasing questions was important; 2) Socratic dialogue is a preferred model; 3) leading through questions to an answer rather than providing an answer is appropriate; 4) engaging students mentally through questions is helpful; 5) asking vague questions should be avoided; 6) enough time should be provided for students to think about a question and; (7) one should listen to a response to elaborate an appropriate answer while assessing the student formatively.

Finally, I believe the following excerpt from Alex’s reflection of what the most common teaching approach used in his mentor’s classroom was, gives a picture of where most of these questioning strategies could have been learned or enhanced.

> [There was] a lot of dialogue between the students and the teacher, and not just the teacher talking the whole hour, so a lot of back and forth. A lot of open-ended questions. I mean, that's the number one thing in my mentors classroom is just open-ended questions where he's not looking for a direct right answer. He's looking for responses and students to think about their responses to come up with a backing support for their responses. So a lot of questions like that and when you don't get exactly what you're looking for you redirect your question and toss it back it out. So it's a lot of back and forth and then it's also a lot of different activities as well. A lot of hands on things, a lot of group learning, things like that (Ref. Int.).

Collaboration. Evidence suggests that Alex had some knowledge of collaborative learning strategies[11]. Alex advocated group learning as a positive way of helping students in their learning of scientific concepts. For instance, Alex made the following comment after he was prompted as to how he could adapt some of the strategies to a college setting:

> …I think getting people [to] work together more rather than just having a lecture. Having more group activities or group projects where students get to intermingle and work together and help each other pulling it. It doesn't mean, I mean there has to be strong ways of assessing that but, just one students leading the group and doing most of the work, but all students getting a benefit of working together. So maybe as far as adaptation, like putting it on the students to help each other out… a bit more like a group study (Gen. Int.).

In this comment Alex focused mainly on group work. It can be argued that this comment could be indicative of a preference towards implementing such a strategy based on the situation portrayed.

Furthermore Alex stated that reducing lecture time to reach shy students that have difficulties interacting in whole class discussions, could be accomplished if groups were established.

> José: How will you get to students like Sarah?
> Alex:…partly it could be if you broke it [class] down into smaller groups and you work on like a group project or something like this, that will be an opportunity [for the student] to go from group to group. And maybe that would open up a student to be able to ask questions if other students from their group don't understand either. If they did, they could share with her. They could help her out, but it's not I mean the whole group sets a question it might be easier [to answer

[11] Collaborative learning has many definitions in the research literature. For this particular document collaborative learning will be seen as a method of teaching and learning where students group together to discuss a particular question or work on a set project.

> or get an answer] in a group of 5 rather than a group of a 100 in a lecture hall (Vig. Int.1).

As we can see Alex's comments not only tackled the issue of shyness but also described how the dynamics of the interaction could work. Moreover, when discussing the issue of diversity in the classroom, Alex made reference to the fact that there were other students that the teacher could draw upon to help in the classroom's teaching and learning environment; "the teacher is not the only reason [knowledge bearer] in class" (Vig. Int.2). When asked to explain how diversity and students knowledge worked in group activities

> José: How will you pick from those things... the fact that the sole knowledge of the classroom is not in the teacher (lecture), for a group activity for example?
> Alex: Well because when they are working together on the same goal, so they are going to have to help bring each other up to speed and keep each other on task and if there…, there isn't as much of an opportunity to leave a student behind because that student has to be participating in the project, they need to have a partner and to have a partner you need to understand what's going on and be involved and having other people on the group will help them in both respects, (Vig. Int.2)

Another aspect of Alex's views regarding collaborative learning is observed in his practice, in particular the video-taped lessons. In most of these (i.e., clip birds- VideoB, penguins- Video2, and invasive species- Video1) he encouraged students to work in groups of 2 to 7 students, depending on the activity. For instance, during the invasive species lesson he encouraged students to work in pairs. His rationale was that by doing this they will be more motivated and could solve problems in an easier way together. The following dialogue depicts this interaction.

> José: Why do you encourage this [collaborative work]?
> Alex: I wanted them to know that they could work with a partner on this because I felt that that might motivate them a little bit more to actually work on this. Because oftentimes there can be the problem is this is where the class stops. Once you set something in front of them for them to do, they're not interested, it gets pushed to the side, they don't do it or it might be too hard or something like that. So I felt like if I gave them that opportunity like, "Well you can work with a partner" that that might initiate, you know more discussion on the task at hand (VSR1)

In his penguin class, where he paired students to accomplish the task of classifying penguins, he acknowledged that other interactions, beyond the goals intended for the group activity, would occur among students. He referred to these interactions as normal and sometimes necessary (VSR2). Looking at group work from a motivation stance and acknowledging some of its weaknesses shows even deeper understanding of this strategy.

Overall, we could argue that Alex's level of understanding in terms of group work was present and may be somewhat limited. Especially if we consider the multiple types and descriptions given by the literature on what collaborative learning is and how it should be implemented (Gross, 1993). Nevertheless, this level of understanding of collaborative work in terms of group work is significant if compared to other fellows.

Summary

Alex is the only participant that mentioned and discussed group work as an instructional strategy. The fact that in his mentor's class group work was encouraged could be a possible explanation for how Alex learned more about this strategy.

Inquiry/hands-on and other strategies. Evidence indicates that Alex had practical knowledge of inquiry-based instructional strategies but there is little evidence that shows Alex could link the term "inquiry" to what he did in a classroom. Cues of Alex understanding of inquiry-based teaching and learning strategies can be observed at various levels of my previous analyses; at the student and curricular level for instance or at the instructional strategy discussion and lecturing level. Although the word inquiry is not mentioned by Alex too often, characteristics of inquiry-based instruction were brought up constantly in our interviews. For example, Alex showed genuine concern about the following features of an inquiry strategy: students' prior knowledge, engagement of students in 'real' science using real examples, weaknesses in students understanding of NOS and guiding students through appropriate questioning to an answer. He believed all these where important pieces in the learning of science and in particular in relation to teaching and learning about scientific inquiry.

> I think breaking down the units like that is great because we're looking at science from a scientist's perspective. We're not just learning about science. We're learning how scientists would learn about science. (VSR1)

One of the aspects of inquiry is learning about the nature of science, also known as scientific inquiry, as Alex proposes here and in his curricular/ student components of PCK discussed earlier.

> So it's giving them a new situation where they have to apply these concepts to explain what has happened… I think it is a good way to better learn the material for from there they had to come up with the explanation, so they're having to draw upon what they've just learned and use what they just learned in a new example (Vig. Int.2)

Furthermore, the way Alex described his reasons behind certain interactions during the reflections of his teaching portrayed further evidence of his understanding of inquiry and students.

> So this comes into overarching a goal of this whole assignment. Like what do we want them to do? Well, we want them to analyze real data. We want them to come to conclusions. We want them to learn about this example. But then you get down into specifics about how you do that. So what we wanted Santa Fe to be, was an example where they would remove the goats, this is what happened to the hawk population. And this happened, you know 30 years ago. And the hawk population did go down after the goats were removed. And assuming of the reasons that we mentioned, you know our original assumptions, but the number bounced back. And I mean there's a stable hawk population there now. And so I wanted that to be an example like, "Well this is what happened then. What can we predict might happen on Santiago now?" (VSR1)

A similar process was seen during the penguin activity, where students went through a process of learning about scientific inquiry and science while classifying this organism.

Alex claimed that he did not know anything about this teaching strategy (Gen. Int.). Previous explanations and the narrative below show otherwise. In an implicit manner Alex is providing a good description of how to promote inquiry-based instruction.

> I've never taken an education class. I don't know exactly what that question means. So how I would answer that is the teaching strategy that I use was I knew what I wanted them to do. I knew what I wanted to teach them about classification, so I wanted to find an activity that applied to that, that was hands-on that they could do that applied these concepts of classification to a real world example, which the penguins worked perfectly. So to carry that further, I wanted to go through the idea of classification, the sort of history, and not just teach them about it, but get them thinking about it - how to organize, and what would be good ways versus what would be not so good ways. And then to have them do an

> activity that involves it, a real world example, and using different ways, and then to, at the end, assess and enforce. And that's what I tried to do. (VSR2)

Alex always chose an activity-based lesson to be video-taped. These videos showed that, during his lessons, he put a high emphasis on student learning about scientific inquiry and students doing inquiry. This emphasis increased towards the end of the program. While it can be argued that this is coincidental due to the nature of the lessons used, it can still be considered evidence of Alex's advocacy towards inquiry.

Summary

While it is evident that Alex is not conscious that most of the time he used an inquiry-based approach to teaching, he is aware that his choice of strategies enhanced and involved students in the understanding of scientific inquiry. Concurrently, his discussions about instances in his practice that demonstrated, directly or indirectly, inquiry addressed many aspects of inquiry and practices that teachers should be promoting more in classrooms as proposed in the NSES (NRC, 1996).

Summary of major methods

Evidence suggests that Alex possessed a wider variety of teaching strategies than other fellows. This could be a function of Alex being longer in the program and therefore having built a stronger connection with his mentor. Although multiple times he claimed not understanding what a teaching strategy was: "I'm not up on my teaching strategies", (VSR1) or "I would probably not be able to identify them as teaching methods" (Vig. Int.2), when questioned he was able to explain in his own way what the goal was for each portion of the activity/lesson. Moreover, he provided strong arguments as to why someone should use certain strategies over others, how to use the strategies, and even delved deep into the specifics of some teaching strategies like discussions. He was an advocate of appropriate discussion techniques were guided inquiry was supported and students were involved in a Socratic discussion mode. Even though he was unfamiliar with the terminology and labels, he showed evidence of understanding the practices. This is a reasonable result of his path – he had been mentored to walk the walk, not always talk the talk.

I believe that Alex's reflection at the end of the program sheds some light in terms of the level of change regarding his understanding of all these major teaching strategies.

> José: So the teaching dynamics in general in [your mentors] class, how would you describe the most common approach that [your mentor] had?
> Alex: A lot of dialogue between the students and the teacher, and not just the teacher talking the whole hour, so a lot of back and forth. A lot of open-ended questions. I mean, that's the number one thing in [my mentor's] classroom is just open-ended questions where he's not looking for a direct right answer. He's looking for responses and students to think about their responses to come up with a backing support for their responses. So a lot of questions like that and when you don't get exactly what you're looking for you redirect your question and toss it back it out. So it's a lot of back and forth and then it's also a lot of different activities as well. A lot of hands on things, a lot of group learning, things like that. (Ref. Int.)

Communication techniques and strategies

Alex's communication techniques and strategies showed some evidence of change. Partial evidence of this change can be appreciated by comparing and contrasting his comments regarding the qualities of a good teacher. For instance, in his first comment, at the beginning of 2nd year, he considered qualities such as: excitement and passion for teaching, sharing of enthusiasm, and patience as important features in good teachers. He also mentioned that teachers should be able to "control the dissemination of information" and they should be constantly adapting and "keeping communications open" (Gen. Int.). At the end of the program he was asked the same question again. Among the themes discussed were the following: a) being in general a good designer (i.e., in the teaching aspect and in the lesson plan aspect) and; b) advocating group work and showing flexibility. He ended his summary of qualities with the following sentences:

> You've gotta be a good communicator. You have to make sure what you're saying is being understood, especially with directions. So you've gotta be ready to look for clues, you know, get feedback from students that, because there's no worse thing than watching an audience and watching an instructor and they're not connecting at all [they are not communicating] (Ref. Int.).

This final emphasis on communication is worth considering when trying to understand Alex's position regarding its importance in teaching and learning. I believe this shows a refinement and expansion of what he perceived as important qualities of a good teacher. He does not talk about enthusiasm or patience, but focuses more on teaching strategies and communication. This is evidence of a change of perspective regarding the importance of these characteristics. Another part of his reflection showed some insight on this matter. “It has strengthened my ability to communicate effectively as a teacher to students and other faculty” (Ref. Sta.).

*Questioning strategies / Verbal and non-verbal communication***.** In terms of questioning strategies, Alex was fond of asking questions that: encouraged critical thinking, guided students towards answers, and triggered students’ desire to ask more questions. For instance, Alex’s answers when critiquing Dr. T.’s teaching provide some insight on the importance he gave to adjusting ones questioning. For example, on the first vignette he gave a nice account of what and how Dr. T. could improve his interactions with the students during the discussion sections.

> At several times he asked broad, vague questions about difficult topics. When no one would answer he would just answer himself. A better way may have been to rephrase the questions and encourage student involvement. There is more than one way to ask a question, especially if your goal is student understanding. Allow students time to generate answers, listen to a response, and adjust or elaborate on their answer. Dr. T. also explained complex processes with new terms. (Vig. Wri.1)

The same ideas surfaced during the discussion we had of Dr. T. teaching strategies in the third vignette.

> Mr. T needs to work on his Socratic method, asking questions that generate answers that generate more questions, and to answer less of his own questions himself. Stop answering his own questions (rather, ask the original question in a different way) (Vig. Wri.3)

The information provided in these two accounts is consistent with Alex’s position regarding questioning students in the “right” way. That is, the analyses done, the recommendations given, and the solutions provided by Alex in the three different conversations are consistent. They also evidence a good understanding of the importance of knowing what to ask, how to ask, and when to ask questions to provide the best environment for students to learn.

Moving to a more specific level of understanding regarding verbal interactions in general, evidence suggests that Alex was cognizant of the importance of verbal and non-verbal communication during these verbal interactions. Alex’s ideas have been grouped into sections, and relevant quotes have been added as evidence.

Knowledge of the level of complexity with regards to content. This was reflected in Alex's critique of Dr. T.'s approach when teaching graphs and equations in the vignettes. He believed that a complex representation (graphs) needed to be broken down to basic component in order to help students understand them.

> OK what can you tell me about them [population growth curves/graphs]? Just to go a little bit further into that… so if they don't answer not give them an answer but [ask] well what are the two axes, what are they how are we breaking this down…(Vig. Int.1).

This idea is highlighted again when he shared an example of what he did in a nutrient cycling class. Evidence of transfer is also appreciated here.

> …To borrow the graph example again. One [task/goal], was just reading the graph like what's [the graph] telling you. Two, then trying to infer relationship from that graph. For example, the nitrogen cycle that we just did in our class [at the high school]. So I had the students graph out ammonia, nitrite and nitrate over time and so they could see what happens to the levels over time. Great, so what does this mean? What's happening as ammonia is going down and nitrite is going up? (Vig. Int.2)

This use of questions to break down graphical functions was also emphasized in other discussions. For instance, in the invasive species lesson (Video1, VSR1), and in the third vignette interview when discussing improvements of Dr. T.'s class. The notion of guiding students, using questions, to break down graphical functions is something that Alex emphasized in these two sections.

Guiding students to an answer through questioning. It was important for Alex to focus his questioning towards obtaining a relevant answer. Evidence of Alex's knowledge about this particular aspect has already been discussed in the discussion strategy section and in stepping-stone fashion throughout the previous sections of communication. The level of detail provided in the following quote shed further light on this.

> José: What do you mean by being more patience?
> Alex: Being patient for student's answers. If they do not answer not to just throw out the answer but that goes back to sort of adjusting while maybe rephrase the question or take a step back if you know if they don't understand one concept they might not be able to make the connection to the one you may be talking about so you may want to back pedal a little anyway adjusting how you are teaching or how you are questioning in order for them to make the connection rather than just giving them the connection (Vig. Int.1).

Similarly, in the other vignettes he also talked about guiding students to an answer.

> …You don't want it to say I'm the professor you are wrong get out or that, so I mean, it is a difficult topic (Vig. Int.2)

Or else critiquing Dr. T. not guiding student's "right".

> Well what might restrict the ability, of a population, to grow?" And then that will lead into the equation, "Well, how does a population grow? What are some of the things that would inhibit that or excel it, population growth?" So, it was sort of that. Before that I mean I think these are good questions, you know, "What are some assumptions of this model?" I think he just hit it too fast. I think he needed to go about it in a different way. (Vig. Int.3)

In his practice this perspective towards questioning "right" also showed up.

> Well what happens if you bump something out of that food web? Or if you introduce something new into that food web?" What are the possible things that could happen? (VSR1)

There are additional examples of him doing this in his practice during his first two video taped lessons.

> Video: What do these things have in common? Should they maybe go in a different group? And the organisms that don't have that characteristic go in a different group.
> Alex: And I started thinking, like, "Well, okay. Let's look at - our how are we going to classify?" "Well, we can look at similarities." "Well, what similarities?" "Well, let's look at this is how people covered it in the past and talk…(VSR2)

We can appreciate that for Alex it is important to guide students to an answer and not merely spurt out the answer.

Encourage students to answer questions by varying the level of complexity. The following quotes deal with encouraging students to participate in class through appropriate questioning. For instance in his practice he encouraged students, through questions, to actively participate in the class.

> T: In this class we are going to answer why we are counting hawks. S: Population.
> T: Yeah we are going to talk about population but a little bit deeper.
> José: [Vid 5:15-5:28] So why did you acknowledge the student's answer in this way?
> Alex: Because anytime you get feedback from the class, when they're answering questions and they're actually thinking through the answer you want to of course acknowledge that.
> José: Why?

> Alex: You want to support that. You want them to participate. You want them to know that that's what you're looking for. You want to engage them. You want it to be an interaction with them. You want them to know that they have a part in this lesson. (VSR1)

He also encouraged students to come up with their own questions. Understanding the reality of the situation in high schools in particular

> José: So why do you think he was thinking something different to what you actually told them? Why?
> Alex: Part of it might have been that I hadn't been complete clear in that I wanted no right answer. I wanted them how to do it. 'Cause I think they're used to they're asked a question; there's a right answer. And I try to leave it more open than that, especially when I give them journal questions when I'm doing the teaching that day, just more open-ended, how they would do it, just to start a dialogue. An I want them, basically, to think of an answer and then try to think of support for that answer. And not so much whether it's the right or wrong answer. And especially with this. I thought my question was pretty clear. I didn't ask for specific-al groupings. I asked how they would group it. (VSR2)

Alex seemed to aim at providing a safe environment to ask questions in his class.

Non verbal cues. Alex uses non verbal cues to assess students' level of understanding to inform his teaching. He mentioned, in several occasions, the importance of considering the non-verbal cues sent by the audience in order to understand the classroom dynamics. Here are two examples.

> Alex -um well I commented on Djuan who seems to have this sort of, the kind of student that will nod all the time. Sending cues of understanding but he really did not understand and I think Djuan is selling himself short. I think he understands more than what he thinks. (Vig. Int.2)

With the prior comment in mind, we can appreciate how he adjusted his reasoning (in the form of questioning), in vignette three, to meet the needs of the hypothetical audience.

> José: And 65, what do you think about those lines in terms of teaching and learning?
> Alex: I think that would be a type of cue for Dr. T. So, he was surprised by the question, thinking that it was the answer was just intuitive. And, the fact that she asked it, should have been, "Okay, I'll take a step back and go through it. It wasn't intuitive, so I have to change my approach. So, I'm going to adjust some things and plan accordingly." So, the sort of constantly adjusting based on feedback that you get. So, how well he did that, I don't know. But I think that's sort of with a question like that would be an opportunity. I mean, she's clearing stating, you know and it's probably not something that is just her. So, it should be, you know, the sign that, "Okay, adjust." (Vig. Int.3)

Summary

In summary, this analysis provides a picture of Alex's practices, position and level of understanding regarding the importance of communication in the teaching and learning of science. He talked about: a) not asking vague questions; b) questioning students so that more questions are generated; c) providing a safe environment for students to feel good about questioning; d) using questions to break down complex concepts; e) guiding students through appropriate questioning, and rephrasing students' answers to help in their understanding. In general I think the following quote from Alex's reflection reinforces some of theses ideas. Alex felt that his communication skills were refined more than changed.

> I mean there are a couple of things that just you can only get through experience, such as having a hand on everything going on in the classroom… So that's been that's been very important. And also being better at just interacting with students. How to get them involved in a discussion or a dialogue. How to sort of be like the manager or the person, you know, sort of guiding where the dialogue's going and fielding questions and responses and posing it back to them. So being better at that, waiting for responses and how to read students better. Like all of that sort of communication that only comes with experience has helped a lot too (Ref. Int.).

Transfer

Evidence suggests that at a basic level some of the knowledge Alex gained in the program had the potential to transfer to a higher education setting. The following examples provide further insight on this matter.

Regarding assessment practices, when we talked about giving students a test at the beginning of a topic to evaluate students' prior knowledge (Gen. Int.1), Alex said that he would certainly use this strategy in a college setting. In his eyes it allowed students to see what they were going to be learning and established a framework of reference. However, when we discussed situations where different levels of assessments were required due to differentiated learning, he added that in a college setting this may not be realistic to do, due to time constraints and class sizes (Gen. Int.1). Alex's position regarding the kinds of assessment one could use in a higher education setting showed an interesting stance. This stance was most likely a result of a decision making process that entailed an internal evaluation of the context's similarities (high school vs. higher education) by Alex. This ended up in a decision as to what could be used, when and why in the different context. As we know the ability for knowledge, skills and such to transfer from one context to another is dependant on similarities between contexts and degrees of exposure.

Regarding teaching strategies, when Alex was asked to discuss the idea of teaching food webs in a higher education context, he discussed the issue from a high school perspective without noticing he was doing this. This could be read as Alex finding enough similarities between contexts to consider his teaching approach indifferent to the level being taught to. Nevertheless, when I asked him if he would teach the same way he described his teaching approach of food webs in a higher education context, he assented. He said that he would deconstruct the overall picture (food web) into different parts and then put it together before just flushing down a food web and expecting students to be able to dissect that on their own (Gen. Int.). This idea of deconstruction has been observed and discussed multiple times in previous sections of Alex's case (PCK: instructional strategies, curriculum and assessment). At the same time the idea surfaced many times in the different instruments (Vig. Int.1, 2 & 3, Video1 & 2).

Similarly, when discussing questioning strategies in Dr. T.'s class, Alex always referred back to high school examples in order to strengthen his explanations as to why and how should Dr. T. approach the concept differently. For example, this happened when discussing graphs in the vignettes or when prompted with the applications/ transferability of his teaching in high school lessons to a higher education context. In addition, when Alex and I were discussing how he pulled examples from his high school experience to explain vignette instances, we diverged into an interesting conversation.

> José: Is this something that has happened to you recently, where you just start observing and picking things up in lectures, from ways of teaching?
> Alex: I've definitely looked at it a lot more closely, you know. Now I think especially [with the constant reflection] even, not even so much last year. I would start to compare teaching methods, you know, at a university level versus the high school level.
> José: Uh-huh.
> Alex: And also really think about, like, "Well, how do I learn? You know, what is easier for what is easiest for me to understand something?"
> José: Mm-hmm.
> Alex: And so, I've been that's how I try approach teaching then well So, when I watch other people, I'm like, "You know, I would have done that differently." Just because I know how I learn and I think there must be other people like me.

> So, I would try to do it like this and I love breaking things down into examples and try to pick, like, a concept apart and think of ways like how to present this in a new way and a way that might be easier to understand and things like that. So (Vig. Int.3)

It is interesting to note that he is actually considering what aspects of what he has learned in high school could be applied in a higher education context. On top of this, in his reflection interview, when I asked Alex if he thought that what he experienced in his mentor's class (i.e., group work, questioning strategies in particular) would work at a university, he assented and added:

> I think there could be a lot more interaction back and forth. I think there could be more group things and not just group huge new projects, like a group presentation, but just maybe a one day activity working in those groups and things like that (Ref. Int.)

Finally when I asked Alex if he believed good teaching looked different in high school than in college, he answered

> Alex: I don't think so. I don't think so. I think good teaching should involve an instructor excited about the topic, interested in teaching, interested in conveying what they know and to broaden, you know, student understanding of the topic, and I think they should be excited about their ways to do that, whether through combination of lecture, you know, activities, group work, and things like that. And assessment, how well do the students learn? What worked? What didn't work? If the instructor is trying to do all those things, I think whether in high school or graduate school that, you know, that would be a good teacher (Ref. Int.)

Summary

In summary, Alex is aware that differences between both teaching contexts exist. He also sees the applicability of some of the strategies he learned as usable in different situations depending on the goals, classroom size, and depth of content. In particular the following components of PCK: assessment, lesson design and questioning strategies, seemed to have a potential to transfer across context.

Potential Sources for PCK

In this section I offer examples of instances that I believe provide information of **potential sources** for Alex's development of pedagogical content knowledge. One level corresponds to those instances external to MOSTEP that could have affected Alex's

PCK, and a second level corresponds to those instances within MOSTEP that could have influenced Alex's PCK.

External to MOSTEP

The following experiences seemed to have influenced Alex's development of PCK: a) undergraduate/ graduate student classroom experience; b) high school student experience; and c) reflection on his own learning. I have outlined a few examples of each of the areas to support this claim.

As a college student. Alex brought up some instances from his college experience, especially when discussing vignettes, about how cookbook labs should be replaced by research oriented labs (Vig. Int.2). He also brought up several examples of how he used to go about learning material presented to him (Vig.Int2, Vig. Int.3,~5:00 & ~9:00).

As a high school student. Alex made many comments where he compared his high school experience to what was going on in high school today. For instance he made a comment that in his high school he did not focus on learning about research as much as they try to do in today's classroom (Vig.Int1)

Reflection on his own learning. He would draw from his own learning experiences when discussing aspects of students' learning.

> I tend to be someone that really needs to hear something clearly in order to be able to make the connection in my head. If it's not loud enough, or it's garbled, I - yeah, it has to be clear. And that's just me. That's how I think and… (VSR1)

On another occasion he mentioned something similar when talking about his ideas on how people learn: "Just because I know how I learn and I think there must be other people like me. So, I would try to do it like this and I love breaking things down into examples and try to pick, like, a concept apart" (Vig. Int.3).

Within MOSTEP

The following experiences seemed to have influenced Alex's PCK: a) other fellows; b) MOSTEP mentor education specialist; c) being in the high school classroom; d) the researcher.

Other fellows. This happened when he worked with a lesson that one of the other fellows had already developed. He adapted the materials but built upon the idea (VSR2).

In addition, this happened during sharing in the group or even discussing the plug-in ideas (Ref. Int.).

Mentors. On several occasions Alex commented on how his mentor was always open for suggestions and included him in as many aspects of the teaching process as possible (Gen. Int.). He also commented on the excellent communication he had with his mentor as an important component (Gen. Int.). Furthermore, Alex's mentor would coach him in-situ, like he did when he was teaching the food web in the Galapagos invasive species class (VSR1) or the DNA classification intervention (during the penguin lesson) (VSR2). Alex's mentor would also make comments to Alex before and after teaching a class (VSR1).

Being in the high school classroom. Many times Alex made comments similar to this one: "I think you need to take things and dice it up into smaller and easily digestible chunks" (Vig. Int.2). He did this when talking about graphs, equations, complex concepts (like phylogeny, DNA, etc) (Vig. Int.3) or even lesson planning or using inquiry in a college setting (Vig. Int.3). What he did in his classrooms (Video1, Video2), was reflected in his comments when asked to provide with teaching alternatives during the vignette interviews (Vig. Int.1, 2 &3).

Regarding reflections as a result of the research process. Alex, like other fellows, always asked for my opinion with regards to teaching and learning processes when these issues were brought up during the different interviews (Gen. Int.; Vig. Int.1). He also talked about comparing university teaching and high school teaching a little more as a result of reflecting on the vignettes (Vig. Int.3). The following comment was made by Alex when asked what he thought about the vignette:

> …it gives you an experience to put everything in the context before if you have never taken or if I would've never taught before or had a teaching experience I would just feel this is the class I took (referring to the university set-up pictured in the vignette). And, having a class you sort of start… I think you sort of star… I think you start thinking more like a student which is weird because you've already been a student. But you begin to think how a student thinks as a teacher which is a very clumsy way of saying as a teacher you start to try to put yourself in the mindset I'm seeing this for the first time what's the best way to learn this. You know, rather than just the way you learnt it which might have been very difficult or not very well (Vig. Int.1).

Summary

Overall, Alex asserts that he puts more value on stopping, asking question, making students think critically and assessing in a constant manner as a result of his MOSTEP experience, which he shares in the following reflection:

> …And so it's something that I think I learned along the way about, you know, interacting with students, how to manage behavior and, you know, managing the conversation and the dialogue between students and then structuring activities (Ref. Int.)

Kate

Background

Teaching and learning. Kate shared some insightful opinions and anecdotes of her past experiences regarding teaching and learning. Like in the previous case most of the descriptions provided in this initial narrative refer to the time before she joined MOSTEP. Kate mentioned that she liked teacher's who were personable and who knew how to guide students towards an answer instead of telling them what the answer was. This was the case with one of her animal science professors. She said that she liked the fact that for him "nobody ever provided a wrong answer…"(Gen. Int.). In contrast, she mentioned that she disliked professors who rambled or went on tangents because she was never sure if they were talking about the main subject or giving a side bar (Gen. Int.1).

From a teaching perspective, Kate commented that she had been a TA before MOSTEP at two different universities. Apparently, she did this for approximately four years. She also said that she felt comfortable teaching any general undergraduate biology class, but not classes related to molecular biology (Gen. Int.).

Motivation to join the program. Kate's motivation to join the program was similar to Alex's. She loved the idea of collaboration between multiple institutions and participants. After a year of being involved in the program she commented having a bittersweet feeling about her romantic views of the program. She mentioned that not every individual or institution embraced the idea as she thought they would. Furthermore, when I asked her about teaching in the near future, she said that she saw herself teaching at a Master's level university and lecturing freshmen and sophomores in the undergraduate level. When asked the reasons behind a Master's level university she said that in her eyes this type of institution had the best of a research university and a community college (Gen. Int.). This meant that, for her, this type of institution had high achieving graduate students, university type resources, lower administrative hurdles and significant interactions with undergraduate students.

In summary, Kate joined the program because she saw the opportunity to work on a novel and romantic idea of collaboration. She also had prior teaching experience at two universities. In addition to this she mentioned that she liked professors who help you arrive to the right answer but disliked those that rambled. Finally she mentioned that she does see herself teaching in a Master's level university.

Pedagogical Content Knowledge

Assessment

Kate had informed knowledge of different types of assessment used by teachers to evaluate student learning**.** In particular she was aware of the existence of different forms of assessment tools used by teachers to assess student learning. Some of the tools she seemed familiar with were essays, presentations (individual and group), journaling, quizzes (oral and written), tests, different question types within tests and hands-on assessments (Gen. Int.). She also talked about alternative ways of assessment, such as, in-class questions, using index cards in what she called the "auction method', informal/formal assessment and a "creative piece" assessment. For instance, in the latter, she basically asked the students to either write a song, make a picture, write an essay or elaborate something unusual to demonstrate their understanding of what was learned in class (Vig. Int.2). Kate also shared some intricate thoughts with regards to assessment types and assessing students. She talked about a free-form assessment (Gen. Int.1) and a multi-approach assessment (Vig. Int.1), both of which combined presentations, essays, MCQ, true/false questions, journaling and demonstrations. Kate believed that using a combination of tools was "the best way to assess someone" (Gen. Int.). It is worth noting that familiarity does not necessarily mean in-depth understanding of how an assessment tool should be used or what kind of information such tool would uncover.

However, evidence suggests that Kate's understanding of how some of the above mentioned assessment types (essays, journals, and presentations) could be used was substantial. In terms of essays she mentioned that if she had a large class (100 students), it was very unlikely for her to deliver an essay question (Gen. Int.1). Additionally, she said that "essays at least give students an opportunity to show… what they know even if ain't everything. [It's] just like this really good chance to demonstrate what they know [even] if it is not what you asked" (Gen. Int.1). Concurrently, Kate added "[essays] are the worst to grade, very subjective. [I don't like them], not even because it is subjective but because it takes so much time…unlike multiple choice" (Vig. Int.1). In terms of journals, she talked about using journaling in college if she had smaller class (Gen.Int1). She also mentioned that this type of approach was very subjective (Vig. Int.2), as opposed to an objective approach like multiple choice tests. Nevertheless, she mentioned that even though it was subjective, journaling allowed students to write and show how much they really understood a concept. Regarding presentations, Kate mentioned that she would use them to assess students as part of an overall mixed-assessment. It was her belief that presentations forced students to synthesize information in order to be able to provide a succinct account of their findings or work (VSR1). Knowing the limitations, the advantages and the different ways of implementing different types of assessment, demonstrates in-depth understanding of the assessment. Kate seemed to do fine in these three domains.

Along the lines of formative assessment Kate's understanding surfaced and seemed to mature with time. For instance, during our first interview Kate shared a couple of ideas she learned about informal assessment during a teaching conference she participated before the beginning of her second year MOSTEP appointment. She said that in this conference they recommended instructors to stop after lecturing for 10-15 minutes so that students would be involved in a discussion or problem to synthesize the ideas just presented. What she recalled was that doing this would allow her to speed up or delve deeper into the topic depending on the student's responses. She finalized this dialogue by saying: "he [the speaker] made me think that at least on a college level, I will probably not give so many big tests, but I probably will frequently quiz." (Gen. Int.1). During the discussion of our first vignette interview (3 weeks later), this idea was brought forth again when I asked Kate how would she improve, if at all, Dr. T.'s teaching practices. One of the ideas Kate mentioned was: "I'd do a review of concepts, perhaps offer a quiz to see if I need to get the TAs to review the concept or offer more examples to help students understand" (Vig. Wri.1). A similar idea arises in the third vignette interview, 7 months later, when she talked about brief discussions to "assess student understanding of materials at certain intervals [of the class]". Moreover, during the first video interview, 3 months after the first vignette interview, further evidence of Kate embracing this concept is provided. Throughout Kate's presentation during this class on invasive species (video1 & VSR1), she implemented this strategy (stopping and questioning) within her class PowerPoint presentation. She had a question at the end of a certain number of slides. The question was related to what she had just been presenting and was used to draw students' understanding on what was being discussed. The following comment was made by Kate while discussing the use of this strategy: "I was impressed. After questioning them, … they were offering really good answers, I think I began to realize they just didn't know the word [hybrid]" (VSR1). Finally, during other instances in vignette discussion she emphasized the lack of probing for student understanding by Dr. T. (Vig. Int.1). At first, Kate declared learning about this assessment strategy during a teaching conference. As time passed it can be appreciated how Kate embraced this idea of ongoing assessment to the point that it became part of her practice and later was used to argue against, what she believed were not appropriate practices in the vignette case studies.

Kate also saw formative assessment being used was to discover student's prior knowledge and to diagnose the class' base level of understanding regarding a concept. For example, Kate thought that pre-quests were great ways of learning about learner's prior knowledge: "I loved the pre-quests. I thought that was a great idea [they] might be a good way to assess prior knowledge too, without taking some class time…, [if used] as a grade [it] is a good incentive and you can also get an extra grade" (Vig. Int.1,2& 3). I also observed that she embraced this idea in her teaching practice. The following excerpt from her first video-taped class sheds further light on this issue. In this instance Kate was teaching students about birds and invasive species.

> Kate: I wanted to know, one, if they had recognized, or [were at] least a bit familiar with any of the birds.
> José: Ok. What did you find out?
> Kate: They were. I was really proud to know that they had paid attention to their surroundings enough to at least know that they've seen this and they've seen that. And I was really excited about the fact that they could name some of them. I was.

> I do know that, at least in the high school, they don't spend time doing classification or talking about stuff like that. So I was little curious to know what their base was. And I also wanted to know if looking at all this stuff, if they knew if one was an invader or not. I did not expect them to know. (VSR1)

It became clear, from looking at the different conversations, that using assessment to inform herself about student progress and her own practice was important to Kate.

Towards the end of the program, Kate shared some interesting ideas regarding assessment and testing. For instance, she said that before she gave a test she would do the test herself. "I tried to put myself in the position of a student and try to take my own test; and I very often asked other people to look at it. Not just peers but I deliberately go out and ask people who I, think are completely unfamiliar with the information" (Vig. Int.3). She also mentioned that an assessment needed to be relevant to students. By this she meant that if students were taking an ecology/ conservation test they should be asked "…to go home and identify something in there neighborhood or work that can relate to the topic… [and] actually have them apply the concept in there own personal life. (Ref. Int.1). Finally, it was important for Kate to provide immediate feedback to students. She said that "it is important to offer immediate feedback. This allows students to fill any gaps in knowledge sooner rather than later" (Ref. Int.).

Summary

Evidence showed that Kate possessed advanced knowledge of the different types of assessments used to evaluate student learning. She was able to discuss advantages, disadvantages and appropriate ways of using them to evaluate student learning. In addition, Kate embraced the idea of assessing as one teaches as a way to monitor student understanding. Although she did not recognized explicitly this practice as formative assessment, her application and discussion show the essence of this form of assessment. Furthermore, evidence suggests Kate was very active and prone to learning new ways of teaching. Assessing individuals was of particular importance.

In retrospect, evidence from the different dialogues suggests that Kate's conception of assessment changed during her second year in the program. This is further evidenced by the following excerpt from her teaching philosophy.

-Informal assessments are beneficial to both instructor and student. A mid-lecture multiple choice question would let me know if the students understand the presented material.
-Formal assessments must be unambiguous and relatively easy to grade. I believe it is important to give students every opportunity to demonstrate what they know.
-Employed, including quizzes, laboratory reports, presentations, learning journals, and examinations. (Teaching goals)

Curriculum

At the beginning of her second MOSTEP year Kate shared some concerns regarding her assigned high school curriculum. She thought that the science curriculum, based on the state's General Learning Expectations (GLE's), was "way to detailed"(Gen. Int.) and covered upper level components. According to her some components were of "higher order thinking'(Gen. Int.) level and too abstract. She thought that students in high school should focus on more concrete materials. When asked to provide examples she said that details in chromosomal crossing-over, mutation, DNA replication, mitosis, and some of the details in biotechnology and PCR should not have been included in the GLE's (Gen. Int.).

In terms of content sequence, Kate had interesting ideas as to how concepts in life sciences should be taught in an undergraduate setting. She said that she would teach an ecology undergraduate class with a "large and coming in" (Gen. Int.) approach (e.g., teaching biomes and then narrowing it down to organisms). She also mentioned using an alternative teaching approach which involved using a "dichotomy"(Gen. Int.) approach. According to Kate a "dichotomy"(Gen. Int.) approach includes presenting ideas in twos. For example, if she was talking about land during the concept of habitats, she would say something along the lines of "lands could be wet or dry" (Gen. Int.), wet could be hot or cold, hot could be salty or fresh and so on and so forth. She also said that her second approach could be embedded in the first one and that this is how things worked for her when she was a student (Gen. Int.).

Additionally, when asked questions about Dr. T.'s teaching approach, Kate said that she would teach Dr. T.'s population class differently. During the first two vignettes Kate said that Dr. T.'s teaching approach was "ok" (Vig. Wri.1) and that she preferred teaching in this manner (Vig. Wri.2). However, in her third vignette interview, Kate said that she would improve Dr. T.'s lecture on population ecology doing the following things.

> I would address the main concept first. Provide the students with the information about the topic (e.g., pop growth, define key terms, give examples his examples were good, brief discussions to assess their understanding of materials at certain intervals). I would [do] discussions about scientific critiques, the scientific process for the end of class as closure. I'd focus less on the official definitions and encourage them to define the terms for themselves (Vig. Wri.3)

The teaching sequence shared by Kate, with descriptions of assessment and other strategies embedded within the description, show a good grasp and appropriate integration of content and pedagogy. One could argue that Kate had appropriate ways to deal with content and sequencing of content as suggested by her integration of pedagogical strategies.

In terms of scope of content, Kate developed some sensitivity towards the amount of content one should cover during class. At the beginning of the MOSTEP program Kate seemed to cover too much material when teaching at her high school (Video A). After being asked what she learned from MOSTEP during the reflective interview, she said: "[At the beginning] I never realized how I was just layering information… so being clear of what I wanted to teach and what I wanted them to know, "Maybe I don't have to go through all the exact details of [it], right now you know…" (Ref. Int.). Kate's first lesson about photosynthesis (1st year) covered too much material for one class (Video A). She covered light and dark cycles, wavelengths, and the general ideas and equations of photosynthesis. She later acknowledged covering too much material and students not understanding many of the concepts (LP1-Photosynthesis). Kate further reflected on the fact that one should not focus on covering too much material, but should focus on general objectives like, students learning about the nature of science and the scientific process. This can be appreciated in the following excerpt.

> As you plan the entire course, you know, don't want to do too much at once [too much content]. So I will emphasize, make sure, you know, by the end of the course the students understand the science, the nature of science in which you do. So, don't feel that in every example you go through, you gotta break down a scientific method in everything; for examples like this is the question, this is the hypothesis, this is the results they drew, and this is the conclusions they came with. (Vig. Int.3)

In retrospect, Kate showed sensitivity and a better understanding of rationalization of content when teaching life sciences.

In terms of knowledge of objectives about teaching and learning, Kate's knowledge changed. The clearest evidence of change regarding knowledge of classroom objectives was revealed by Kate's teaching philosophy statement and also by her comments during her reflective statement:

> I have learned that outlining desired <u>learning objectives</u> assists me in addressing topics better and keeping students focused on major concepts. I have also learned the importance of distinguishing <u>content learning objectives</u> from <u>performance learning objectives</u>. Content learning objectives include the concepts, vocabulary, and other pertinent information I expect students to comprehend. Performance learning objectives include demonstrating an understanding of the scientific process such as identifying experimental variables, recording data, and summarizing data properly. (Teaching goals)

Later she wrote:

> I found that students respond more favorably to lessons when they are alerted to specific principles they are expected to know, comprehend, and apply as they receive the information. Keeping it fun is nice, but it can be ridiculous if it doesn't relate to the class. They already don't want to be there, so why make it more painful and confusing. (Ref. Sta.)

The same idea permeates in her reflective interview when she was questioned about the idea of objectives. The build up to this level of reflection and understanding is evidenced through the different comments obtained from Kate during the interventions done prior to this interview. For example, during her first lesson plan (i.e., photosynthesis), the objectives where as clear as the follow up lessons. Interestingly, during the implementation of her invasive species lesson, she mentions a "learning wheel objective idea" (VSR1) and affective objectives as important components of her invasive species class. She explained that her intention for the class (VSR1) was to introduce a new concept related to conservation. She also hoped to get students to think about the issues behind conservation, and how invasive species were important actors in the process, hence she tried to meet an affective objective. During her vignette discussion, similar ideas about guiding students and having objectives clear for students also transpired. In her third vignette interview, she talked about the importance of "essentially telling students what they should be learning" that day (Vig. Int. 3). She also highlighted that using an outline slide to introduce the subject was a good thing that Dr. T.'s did in his class.

In terms of knowledge about materials available for high school life science, Kate draws ideas from multiple sources. She used materials from the internet (VSR1), other fellows (e.g., landfill and invasive species, VSR2, VSR1), other graduate students in her department (e.g., bird dissection, and reptile dissection), her undergraduate TA lab manuals (e.g., tooth pick lab for natural selection, LP3-Camouflage), and outside organizations (e.g., local zoo, the state's department of conservation and botanical gardens). Additionally, she was aware of various population and evolution computer simulations (LP3-Camouflage, Vig. Int.2 & 3). However, she did not implement any of them in her high school class. Her reason was lack of computer accessibility (e.g., Netlogo from Northwestern University). She also showed awareness of other sources such us TV programs from National Geographic and Discovery Channel (Ref. Int.).

In terms of lesson planning, evidence suggests that Kate's understanding of lesson planning changed. This change was strongly related to Kate's claim of understanding the particulars of Madeleine Hunter lesson plan (Ref. Int.). During her first year Kate did not like, nor did she understand the proposed lesson plan format (personal communications, May, 2006). She had trouble figuring out the three different kinds of objectives (cognitive, affective and psychomotor) and also had problems understanding the learning cycle sequence embedded in it. Nevertheless, in her second year of the program, it seemed like she got a better grasp of the whole process, as evidenced from the following dialogue:

> José: So, from your experience in high school teaching and learning environment, is there anything you have learnt that could be applied at university?
> Kate: Yeah I don't doubt it, yeah a lot of stuff.
> José: Can you give us some examples?
> Kate: Like the [lesson] plan development, and may be not in detailed as the educational specialist meant… I resisted [using the LP] at first, but actually I appreciate [it now]. I really do, I resisted at first… I think its okay to teach two to three concepts per day [at college] that are related. In high school you should stick to one. (Ref. Int.)

She also mentioned that when you are teaching you should announce to the learners the learning goals and objectives if you want them to really understand (Ref.

Int.). Additionally, when describing her first video-taped lesson she stated: "…the presentation was a part of the concept formation and then the activity was the application" (VSR1). This is discussed while looking at the first of her invasive species slides where different organisms are depicted. Based on these previous quotes and follow-up discussions, it can be argued that Kate's concepts of lesson planning changed as she navigated through the program.

Summary

Overall the excerpts quoted in the above sections of this curriculum part (especially the Ref. Int. and teaching goals) summarize nicely the degree of Kate's understanding of what a curriculum is and how a lesson plan works. In terms of the latter, she seemed to gain further understanding of the process as the years progressed. Finally, the ideas she shared about content scope and sequence, provides further insights as to how Kate's notion of "less is more" (i.e., covering less content and achieving more learning gains), learned from one of the education specialist in MOSTEP, played a significant role in her development of PCK at the curricular level.

Students

Learning theories. Kate had a desire to learn about different educational theories that would inform her practice to enhance student learning. Educational theories were not dealt extensively during the program albeit they were addressed, superficially, during the first summer workshop. Kate went out of her ways to learn about them. She would go to seminars, conferences, or even hang out with friends in psychology to learn about mental development and child psychology. The extent to which she did this is uncertain, but was evident from our interactions. For instance, during one of our conversations she said: "I wish I had a little bit of that background that education majors have. I still feel like I'm walking into that classroom and someone, you know, is keeping a secret from me…" (Gen.Int1.). She also expressed that she had trouble trying to implement new ideas "…no matter how much I thought about it [the activity]…I spent all this time practicing and trying it [the activity] out, to make sure it was useful for students that age, it was always ten times above their level…" (Gen.Int1). Other times she mentioned having heard about some of these theories, like multiple intelligences, on NPR (Vig. Int.2). When I asked why she liked this information she said: "…what I liked about it was one it doesn't place one type of intelligence above the other, so now we're not telling some people that they're more valuable than others" (Vig. Int.2). Prior to this mention of NPR in our interview, she mentioned the following: "…some students do better with verbal information like some people have phonographic memory…" and others "…have photographic memory. If they write it down or they see it written [is better]. [For] others words don't mean a thing [to] them, they do better with pictures and diagrams or they need a little mix". (Vig. Int.1). It is worth mentioning that almost 3 months later she mentioned multiple intelligences as something new to her. Kate did share that at times she got "hinted" by friends in psychology about the idea of different learning styles (Gen. Int.). Also, during the second video-taped class, the way she structured her landfill activity, by providing multiple alternatives to making the landfill (manipulation of artifacts, written portion, a visual presentation, etc), demonstrated that she was considering multiple perspectives probably to hit on different learning styles, something that was not observed in her previous classes. Finally, she said that, in a very particular case, she allowed for a student (that had speech problems) to present his assignment in any form he liked.

> There was this one kid. I think he had a bit of a learning disability. I know he spoke slow … And he didn't interact much in class… His artwork was beautiful. And he didn't normally perform very well in class... I gave him an opportunity to do an assignment based on we were doing [in] ecology, so like community relationships…He wrote a song (Vig. Int.2*)*

It is evident that Kate was trying to incorporate in her teaching practices the idea of multiple intelligences. Applying what is known to a different situation than where it was learned is a sign of more in depth understanding of the concept.

Concurrently, Kate mentioned, in an indirect way, that dealing with the nature of science as an important goal in her teaching philosophy: "As students become comfortable with the processes of science, they come to understand the concepts and content better" (Teaching goals). This is something she tried to mimic in her after-school science program. Other ideas related to student learning theory that Kate mentioned were: Haberman's Pedagogy of Poverty (HPP) and students internalizing concepts. She said that her school was a perfect demonstration of Haberman's Pedagogy of Poverty (Ref.

Int.). She also stated the importance of students internalizing concepts instead of memorizing them: "…too many students try to memorize things perfectly and in the effort of trying to memorize perfectly they often hesitate because …they are trying to recall or recite and not really trying to internalize … putting things in their own words" (Vig. Int.1). The same idea transpired from a later conversation, in more detail, when I asked her what she meant by internalizing the material.

> …give them time to think and reflect even if they don't vocally tell it back to the teacher. Give them a moment to pause and go… 'okay I just learned a big chunk of information, Let me get a moment', and with every learning style that the student uses, let them draw the pictures, thinking it out, talking to their neighbor, asking a question to the teacher. But before they leave that lecture hall… they should understand what went on during that day…(Vig. Int.2)

It can be argued that the way Kate discusses and includes in her conversation and practices the NOS, HPP, multiple intelligences and students internalizing concepts shows Kate's level of understanding regarding these ideas. Kate seemed to have acquired these notions during her participation in MOSTEP but not necessarily in MOSTEP per se (e.g., outside seminars and conferences). It can also be argued that this desire to learn more about pedagogy was triggered by her MOSTEP experience and was then used and related back to the her classroom.

Evidence suggests that Kate's understanding of how student prior knowledge plays an important role in learning changed in her first year and seemed to have been enhanced in the second year. Kate's recollection of what she learned regarding prior knowledge her first year is nicely synthesized by a comment she made during our first interview.

> [In my school] I learned how important [prior knowledge] was. I just I found… [that] we were giving, what seemed in our heads, the simplest examples possible to make it real and relevant [to the student]. And I noticed it still didn't get through to them. And finally I said to myself, "you know what, these are really simple examples considering we all at least have college educations" (Gen. Int.1)

After this reflective comment, Kate tried to make sure she did not make the same mistake twice. For instance, during her invasive species class (LNote1, VSR1), when showing pictures of different resident birds for the state, Kate thought that students would not be familiar with vultures (which they did), and they would know about sparrows (which they did not). Later, during the same interview, she acknowledged the importance of testing for prior knowledge and reflecting on the findings to inform her practice. However, she said that even though student's prior knowledge might have surfaced and the connections between this knowledge were made to the topic being discussed, she was skeptical that students really could make the connection visible. This was the case of a discussion she had about species hybridization during the invasive species class.

> They're very clever but I've learned that they don't know how to cross- supply information across context. Like they might know what a hybrid is, but they know the word. But did they understand that it was bringing two different things together? Or is just that what you call one of those new cars that get lots of gas mileage. They might associate the term hybrid with gas mileage not with part gas, part electric. (VSR1)

In retrospect, this level of scrutiny reflects a high degree of understanding of student prior knowledge and the difficulties of transforming some of these pre-conceptions.

At another level, for instance, during a discussion about pre-quests in the first vignette interview, Kate said that she loved the idea of pre-quests because they informed Dr. T. of what the students were bringing to the class. In that particular moment of the interview, she said that she had just realized that those prequests "would be good [tools] to assess prior knowledge"(Vig. Int.1) without taking class time. Other instances, during the second video-taped class, reinforce the idea of working with student prior knowledge to inform teaching. For instance, when she was questioned about probing students to see how much they knew about landfills, she said: "I was curious if they were aware, you know, if they actually knew what a landfill was. Or were they just like when I put it in the trash it completely disappears" (VSR2). This also occurred when students were trying to build a model of a landfill and she was observing what variables (clay, sand, plastic, size of grain, etc) student's used and how they used them to determine the best model. She apparently realized that a lot of her students had some problems with this and added: "To try to get them to find their own variables. It is hard. It would take the whole class"-(VSR2) so she had plan ahead of time to expedite this part of the class.

Finally, Kate shows a strong disposition towards making a priority knowing about student prior knowledge. The following quote is a very strong criticism Kate makes towards building assumptions of student's prior knowledge.

> There's an assumption, a huge horrible assumption, cannot say that big enough, huge, horrible assumption that student come to your class already knowing [the material]… And they don't. They have not really been prepared in high school… then you get to college and the professor treats you like you should know, and so they don't take the time to make sure you know and what happens is you have a whole bunch of just kids falling through the cracks. (Vig. Int.2)

Overall, the comments made by Kate, in relation to prior knowledge, indicate that assuming students were blank slates was something she would avoid in the future.

In terms of examples and making connections to student learning, Kate shared two interesting insights. The first one at the beginning of the data collection, and the second one towards the end. At the beginning, during a vignette discussion, she said

> Several examples can really solidify the [learning] situation because sometimes… I don't know about a lot of people but I was guilty of [this] earlier in my education. If you gave me an example, I often thought it was the only [example]. [Basically] it only happen in this situation. So it wasn't until I saw several examples could I pull the pattern out of it. (Vig. Int.1)

This comment was made after discussing the importance of providing examples to students. Later towards the end of the program she shared another reflection.

> I have found that using examples from pop culture or science fiction movies to illustrate biological and ecological concepts is often well-received by students. (Teaching goals)

Both comments show Kate's developed sensitivity towards providing multiple context related examples to enhance student learning.

Parallel to multiple examples and prior knowledge, evidence suggests that Kate had some understanding of the main misconceptions people have in some life science topics, but she seemed to have little understanding of how to use misconceptions to her teaching advantage. From our conversations, the use of misconceptions to enhance student learning was not visible. What was observable was that, when probed, Kate was able to acknowledge misconceptions in different areas of the life science. For example, during discussions about evolution misconceptions, she showed knowledge of the underpinnings behind the ongoing educational debate that was taking place at the time and had a very strong point of view about this. For instance, the following argument was brought forth by Kate when asked about main misconceptions about evolution

> …the overall misconceptions, is, people confusing speciation or the development of the human species with evolution as a whole (54:00). People trying to reconcile the age of things in particular the earth and how long people have been around based on what they were told by theologians. And the big one is just the theory of the common everyday use of the word "theory" is not the same as how scientists use the term theory. (Vig. Int.2)

Another point where she showed awareness of misconceptions was during the determination of species as being foreign non-invasive and foreign invasive, like the case of house sparrows and Eurasian tree sparrows (VSR1). However, little evidence is provided of her understanding of uses of misconception to help students conceptual change in science.

Evidence also suggests that Kate had a good grasp of concepts that might be complex for students (high school and college alike) depending on the topic discussed. For instance, she talked about students having problems with the concept of energy when probed about teaching a class using food webs. For them, she said: "this concept was too abstract" hence she added that she would try to make the concept more concrete by making analogies with currency or food (Gen. Int.1). In another example, she mentioned skipping the derivation of population growth equation, she said: "I don't think it is key to understanding the concept. I'd explain the phenomena and define the equations and leave it at that" (Vig. Wri.1). In the same vignette she mentioned that students, in freshman and sophomore years, would have problems understanding graphs, so she would need to do more interaction with them. Kate believed that students tend to have problems with graphing. Furthermore, she also talked about students having difficulties dealing with concepts around evolution, gene flow, founder effect and Hardy Weinberg equilibrium. She claimed that the way this material is usually presented in college "…could be very confusing when you're finally trying to wrap your mind around evolution and change of gene frequency. And then you throw in there… these are the exceptions to the rule by the way" (Vig. Int.2).

In addition, Kate was able to recognize some difficult concepts for students during probed lessons. For instance, in her invasive specie class (Video1, VSR1), she shared that students had difficulties with species being invasive or non-invasive, foreign or not foreign. Additionally, she also said: "I'm not exactly sure at how well they [students] appreciate kind of boundaries, and what and I'm also not sure they appreciate that the state is a distinct place with its own distinct ecosystem but for species boundaries in terms of state line do not really exist" (VSR1). If we think about the idea of being invasive or exotic to a place based on imaginary boundaries (like state lines) versus real natural boundaries (like rivers or mountains), it can easily become complicated. This is the case not only for student but most likely to any citizen.

Knowing about difficult areas for students in science (such as graph interpretation and energy), and trying to tackle these areas in class more effectively reflect good teaching practice. The previous quotes showed that Kate was struggling to do this in her class, but seemed to be actively thinking about them.

Finally, Kate believes that understanding prior knowledge, misconceptions and areas of potential difficulties, and how they might affect ones class is not commonly acknowledged by teachers at universities. Like Kate said in one of her final reflections:

> I definitely can appreciate what students are coming to the table with [prior knowledge] when they come to the university, I now understand why so many of these freshman can make you pull your hair out, because they are not coming to the table with what we think they should come to the table with. (Teaching goals)

Kate had an interesting point of view regarding students constructing knowledge. Unlike other fellows she did not use the word framework (Chris) or skeleton (Taylor) to refer to a place where concepts were added as part of one's internal mental schemas. Instead, **s**he mentioned the idea of putting slats across gaps in students' knowledge to allow a better understanding of the content that was going to be taught in class. This idea transpires from the following comment Kate makes after discussing what concept she thought students need to know if coming to Dr. T.'s class.

> José: So what concept do you think students need to know before they come to you, know a class like this?
> Kate: That is a good question. I'm not really good. I'm still not good at that. Like when I have to fill out the lesson plans, like prior knowledge. I'm still not good at that. Because what I think, they should know they don't know. And you can think they should, whatever. But if they don't know it, you gotta, you know… just ignoring that gap (53:00) so to speak doesn't [solve the problem], and saying well you're supposed to know [this] so I'm gonna start here. You have seen yourself as a professor or as an instructor because you just pretty much said, you know what you were supposed to know that, so [since you don't know it] I'm not gonna teach it. I'm gonna start here. They're never, ever gonna be where you

> want them to be. And so yeah I think they should know it, but if they don't know it, I've got to at least, tell, give them, even if I don't fill the whole gap in I need to put some slats across. I need to make sure there's some slats there even if I don't fill it in. (Vig. Int.2)

This visual of knowledge gaps and filling gaps with slats is an interesting depiction of learning. Interestingly, before the second vignette interview, seldom Kate mentions the idea of constructing knowledge or mental frameworks in relation to this. Furthermore, her reflection on the third vignette really puts the idea of knowledge construction and the integration of prior knowledge into further perspective. After being asked the same question as in the second vignette (i.e., what concept do you think students need to know before they come to you, know a class like this?) she elaborated with the following comment.

> Kate: (Laughter) I don't know. I make so many assumptions about they knowing nothing. (laughter) … It would be easier if they knew nothing.
> Kate: {Like] Blank Slate. Well, they don't. They're not likely. Hum-- Not so much what they need to know. I'm sometimes more interested in what they think they already know
> José: What?
> Kate: Because that's really what you're working with. You're really working with hum, you know, either adding on to what they think they already know, or more importantly deconstructing any misperception that they think they have about the information at hand and have them build up, you know, correct information in its place of its foundation. So is not so much you need to know what blablabla means -- or know what you think you know about blablabla before I try to build anything else on top of it, before I try to add anything else to the fact of that, that complements that I wanna know what you think you already know. Go ahead and make sure we are all on the same page at then take it from there. (Vig. Int.3)

The way Kate discusses this question for a third time in the third vignette, suggests an increased understanding in student knowledge construction. The clarity of her description could be interpreted as an enhanced understanding. Before it was filling gaps now is about constructing on top.

In terms of motivation of students, Kate said it was hard for her to teach a group of students so unmotivated. Evidence suggests that Kate's notion of lack of motivation in a high school classroom was consolidated. These ideas transpired from a reflection during her first year at MOSTEP when asked what were the roadblocks she encountered in her first year? She said:

> …It was just really, really disheartening. It was really hard to come in [to the class] to help people who were not at all interested in learning. I had a really, I still have a hard time comprehending how someone isn't interested in their own well being… [They] really [have] poor motivation or worst yet, they have these really big ideas for themselves, these delusions of grandeur if you will, but they have no clear idea, not even a plan, an idea of how what they do relates to where they wanna be… You know like, I wanna be a pediatric surgeon, but you don't come to class or you make bad grades or you got yourself knocked up in the ninth grade. (Gen. Int.)

Furthermore, towards the end of the program, Kate shared the following thought while we were discussing the reaction of a student when she [the student] was asked to do the task at stake. The student basically answered to Kate that she wanted the worksheet to start the activity. Kate's reply to this instance was.

> [Imitating a student] Give me my assignment. Let me do my assignment so I can get back to doing what I want to do. Or at least keep off of my back. So they really and i've encounter this last year and this year. Do they get used to unless this is a part of what they do all the time, they will really hate. They really despise this whole making me think. Making me think and do work. They really don't like it. (VSR2)

Even though motivation seems to be something that bothers Kate, she always prepared her classes trying to consider the variety of student's attitudes and interests. For example, in the case of building the landfill model, she used a similar sheet (with parts to fill and draw) for all students, but left it open for students to plan the landfill however they wanted. Then she would go around their tables prompting them with questions so that they reflected on why they were doing certain things or making specific decisions (VSR2), trying to motivate students. The lack of motivation is something that was emphasized and targeted by Kate, and she also reflected that it is an issue that she would like to address in the near future (VSR2).

Student diversity. Moving away from knowledge about learning processes, evidence suggests that Kate's understanding of how student diversity affects teaching and learning, in science classrooms, changed.

> José: Do you think having a diverse group of students, matters?
> Kate: Yeah, I think it keeps the professor on his toes.
> José: How come
> Kate: Well…how so? Because if you are at least sensitive to your students you are at least trying to make sure you are reaching them and you recognize that [at] once, [that] they don't look the same. I can't make an assumption about their

backgrounds being similar and it really makes you think I got to make sure I'm at least trying to communicate effectively with every demographic in here. So I think having diverse students keeps you on your toes. Some students are going to ask you some more questions than others… (Vig. Int.1)

When trying to probe this same idea later, her response targets more of a 'student perspective' rather than focusing on the teaching perspective.

José: Do you think having a diverse group of students, matters?
Kate: I think it is important to have a diverse group of students. I would not have thought so many, many years ago. But I see the value of having students from different walks of life, students who learn differently. Students who have different, you know career interests in the class. I can see how it could be very, very good.
José: In what sense?
Kate: We don't all see the world the exact same way. So by kind of mixing things up you know suppose you have someone who's a little more visual or auditory, or someone who's more into memorizing simple facts by putting them altogether they all can help give a more complete picture, hopefully I imagine. (Vig. Int.2)

It seemed like Kate was reflecting more about the effects of diverse learners in a classroom from a learning perspective (i.e., students having different learning styles and career objective) rather than a teaching one (i.e., keeping teacher on his toes and communicating to all the audience). Apparently, she used ideas learned before (i.e., learning styles) to expand on her answer. However, in the last vignette intervention, Kate's explanation depicts a fusion of Kate's initial conception of diversity in a classroom "to keep professors on their toes" into a more solid description integrating learned concepts.

José: Do you think having a diverse group of students makes the difference in a class?
Kate: I do, I do think it makes the difference because if
José: How?
Kate: How individuals relate to the information makes an impact into how they understand it. How they translate, you know, all this stuff into bits and pieces that make sense to them and sometimes no matter how well meaning you are, or no matter how much information you may have in your head, you may not be able to communicate that to the students… and so having all these different types of people, … I mean different types of students having an input, it exposes the instructor, exposes other students to all of these other valid ways of understanding information. They all bring to the table these different experiences, which could bring different perspectives of the same information. Like a little networking seminar. One of the things… is that you want to have a diverse network of people; not just to work with it but sort of … bounce ideas off them, so that you

> work constructively, critique to each other and build ideas out. Because if you are around people who are too much the same, either in the same field or who think like you or have the same psychological trait, you can compound your flaws instead of identify them. You're more, I don't know, intellectually heterogeneous, in other words, you have more eyes looking out. You have different perspectives that can identify the holes or gaps or bring more to the table. That's why I think, having a diverse group of students, not just, you know, racially diverse but the, or, you know, gender diversity but also this diversity of background. I'll bring some different things to the table. (Vig. Int.3)

In general, Kate not only talks about diversity of student from a student perspective, but she does from a teaching perspective and synthesizes very well the potential advantages and disadvantages she sees of having different types of groups homogeneous versus heterogeneous in a classroom.

Summary

Kate's knowledge about students changed especially at the level of knowledge of learning theories, prior knowledge, pre-requisite and difficult concepts for students and the effects of diversity in classrooms. The passion Kate had when referring to these different areas was evident. One could tell her growing concern for students going through a pipe-line, being unmotivated and not appreciating education. This felt true to her especially when she considered that this happened more often in student's that were considered a minority in the population. Finally, Kate's understanding seemed to have focused more on the high school setting, even though the vignettes strictly portrayed an undergraduate setting.

Instructional strategies

Activities and representations

Evidence suggests that Kate was capable of creating and modifying practical science activities and representations to enhance student learning. For example, for her first video-taped class she created an activity where students had to craft a public service announcement (poster to educate) to teach the community about alien species. Part of the requirements of such an activity was to determine: who the players were (e.g., kudzu), what the problem was (e.g., displacement or eradication of native plants), why should they care (e.g., to avoid native species from disappearing) and how they could help (e.g., helping in efforts to remove kudzu) (Video1 ~30:11). For this activity she used construction papers, visual aids (e.g., PowerPoint slides and laminated cards), live specimens when possible and invited experts from the states department of Conservation and scientist from local universities to help students on their projects. Her overall goal was to give students a hands-on, real representation of the invasive species problem and provide live interaction with professionals in the field (VSR1). During the second video-taped class she modified an existing land-fill activity, to fit her educational context. Similarly she included a hand-on component, real examples, and related the experience back to a potential situation in the community (VSR2). This level of creativity reflects Kate's level of understanding with regards to how a concept, like invasive species or land-use, could be accurately represented to make as much relevancy to high school students as possible.

Kate was quick on her feet when asked questions about alternative ways to teach topics like: evidence for evolution (Vig. Int.2), food webs (Gen. Int.1) and population growth (Vig. Int.1), and provided examples and suitable representations to teach each of them. When she was asked to reflect on Dr. T.'s instructional strategies (Vig. Int. 1-3) and provide alternatives to the approach if disagreed, she provided well thought substitutes. For instance, when asked about population growth she discussed ideas about using many different examples as she believed Dr. T. did not use that many. Her examples included talking about different things that might affect population growth, like variation in life history of organisms: long-lived versus short lived and big versus small. In addition, she said that Dr. T.'s discussion/class could have been enhanced by adding a lab about mold growth limited by container size, or the Myrtle bean counting lab about population changes that also dealt with the concept of evolution (Vig. Int.1). Likewise, during the food web question in our first interview, she shared the idea of using currency to represent energy flow through an ecosystem.

> The gist is that energy, and I would like energy as nutrition and I'll keep there. Energy as nutrition is this currency that must be circulated within a system. That's the main gist… So that would be my big category and my next category is this currency is degradable. It does not stay in the same proportion as it moves around. Someone always takes something away. And you can't ever get as much as whatever it started out. That would be the main thing. That's the main if they didn't understand anything else, I consider them passing if they could communicate that in some sort of way (Gen. Int.).

Finally, during the evolution discussion in the second vignette, Kate shared an alternative way of presenting the evidence of evolution to students. Her goal was to help students "see for themselves how something is very similar but just a little bit different [at the same time]", making reference to variation. The following quote sheds further light on this example:

> Kate: …I would start you know at the visible level,… like looking at hands, arms or feet. And then I would take it down to like cells, homology, the DNA, amino acid, proteins. I think once people can see something's the same but just a little bit different then that's a good. It's a gateway for them to start looking at things that way. And I think, now that we're talking it probably wouldn't be bad to start there with teaching evolution. Now that I think about it. That might be a real easy place. Teach that first, then introduce the terminology of evolution and once they can go okay I understand homology, so I think the same but different… They have something that they can wrap their minds around. And if they can see if something is large, something visible that they have and can see and touch and feel and then take you down to the microscopic level like DNA. You know what it's all different. Like I can show them a DNA strain, see how they're all shaped the same. Let's take it a little bit further. They all have A, C, G, and T but bam, all proteins come with this. That's homology, and then all that other stuff. But bio-geography I'm still a little, I learned it but it never stuck in my head. I don't think I was that interested in it. (Vig. Int.2)

Summary

Although no change in understanding with regards to activities and representations is directly observed, it is clear that Kate was able to come up with very creative ways of representing information to high school learners and undergraduate students. Moreover this creativity was guided by her knowledge both of the context and her learners.

Major methods of instruction

Lecture. Evidence suggests that Kate's understanding of lecturing was challenged. In Kate's eyes lecturing was still the preferred teaching approach at the undergraduate level. She was very keen to share the following description of how a lecture would function in an undergraduate setting.

> …the traditional ideas [are] you have a professor who lectures from the book and they talk excessively. You write notes, you try to keep up. You go home that night to read, to try to keep up, you turn in assignments hoping you don't fall behind and that it's complete and it's all about… it's like you're racing to keep up with the professor. And it's always talking, no breaks, hardly any time for questions or

> they better be very, very simple, practical questions. Yeah, that's the traditional. (Gen. Int.)

The above description of lecturing is a good representation of what Kate thought happened in a strict didactic lecturing situation. For Kate, the ability to memorize facts and state them on a test, as the result of lecturing, is not a demonstration of learning. For her, this shear memorization, "… demonstrates someone's ability to regurgitate information, which isn't learning… It's a reflex" (Gen. Int.1). However, Kate pointed out that this "idea" (lecturing) seemed to be slowly changing since the inception and incorporation of centers for higher education teaching and learning around the country with in universities (Gen. Int.).

The above comments indicate Kate's dislike towards lecture approaches. However, during follow-up conversations and discussions related to lecturing, Kate presented some interesting views regarding lecture situations. For example, she had some pointers regarding the teaching of lectures that she believed were applicable to any level of the education continuum.

> …Like, quit lecturing for an hour and a half and expect all that [content] to get through… teach 10, 15 minutes max, do some sort of problem, or have some sort of discussion to synthesize it (Gen. Int.).

As a side note, the two components she mentions in this quote (i.e., 10 min with discussion and synthesis) where actually used/implemented during her first video-taped class about photosynthesis (VideoA). In this class, she had a PowerPoint slide with a question after every three to six slides, where she would call on students to discuss what was just covered previously in the lecture or summarize some of the points she made. For example, the slide name would be "Checking for Understanding" followed up two questions: a) What's the ultimate source of energy for plants?, b) And How do heterotrophs obtain energy?. Prior to this she had talked about sources of energy, autotrophs and heterotrophs.

Three weeks later, after being questioned about one of her reflection comments regarding Dr. T.'s teaching approach, she re-commented that not everything could be taught in an interesting manner through lecture. She added: "I'm still riding the fence and I think some material, just because it's so complex, you just got to sit down and lecture it.

I don't think there is an interesting way to lecture everything." When discussing human anatomy she said:

> You just got to tell them what is what, and where it is. You just got to. There is (laughs) this is an arm, this is a leg, this is the stomach, this are the cells. You just got to lecture that, get it out of the way (laughs) as in other things like physiology some concepts you need a little, you need to explain it… (Vig. Int.)

My understanding of "riding the fence" is that Kate was hesitant towards using or not using lecturing as a teaching strategy. Somehow this hesitation showed some of Kate's internal debates and hence the potential for growth regarding her understanding of such strategy. Two months later, Kate showed some strong feelings regarding lecturing. She said: "…when I was in college I was often overwhelmed by professors that would zoom through the material. (Vig. Int.2). Concurrently, in her written reflection of what she liked about the vignette, she said "I prefer teaching in this manner [lecture and facilitated discussion], myself. I think it blends the best of two approaches and provides new or complex info to students and then gauging them for understanding" (Vig. Wri.2). It seemed like Kate was going back and forth as to what stance she should take with regards to the use of lecturing strategy and its variations.

Finally, during the last vignette intervention, Kate was asked to provide some pointers regarding lecturing.

> Kate: Oh. -- The one thing that I'd take away from it that I'll give to you or anybody else [is] before you go into that class,[make sure you know] what is it that you want them [students] to know? What is the most important thing that you want to make sure they understand before they leave that class today? And write it down, and tell them. It should not be a secret to students what they are expected to know and how much they should know…. (Vig. Int.3)

It is clear from the vignette conversations that Kate's views regarding lecture are being challenged all along.

Parallel to this, we observe that in her video-taped classes a progression from lecturing (videoA- photosynthesis class and videoB- community ecology class) towards using more activities, hands-on experiences and inquiry strategies (video1, video2). For example, in the first video she implemented some of the strategies she discussed in the first interview, specifically about stopping after 3-6 slides to have students think about the material. However, the class itself was mainly lecture with a few discussion sections

(Video A). In the second class she dealt with niches, communities and species interactions. The format was very similar to the first video but included, for the most part, more discussion sections (Video B). In the invasive species video (2nd year in MOSTEP, Video1) and the landfill activity (Video2) Kate used more of a hands-on approach. She did not lecture as much but incorporated activities that required manipulation of materials, and asking questions to stimulate more critical thinking. For instance, in the landfill activity she asked the students to think about what variables to include in order to design the best landfill model (Video 2).

Finally, Kate took some time to discuss some issues about using PowerPoint's in lecture. For her, talking about the dynamics of PowerPoint was very much related to lecturing. Nowadays it is one of the preferred visual aids professors used in their lectures. Kate basically talked about PowerPoint's "fooling you in to thinking that you are covering more material, when you really are not" (Vig. Int.3).. She believed that students did not understand the content that well when a PowerPoint was used.

> I'm a Power Point minimalist. I would, and this is just me. I'm against putting too much on Power Point. Because I think that you should take notes. I wouldn't put anything up for them to print off later other than my objectives that I expect them to know by the end of the day. Unless you get some really neat pictures, unless they really need pictures, I will put those up other then, you know that I wouldn't give them too much. That's the purpose of coming to the lecture. If they don't think they get anything from coming to see me in lecture they don't have to come, but I at least would let them know what, you know, the learning objectives for the day. (Vig. Int.3)

Summary

In general, it seemed like Kate had some internal deliberations regarding the effectiveness of lecturing as a teaching strategy. Maybe this debate had more to do with the context in which the discussions took place (i.e., high school versus college). For example, she shared good ideas of how to lecture and at the same time provided negative feedback about the effectiveness of the strategy. Moreover, the transition shown by her choice of teaching approaches, from a lecture-base class to an activity-based class, could be indicative of change, at least within a high school context. Overall, she basically knew about: some of the problems behind lecturing, current trends in terms of teaching and learning at college level, and some of the problems with tools being used during lecturing (e.g., PowerPoint).

*Questioning/Discussion***.** Kate's understanding of discussion, as a teaching strategy, seemed to have changed. When prompted with a similar scenario in two different occasions (i.e., vignettes), her observations and suggested improvements seemed to change. For example, during the first vignette Kate said that she liked the fact that the instructor (Dr. T.) invited students questions and comments and she also felt like students felt comfortable enough communicating. What she disliked was that Dr. T. did not give students enough time to think about the questions, answering them himself quite quickly. When asked how she would improve on this approach she said:

> I would call on specific students and ask them to try to explain the concept in their own words. I might even promote a mini-discussion among the students and ask them to provide some examples of each type of growth. I'd also omit some of the details about deriving equations. I don't think it is key to understanding the concept. I'd explain the phenomena and define the equations and leave it at that. (Vig. Wri.1)

Towards the end of the program, 7 months later, when asked the same question she commented that she liked the same things but she disliked the fact that Dr. T. was not sensitive enough to the level of understanding that students might have had. When asked how she would improve on his teaching she said:

> I would address the main concept first. Provide the students with the information about the topic (e.g., pop growth, define key terms, give examples and brief discussions to assess their understanding of materials at certain intervals). I would [have] discussions about scientific critiques, the scientific process for the end of class as closure. I'd focus less on the official definitions and encourage them to define the terms for themselves. In lines 145, 146, they wrapped up the discussion talking about predations, disease, and behavior. I would have introduced these examples first, during part two. Then I would have explained how they are examples of density-dependent and density independent control. If I needed to, hopefully they would have noticed the pattern on their own (Vig. Wri.3)

The detail into which she goes when explaining how she would improve the practice the second time around can be seen as a surrogate of Kate's change through reconciliation of what she had learned, into a particular discussion situation. We could argue that the logical composition of her explanations is an indication of change regarding the use of discussions.

Concurrently, if we look at some of her other comments during other interventions, we can appreciate Kate's developed inclination to guide students through appropriate questioning during discussion more so during her second year. For example, in her first videotaped lesson (VideoA- i.e., photosynthesis) she taught mainly using a lecture approach with little discussion embedded. In her second year, both video-taped classes (VSR1- Invasive and VSR2- Landfill) showed a different approach to things. The lecture sections had more discussion embedded in them, and she interacted and probed students for understanding more often. She shared that she also liked to nudge students, "I don't tend to give them the answer. I nudge them" (VSR1), as a way of guiding them towards an answer instead of giving it to them. Different from her first year and consistent with the vignette analyses provided above, Kate also mentioned, in the second video stimulated recall interview, that she would use discussion sections as a way of summarizing or getting students to interact among themselves. These alternative uses of a discussion section demonstrate the creative way in which Kate envisioned using discussions other than dealing with controversial topics.

Summary

Most of the ideas presented by Kate are interesting ideas about how to deal with discussions in class and uses of discussions. Discussion-based learning is more complex than just talking about an interesting subject or topic within a subject. The lack of control regarding direction, appropriate questioning, and required wait-times, if handled incorrectly could result in chaos. The fact that Kate provided some pointers regarding discussions and questioning approaches and the way she challenged Dr. T.'s approach to discussion, showed a degree of understanding regarding such strategy. We could argue that her level of integration of other components of PCK into this strategy, like NOS and assessment, could indicate an increased understanding of discussion-based learning.

Inquiry/hands-on. Evidence suggests that Kate's understanding of inquiry as a teaching and learning strategy changed. When talking about bad teacher qualities, Kate criticized science teachers that gave the answer to students instead of helping them figure out an answer (Gen. Int.). Later during one of her interviews she shared that:

> Even if the teacher teaches you all the great key words, what I found is that, even at the best school, they don't teach them process… like doing experiments, understanding an experimental design… (Vig. Int.1).

In another instance, when talking about some college teaching strategies, Kate brought up an interesting comment about labs at universities.

> I really think labs really need to be revamped in this country. Labs are really an under utilized learning tool. They've become, babysitting classes at a lot of universities… Well, student sit through a lab and they do stuff for the sake of doing it and they don't always know why they are doing it and it's not always very clear how it reinforces a concept (Vig. Int.1)

The previous comments tackle the essence of scientific inquiry. The first comment implies the idea of guiding students towards an answer through adequate questioning. The second comment touches on the idea of the process involved in doing science (i.e., scientific method and designing experiments). Kate's stance suggests disapproval of how inquiry and processes that can benefit from inquiry approaches are handled in teaching and learning environments at various levels of the education continuum. She further reflects on these issues and proposes alternatives to deal with some of them. For instance she proposed that to improve on the lab experience one should:

> Emphasize, … instead of 'we are going to do this today' you know just before we get started, give the overview. 'Okay, so what do you think the hypothesis is'. Before we just start, what's the hypothesis? What are we going to do? What are we going to do with these results? What are we going to conclude? Most of the times we just do it, we write the answers down and you go…so what do you think that means, uh? How does this fit with what you've been learning? Does this have something to do with what we are learning? It's just…it's [just] activities [for them] and they don't see the scientific method in it. So when they are expected to do this independent project they are lost because they are thinking "oh men I got to remember the scientific method. Men, I don't know what parts are what". (Vig. Int.1)

Guiding students through the process of doing an investigation and making students reflect on their practice, like she proposes, would be a better approach, and more in tune with scientific inquiry. It is clear that Kate's experience in both high school and universities gave her an important perspective on this. Furthermore, Kate emphasized the importance of NOS in relation to designing and running experiments. She talked about working with students to help them understand the scientific process by, for example, realizing that there was no mistake in arriving at a conclusion that does not support your experiment thoughts.

> Let me tell you a secret. This isn't about there's a right answer. You are testing an experiment. If we knew the answer we wouldn't be doing the experiment…

Later she added,

> Okay, well let me tell you. Okay, you know? Sometimes we do stuff wrong and we don't know it. That's why I ask you to write everything down. That way you can go back and retrace your steps if something goes wrong. Okay? (VSR2)

Apparently, Kate tried to ease some of the helpless feelings students get if they do not get the right answer during in an experiment. In a high school setting sometimes not having a correct answer usually ends up in a lower grade, even if the discussion of the results obtained would have been more fruitful in developing an inquiry mind (VSR2). The fact that Kate stresses the importance of doing this in one of her classes speaks up to her stance regarding the importance of teaching the NOS.

At a different level, from a curricular point of view, Kate demonstrated some level of understanding regarding the learning cycle (LP1, LP2, Video2). The following reflection made by Kate shed further light on her position regarding inquiry as a teaching and learning strategy as shown by the following comment she made.

> Kate: … the learning cycle… I just don't think its time, time wise, in a college setting for us to do that for, because in a college classroom, I think it's reasonable to teach multiple concepts in a day, instead of one concept in a day. I think its okay to teach two to three concepts per day that are related… So I will [also]… make sure the laboratory component was a part of there learning cycle …the application of it. (Teacher goals & Ref. Int.)

Looking at the lecture being synchronous with the lab so that the learning cycle could be applicable to help students develop as scientist is a strong indications of Kate's level of understanding regarding the use and implementation of inquiry. Her rationale of using or not using inquiry according to the context and circumstances seem appropriate and probably are the result of change.

Finally, some of Kate's comments during her landfill lesson and the teaching approaches she used reinforce are evidence of Kate's understanding of inquiry-based instruction. For instance, she allowed students to experiment with their own landfill model design while she went around asking students for reasons behind their chosen variable and designs. She also asked them to keep notes of what they were doing (VSR2).

Summary

Kate's reflections show further insight with regards to her level of understanding and change regarding inquiry-based teaching and learning strategies. Her descriptions of what inquiry is, the roadblocks and how it should be used in classrooms are very insightful.

> Teaching via Inquiry (problem-based learning) is very hard. At first I didn't understand it (and don't get me started on the Enquiry vs. Inquiry thing). But I soon realized that inquiry is what scientists do all of the time. I became interested in figuring out how to convert a normal activity into a useful and effective learning tool for high school students. (Ref. Int.)

In her teaching goals she further outlines how she would like to engage students in inquiry and further discusses some of the roadblocks one could encounter while teaching inquiry. She includes some of the ways she would avoid this roadblocks.

> Engaging students and encouraging them to become critical thinkers is paramount to the understanding of scientific principles. As a result, I am a strong proponent of inquiry-based learning. Inquiry exercises via lecture, laboratory, or authentic research experiences allow students to pursue knowledge of a specific area as well as to learn how science is done.
> Roadblock 1: High school students do not know what inquiry is and they are uncomfortable with this learning style.
> Resolution: Tell students what inquiry means. Teach them how to explore phenomena. Explain the concept to them. Give them simple exercises to introduce the method to them. Reinforce the concept of Inquiry and relate it to active or self-directed learning, a very valuable learning tool for them. Introduce this teaching method slowly and start early. Teach via inquiry the beginning of the year and continue. Do not rush into it. Ease them into meeting higher and higher expectations. Focus on the process. Emphasize the importance of developing well-thought-out answers. Reassure them that it is okay to keep on trying. Encourage them to revise their position or answers. Reward students for trying and help them build confidence in themselves. (Teacher goals & Ref. Int.)

> When addressing the scientific method.

> "Tell me and I'll forget. Show me and I'll remember. Involve me and I'll understand." I believe this quote best summarizes why active learning is so important. Active learning involves student participation in a lesson, and inquiry activities can be used to illustrate, demonstrate, and verify scientific concepts. Plus, such activities are perfect opportunities to teach students about the scientific

> method and can be implemented in both laboratory and lecture sections (Teacher goals).

This level of understanding and reflection about: the pros and cons of inquiry-based instruction showed evidence of change in Kate's understanding of inquiry-base teaching and learning strategies.

Other strategies. During our conversations regarding teaching approaches, vignettes, and video-taped lessons Kate brought up a number of instructional strategies that were not mentioned by other participants. Apparently, she seemed to have learned about most of these strategies while she was involved in MOSTEP. The strategies discussed fell mainly into three groups: 1) group work; 2) role-playing and; 3) sign-posting and summary rounds. Regarding group work, Kate praised her mentor's group teaching strategies. She specifically addressed the jig-saw activity.

> …She's really good at doing lots of group of activities with the kids. There's this thing, I don't know all the different words they use, but she called them jigsaw activity, where everybody reads the same page, but one specializes. That was a neat technique that I had I'm sure our teachers did it, but I don't remember (Gen. Int.1).

Furthermore, she commented that, even if she had a big lecture class, she would definitely encourage group work to help students interact with each other. When asked why she would do this, she said that she personally had done better when working in groups because she "talked things out" (Vig. Int.3). When dealing with a specific issue related to group work, for instance during the second video tape interview, she commented that she had changed the original activity which was meant to be done in groups to an individual activity. Her reasons were the following:

> I modified this [landfill activity because] she originally had them [students] working in groups. Several [students and groups]. And I thought this would be more, I thought it was simple enough that they [my students] could do it individually. Because when they work in groups there's always one or two kids that do the work. And the others just look (VSR2)

In her reflection interview Kate talked about group work as a way of promoting student-centered approaches and something she would advocate (Ref. Int.). Although Kate mentioned group work as a strategy she would use, it is questionable to what degree she understands the specifics of such strategy. Not enough information was provided during our interviews to uncover this. What can be said is that, she believed using such strategy was important and that she was able to distinguish the limitations of such strategy depending on the context.

A second strategy she talked about was role playing. For instance, during the first interview when I asked her how she would teach food webs, she said that she would make every student be an organism. She provided the following explanation as to how the activity would work in a class.

> …[So]…every student would be at least one organism here. You'd be an organism and in this case, the krill is the center of attention, I might have a few students be the krill and basically I tell them, this is your system. (51:00) You all gotta eat. Find your food. You know, you can see what each of you all are. It can not only demonstrate the energetics that are involved, but we can also get into some other topics of what I call before organism response. What do you have to do to get your food and not get your food? I believe in role playing to demonstrate it, because all too often because of sitting in lecture, we're expecting people to run these little mini movies in their head or slides coming across the middle of their brain to understand visually and in 3D perfectly what's going on at this macro scale or micro scale, that they just can't relate to. It's not real to them. So I think by making students even at the college level, because I've done this even with undergraduates, get up and now you take on the role of the subject in this matter and at least gives them an opportunity to experience what might be happening (52:00). I just maybe because I'm just a little bit more animated I think. (Gen. Int.1)

This description of how a particular role-playing activity unfolds and how to run the activity demonstrates a good grasp of such strategy. Similar instances of role-playing had been observed in the two last video-taped classes (Video1 &2). In the first video, Kate's initial thought was to ask students to write a legislative proposal pretending they were the city council to get rid of an invasive species of their choice. When reflecting on this activity she acknowledged/realized that she was not going to have enough time in class, so changed the activity. She made students pretend that they were in charge of communicating with the local population about an invasive species via a wanted note (VSR1). Later on, in a different activity, she asked the students to pretend they were going to design the next landfill architecture for their local municipality (VSR2). Looking back at the examples presented it seemed that role-playing and simulations are a preferred teaching strategy for Kate.

Finally, in terms of sign-posting it seemed like Kate liked this approach, especially when referring to a college level context. In one instance, during our first interview, she said: "I believe in kinda sign-posting" when asked about how she would teach students energy transfer across food webs (Gen. Int.1). The explanation she gave in terms of sign-posting was that she would let students know ahead of time where they were heading during a lecture (i.e., objectives, a graphic organizer with words/concepts) and what skills or concepts they might need to revise for coming lectures. When interviewed, she pointed at some of the benefits she believed sign posting had.

> Sign posting is a very good strategy, especially in an intro level course with students that come from a variety of backgrounds. It helps students see where they have been, where they are going, and how it all fits together. (Vig. Int.1)

A similar use of sign-posting, to overcome lesson road blocks, was discussed further during one of the interviews, she commented: "You should let them (students) know where you're going and you should stop along the way and make sure they understand it [the topic/ concept]." (Vig. Int.2).

Summary

Role playing, sign-posting and group work were some of the strategies that Kate seemed to have some knowledge about. Apparently, one specific strategy, with in the group work strategies, i.e., jig-saw, was learned during her time with MOSTEP. Other strategies like sign-posting seemed to have been gained during this time but not in the MOSTEP program. She learned the strategy from a professional development teacher's workshop she attended on her own accord. We could argue that Kate's instructional repertoire changed during her MOSTEP years.

Communication techniques and strategies

Kate's communication techniques and strategies seemed to have changed. In general the idea of communicating effectively is something that did not come up too often during our conversations with her until the last few months. When it did, the information provided insights into Kate's perceived change in her understanding of them. For example, at the beginning of her second year in the program one aspect of communication that Kate brought up to my attention was that one of her goals was that this year she needed to be an effective communicator. In particular when considering the demographics of the population she was going to teach (i.e., mainly African American) (Gen. Int.). Later in the program, Kate added that she had become more cognizant of how other people communicate their scientific findings or teach their lessons to a point that she would think of ways these could be improved. The following reflection sheds light on this matter.

> I found it really clear when I go to meetings, that… they are not necessarily teaching but they are trying to compel people to do something. Which that's what we're doing in teaching, we are compelling "them" [audience] to think about a stuff [a topic or content] differently, and sometimes we compel them to do an activity that changes how they think. But I find myself … critiquing how they present their information. How well they communicate their objectives and what they are trying to do and I even find myself critiquing people what you wanted was blank. How you presented to me didn't really compel me to want to help you with that. You didn't compel me to give you my attention, or to give you my time. Or a call signs on your adventure, because you know, of how you presented it. (Vig. Int.3)

I think her comment reflects the level of internalization Kate had undergone with regards to appropriate communication. However, she also shared that putting scientific concepts and ideas into a more "colloquial" language, was not welcomed by some scientists and was not easy at times. She said: "When I talked to other scientists and I give… my general public explanation of my research, suddenly I get scalds and people asking me that's not the right word… I mean it really bothers some people" (Vig. Int.3). Nonetheless, Kate concluded that after participating in MOSTEP she felt that she had improved her ability to communicate to the general public more effectively. Finally, she shared that she felt like she could, by modulating her way of communicating, reach students that might be behind a few steps, with them (Ref. Int.).

Questioning strategies, verbal and non-verbal communication. In terms of questioning strategies and verbal/non-verbal cues, Kate had interesting points of view as to how these ideas operated in a learning environment. Ideas such as: guiding students through questioning, re-phrasing and non-verbal cues have been outlined and grouped together in the following section. Relevant quotes have been added to provide further information on Kate's perspectives regarding each idea/group. At times her level of understanding remains consistent, at other times it changes.

Guiding students to an answer through questioning. In some instances Kate talked about guiding students to make them think about the content at stake. The following quote was in response to what she liked about Dr. T.'s teaching approach. [Quote1]: Even when students provide inaccurate answers he tries to steer them in the right direction (Vig. Wri.1).

A similar example is discussed later during vignette interview #1 when Dr. T. re-verberated a students answer (Vig. Int.1).

> …He asked the students to try to explain the graph in their own words and even when a student gave him an answer he wasn't expecting you know he didn't berate the student he just um not exactly. And then he re, he read. I can see here that he's trying to re-direct the student (Vig. Int.1).

Mentioning these instances when critiquing Dr. T.'s teaching approach suggests Kate's has awareness of such a strategy. In a further reflection during her video-stimulated recall interview she shared how she wished she had incorporated more guiding.

> José: Could you have a foreign noninvasive species?" I was supposed to ask that here.
> José: Ok. What effect would that have had?
> Kate: I hope it would have got them to thinking so that when I finally show them these two I would have gone, Ta da. You can have a foreign but not invasive species. (VSR1)

Finally Kate also wondered about guiding students too much.

> José: Why did you ask this question on pluses and minuses of biological control?
> Kate:Um. I wanted them to think about, you know that it's not all one or the other.
> José: Ok.
> Kate:And as I did it I realized I probably gave the answer away by throwing it in there at the end. But.
> José: Why do you think you gave the answer away?
> Kate: Cause if I had just said, "Do you think it's good or bad?" Ideally, you know some kids had said good, some had said bad. Then kind of go, "Well, could it be a little bit of both?" I could have probably facilitated it a little bit better. (VSR1)

And,

> I was hoping not to guide them so much but their faces were completely blank. They had blank faces and so that's why I threw in the guiding (VSR2)

Guiding students to an answer is not an easy task, especially because every individual comes with a different prior-knowledge. Nevertheless, critiquing questioning strategies, even at a superficial level and providing instances where the strategy was used could suggest that a certain level of understanding of this communication strategy was developed.

Using questions to bringing forth prior knowledge. At times Kate seemed to help students articulate their ideas and bring forth their prior knowledge using guiding questions. For instance, in her Photosynthesis lesson (Video1), before teaching about factors that were important for photosynthesis she asked students questions as to what kind of energy different things (e.g., cars, mp3, people, animals, plants) need in order to function. In similar ways she asked questions during her invasive species activity/lesson (Video3) when discussing different birds species and their status regarding invasiveness or not. She would ask questions like if a bird or organisms was a resident of the state or not (VSR1). Finally she does this same drill during the land fill activity when looking talking about the specifics of landfills structure and locations (Video4). She asked students questions about locations of some of the states landfills, or what they were made from (VSR2).

Tone of voice, modulation of voice or ways of saying things. Kate believed that the way Dr. T. asked his question in the evolution vignette was very confrontational. She said: “I wouldn’t have made the comments in lines 289-290, they seem confrontational “ (Vig. Wri.2). In her practice she constantly changes her way of saying words to students, for instance the phrase “all right”.

> Kate: Aaa right. All right. I never noticed that. That’s two different ways.
> José: Yeah. My question is why.
> Kate: I never knew. I never registered that I did. Aaa right is more conversational. And then all right I guess I was getting back into my adult mode. (VSR2)

What is interesting is that she does not realize this. In another instance she talked about the tone or the “confidence” in students’ voice as a cue to know that they are not comfortable with the issue at stake

> Kate: I was, I don’t know, giving her a pat on the back. Her voice made her sound as if she wasn’t very confident in what she produced. (VSR1)

Non verbal cues. Kate was very big in non-verbal cues. She often criticized professors for not observing students' facial expressions to understand what was going on in the classroom. For instance she said that it is important for you to know by looking at those faces if they're not getting it or if something is not right (Gen. Int.1). The following excerpt sheds some further light on this.

> One just try to tell yourself or remind yourself not to go so fast. Give students a moment um read their faces and their body language to actually see what's going on at their… really trying to figure it out or they just sitting there going ok you give us the answer so that I can write it down and if necessary just start calling on students insisting that they give the answer like: … (Vig. Int. 1).

In her practice she also seemed to be aware of facial expressions in order to know what was going on in her classroom too.

> Kate: The reason I I was hoping not to guide them so much but their faces were completely blank. They had blank faces and so that's why I threw in the guiding. Because they were just like ah, ah. They were looking blank (VSR2).

Also during the second vignette, Kate brings back the idea of non-verbal cues as an important aspect of teaching and learning.

> José: Okay. Now as a teacher how would you notice that if they are going out or not with your, with what you're intending?
> Kate: Well you never know. And I know you don't know. You can read body language but then that can be deceiving. Because who's that one kid who nodded when he was really confused
> José: You see that often.
> Kate: Yeah, I do see that. I do, yeah I'm learning to read people. (24:00) Some people you yes when it doesn't mean yes I understand. It just means yes input information received. It doesn't mean -- José: Not process, input.
> Kate: Yeah, input taken in. I've read about and so I'm not, I wouldn't know enough to use it myself but (Vig. Int.2)

At a later date, in a similar manner, she also addresses this issue.

> Kate: Hum -- try your best. Train yourself to start watching them to make you know, to watch them, if you can get some feedback. They may not always give you verbal feedback, --to start looking for some body language. (Vig. Int.3)

Non-verbal cues seem to be an important aspect of communication that Kate considers in every aspect of her practice. Even when critiquing colleagues or teaching at a high school level.

Summary

Overall, Kate seemed to have some basic knowledge of the importance of asking questions in an effective way to guide towards an answer and not provide an answer. In addition she was very sensitive to the importance of non-verbal cues and how to read students' expressions in class to assess student learning and hence direct her teaching.

Transfer

Evidence suggests that some of the knowledge gained by MOSTEP, related to her PCK, had the potential to transfer across context in a bi-directional manner. In some instances Kate shared ideas of how things she learned in the high school context could be used in a university context and vice-versa. The first analysis will focus on transfer from high school to college. For instance, while discussing the kinds of strategies that were used in her mentor's classroom, I asked Kate if she thought these strategies could be used in a university setting. She answered that sometimes and said that it depended on the class (e.g., size and topic). Then she added:

> I can see doing [group work and inquiry] in discussion sections. Definitely in labs, so that students just aren't feeling like they're just doing recipes all the time. So it's a good chance for them to, excuse me, sit and think and present information back to lab mates where you have smaller groups (Gen. Int.).

On another occasion, during the same interview, she added that she would definitely work on team building and mixing groups during laboratory experiences in universities, much like it was done in her mentor's class. The following comment sheds some further light on this matter.

> The other thing that they do or at least they try to do at the high school level which I think would be good at the college and university level is do some sort of team building, even if it's a really small the first lab day, because first labs always either be are usually nothing and bore the hell out of everybody or they throw them right into a complex situation and they don't understand what's going on. So at the high school level they usually do some sort of team building so they get to understand each other and ask them how they work. So I do that. And at the high school level, they tend to mix groups up constantly, who they work with in groups. I think that's a good thing at the college level too. (Gen. Int.)

During a vignette discussion Kate added that she would definitely pay more attention in the area of student prior knowledge when teaching at a college level (Vig. Int.2).

Additionally, she said that she would definitely emphasize learning about the NOS and scientific process skills especially in college laboratory sections. This idea transpired from the following comment.

> And the one thing I have learned and I have started thinking about as of this year, actually because of MOSTEP is using labs to reinforce what I call “scientific process skills.” Labs are designed to do that. But they don’t because I think far too few people have deliberately thought about how to teach those things. There’s an assumption, a huge horrible assumption, cannot say that big enough, huge, horrible assumption that students come to your class already knowing at least what they should be doing. And they don’t … But there’s nothing deliberately done at the college level to show science majors how science is done and what science means. And labs are the opportunity to teach it at the freshman and sophomore level and to reinforce it at the junior and senior levels (Vig. Int.2)

Later on, she made a similar claim but emphasized that she would also mentor TA’s with regards to the implementation of NOS.

> …I will, even in freshman level, in lab, lab should be, I would, I would make sure if I’m teaching at lab or that TAs that I work with, I would make sure that they would be completely cognizant of the scientific process that they would do in labs. Not just doing it so they can rush out (Vig. Int.3)

In contrast, when looking at transfer from a college level to a high school level Kate shared other interesting ideas. For example, something she learned from a college professor teaching workshop that was transferred to her high school context was the idea of stopping during a PowerPoint presentation and checking for student understanding using a pre-fabricated question. The following comment sheds some light on this matter.

> This [workshop] was for college professors. But I thought a lot of what he said rang true…he was like quit lecturing for an hour and a half and expect all that to get through… And I’ve heard it from a couple of others like teaching conferences that said teach 10, 15 minutes max, do some sort of problem, or have some sort of discussion to synthesize it. (Gen. Int.)

Kate used this strategy in her first video-taped class (VideoA- Photosynthesis). She then used similar probes during other video-taped classes. A second example is the use of role-playing. As discussed earlier, Kate used in many of her video-taped lessons a role-playing approach of some sort. Apparently, this particular approach was tried before by Kate during her undergraduate TA experience. The following comment sheds further light on this matter.

> I believe in role playing to demonstrate [a concept], because all too often because of sitting in lecture, we're expecting people to run these little mini movies in their head or slides coming across the middle of their brain to understand visually and in 3D perfectly what's going on at this macro scale or micro scale, that they just can't relate to. It's not real to them. So I think by making students even at the college level, because I've done this even with undergraduates, get up and now you take on the role of the subject in this matter and at least gives them an opportunity to experience what might be happening (Vig. Int.2)

Summary

It seems for Kate transferring across contexts is certainly plausible as has been presented above. In particular, group work (i.e., team building, group manipulation and collaboration), ideas of NOS, stopping during a lecture to probe for understanding (i.e., formative assessment), inquiry learning (during lab work) and role-playing strategies are some components of teaching and learning in science that could have the potential to transfer across contexts.

Finally, the following reflection summarizes further Kate's perception of what she learned that had the potential for transfer.

> I feel my experiences (during MOSTEP] have prepared me to be a fantastic freshman and sophomore level life sciences instructor... I feel more confident about my ability to make a positive impact on my students and their understanding and perception of science. (Refl. Statement)…
> José: So, from your experience in high school teaching and learning environment, is there anything you have learnt that could be applied at university?
> Kate: Yeah I don't doubt it, yeah a lot of stuff.
> José: Can you give us some examples?
> Kate: Like the [lesson] plan development and may be not in detailed as [the education specialists plan] but if, but you know what though I resisted there at first.. I appreciate them now, I really do, I resisted at first (24:00)… You know hold one concept at a time. I never realized how I was just layering information on, so being clear of what I want to teach and what I want them to know, may be I don't have to go through all the exact details of, right now you know my starting exploration, formation, application and summary. (Ref. Int.)

Something she believed was not transferable was the use of the learning cycle, especially in a lecture situation.

> Kate: … I just don't think its [appropriate] time wise, in a college setting for us to do that for, because in a college classroom, I think its reasonable to teach multiple concepts in a day, instead of one concept in a day. But what I would say from that is, you know announcing, 'listen these are the three concepts I'm going to cover, these are the two objectives, three objects per concept that I want you to

> understand (25:00). So I will be clear that way, and then I would, yeah that's what I would take from it, and I would make sure the lab, the laboratory component you know was a part of there learning cycle (Ref. Int.)

Potential Sources for PCK

External to MOSTEP

Outside MOSTEP. The following experiences seemed to have influenced Kate development of PCK: a) scientific presentations; b) seminar and workshops; c) reading materials; d) high school and undergraduate/ graduate student classroom experience; e) TA experience; and f) reflection on her own learning. I have outlined a few examples on each of the area to support these claims.

Scientific presentations and her research. As the puts it herself: "*Even with my research. Like before I get started I have to have everything set up in a certain place. Like my tape recorder has to be there. Gotta have my pen and my paper before I can get started (VSR1).*" Her approach to research is as methodical as her approach to developing herself as a teacher.

Seminar, workshops and conferences in education. In several occasions I heard Kate mention strategies she learned in conferences and future professoriate seminars. One example of this was the North Carolina A&T Engineering department seminar. She learned about stopping to assess students and sign-posting/ guiding students (Vig. Int.2). She actually used this idea when teaching some of her classes and video-taped (Video1). She learned also a cliché phrase that she used quite a bit during our conversations:

> I think I heard it in some sort of little lecture, workshop. Someone else teaching workshop on one of those little nice, little feel good things, tell me and I forget show me…teach me and I might remember show me and I'll understand, involve me and I'll know one of those cutesy little saying but. (Vig. Int.1)

Finally another instance where she learned about pedagogy was through NPR and her psychology friends. Like the idea of multiple intelligences discussed in the second vignette interview (Vig. Int.2).

Reading journals. Kate had subscribed to an e-mail periodical listserv from Stanford's e-List. She also apparently revised other literature related to teaching and learning for example Habermas' theory of poverty (Vig. Int.2). She shared that she learned ideas like using index cards (she called it the auction method) from a book "I've read about and so I'm not, I wouldn't know enough to use it myself but I've read about giving like quite little oral quizzes so you know like, or fill out an index card and hand it in and read through them." (Vig. Int.2). She also read about using a multiple choice to perform some formative assessment; "… And [the author] gives multiple-choice questions at the end of every concept. And then they raise the appropriate letter, and he gauges the audience to see which is which, you know what percentage of them" (Vig. Int.2).

As a college and high school student. While discussing good and bad practices of teaching Kate said: "I never understood where he [college professor] was going and where he was, plus he was monotone" (Gen. Int.). Furthermore, the idea of sharing the goals with the class was a common topic brought by Kate during our discussion (Vig. Int.3). Another reflection she shared was how one of her professors engaged her in a class in a way that made it worthwhile to her: "The labs always had something to do with the lecture, and it was a very, very hands-on lab. The professor gave you 10, 15 minutes of instruction, so then you work with your group to get things…" (Gen. Int.) Moreover, other instances, like teachers calling her by her first name, were something she appreciated (VSR1). Finally she made comments of students being overwhelmed in college by professors *"zooming through materials"* much like she had experienced in the herself (Vig. Int.2).

Regarding her TA experience. Some of the activities Kate uses in her high school mentors class were activities that she had done before during her TA (e.g., tooth pick/ natural selection lab). Also, her way of bringing to our conversations ideas about changing TA training reflects in her TA background as a source to make judgments during our interviews (Vig. Int.3, and Vig. Int.1).

Regarding reflection on her own learning. As Kate states herself: "I found that it was better for me as a learner when they stopped and asked questions of to make sure we understand"(Vig. Int.2). Moreover, when discussing group learning as a strategy that worked for her she said: "… I've noticed I've done better when I worked in group even if, even if we just talk it out, sometimes I go, Oh, now that I've talked it out…" (Vig. Int.2). Apparently, this reflection was something that Kate did when she finished teaching in her MOSTEP class as she shared later: "so I revised whatever I thought went wrong in the activity and then in the notes section, it's like a page long now, I say what I would add and other" (VSR1). She explained that she also wrote things down on her journal. Finally, in the lesson plans she posted on MOSTEP Blackboard site she was keen to share what worked and did not work in her lessons to be reviewed.

Within MOSTEP

Within MOSTEP the following experiences seemed to have influenced Kate's PCK: a) education specialist; b) MOSTEP mentor; c) the researcher.

Educational specialists. For example on idea of covering appropriate number of concepts depending on the context (i.e., high school vs. college), she reflected:

> I actually picked this up from [Education specialist1]. That was one of the first things he talked about as far as lesson plan development. A lesson plan should cover one concept. Don't confuse or distract students with other stuff, no matter how interesting it can be. Stick to the topic (Vig. Int.2).

Another idea that stuck into Kate's mind was brought up by another Education Specialist, she comments I have to think of remembering [Education specialist2] words were coverage is your enemy. Coverage is your enemy because you feel compelled to cover something thoroughly" (Vig. Int.1, Vig. Int.3, Ref. Sta.*)*. A third idea was regarding prior knowledge. When we were discussing pre-quests she said: "…as [Education Specialists 1 & 2] put it, it assumed prior knowledge. 'cause maybe they are, and you know what now that I think about your previous questions pre-quests might be a good way to assess prior knowledge too, without taking some class time."(Vig. Int.1). A fourth idea was the learning cycle and lesson plan presented by Education Specialist1 and implemented by Kate during her third video taped class (VSR1). "Like when I have to fill out [Specialist1]'s lesson plans, like prior knowledge" (Vig. Int.2.). Kate initially did not understand how to use the lesson plan (or fill it up) and then eventually, in her second year, became a person who revised other fellow's plans. She also added: "As I've been reading the lesson plans of the new fellows, I can tell that not being at least introduced to these concepts has cheated them in understanding more about teaching and learning" (Personal Communications, May, 2006).

Kate's mentors. It is apparent that Kate's mentor did not have a good rapport with Kate: "As far as this whole enrichment and partnership thing and I recognized, I began to soon recognize that the teacher in my opinion didn't have a really good understanding of

GK 12" (Ref. Int.). Maybe this was a reason for Kate to seek information outside the MOSTEP environment. Although we are aware that Kate's mentor still influences some of her learning like the group learning activity of jig-saw.

Regarding reflections as a result of the research process. Kate commented that reflecting on her own practice through video stimulated recall interviews and critiquing Dr. T.'s teaching practices, helped her in furthering her understanding of teaching and learning processes in science (Personal Communications, May, 2006).

MOSTEP in general. The following quote sheds some light on this: "And the one thing I have learned and I have started thinking about as of this year, actually because of MOSTEP is using labs to reinforce what I call "scientific process skills." (Gen. Int.). It can be seen how this emphasis on scientific process also moves along to the discussion on the vignettes (Vig. Int.3). She also mentioned that she had become more observant as to how people present information: "I found myself super observant of people in general of how they present information to people" (Gen. Int.). Finally she said that being able to understand where future college students came from was important for her.

Summary

In retrospect it is interesting to see how events within MOSTEP and outside of MOSTEP seemed to have played a role in shaping Kate's understanding of teaching and learning processes. Although the outside experiences were not provided by MOSTEP per se, Kate's curiosity to learn more about these topics could have been triggered because of her experiences at MOSTEP. Furthermore Kate seemed to have been influenced from the research interventions of the research study.

CHAPTER 5

Cross case study analysis

Understanding how biology graduate fellows' (BGF) changes in Pedagogical Content Knowledge (PCK) are similar or different, as a result of their participation in programs like GK-12, is important. For decades, higher education faculty have been learning how to teach by "doing"; that is, they learn how to teach during teaching assistantships, by observing their graduate advisors and peers, or else recalling high school learning experiences (Dobson 2001; Park & Ramos, 2002; Wulff & Austin, 2004). Therefore, looking at the effects of alternative programs like this in future faculty, in a holistic manner, is critical. Table 5 (pp. 222-230) and Figures 8 will facilitate the navigation of the trends presented in this chapter.

Chapter 5 is presented in three main sections. The first section covers fellows' changes in PCK, specifically at the level of components of PCK. The second section addresses the main sources of PCK that could have contributed to BGF change in understanding of PCK. The third section discusses issues related to the potential of PCK to transfer across educational contexts.

PCK

Assessment knowledge

At a general level, all four BGF believed that student assessment consisted primarily of end of unit tests or semester/final exams to evaluate students' performance and level of understanding of science concepts. Interestingly, towards the end of my research intervention (i.e., 2nd year in MOSTEP), most fellows' philosophical understanding of assessment seemed to have shifted beyond the idea of a grade. For instance, during latter discussions when assessment was a critical issue in the interview reflections, BGF conversations included more elaborate ideas. For example, fellows mentioned more often the importance of checking for student understanding during a class, questioning students to elicit prior knowledge (as was the case with the Pre/Post assessment ideas), and using these results to inform their practices. They argued that these ways of assessing could help them enhance and improve their teaching practices in

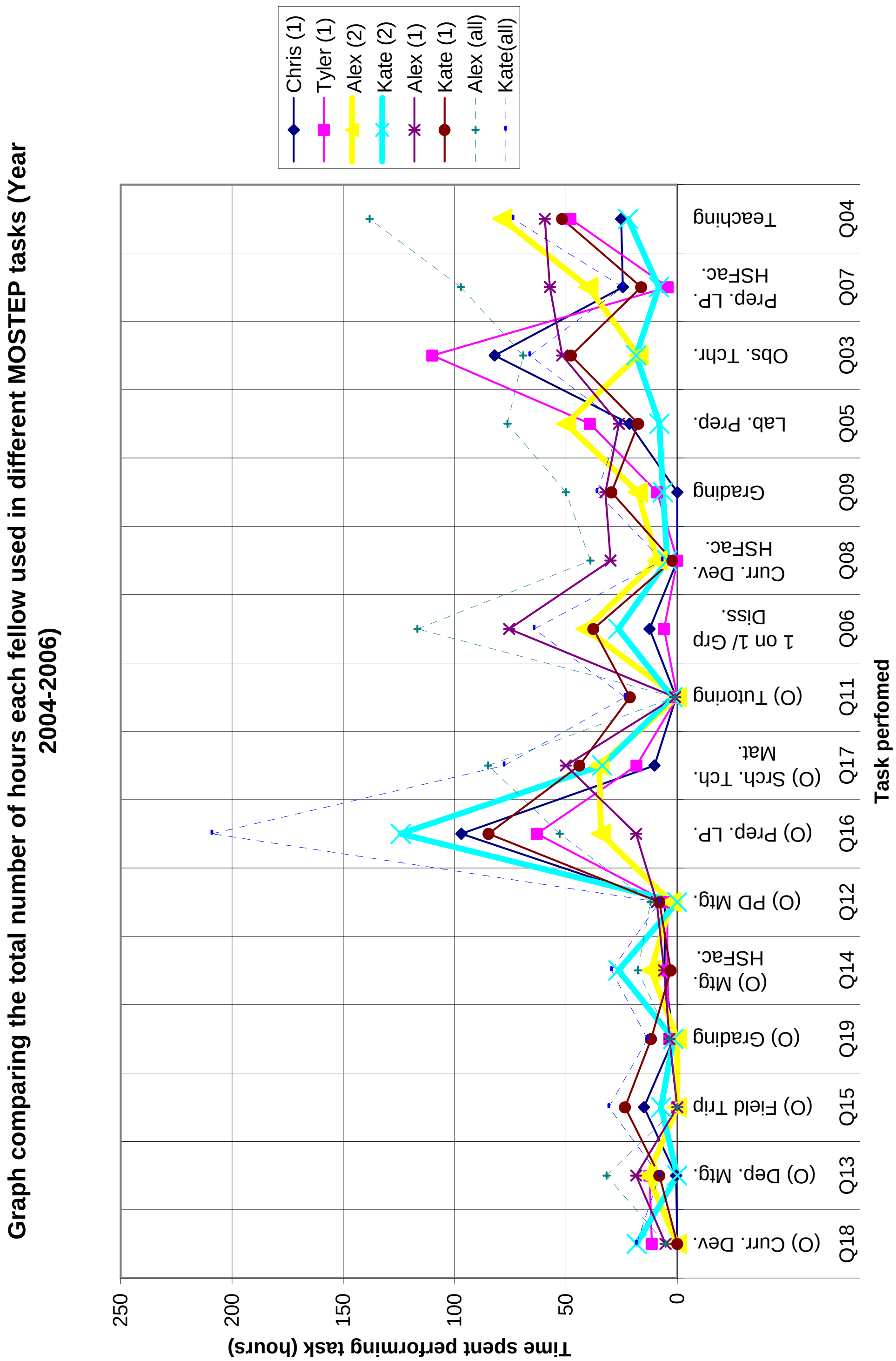


Figure 6. Graph representing the total number of hours fellows invested in tasks related to teaching and learning. Note. In the legend, the number beside the name shows the data for the fellows first year or second year in MOSTEP (e.g., Alex (1), means Alex's first year in MOSTEP, i.e., 2004-2005). Therefore the first four values in the legend represent the hours invested by the fellows during the academic year of 2005-2006.

future classes. However, even if assessment was not a critical component of our conversation, at times it was brought up by BGF as an important aspect of PCK to consider when teaching. For instance, while discussing Dr. T.'s lecture/discussion teaching strategy, Alex and Tyler brought up issues related to Dr. T.'s lack of assessment in class. Alex would discuss ways in which Dr. T. could improve his teaching strategy by prompting students with questions that would allow Dr. T. to see how much his students remembered from previous classes (formative assessment). Tyler would suggest the use of pre/post assessments to inform Dr. T.'s class direction.

In the context of cross case analysis it is interesting to point out that assessment was also discussed by fellows when we were engaged in conversations related to curriculum (Tyler's case) or instructional strategies (all cases). The fact that assessment ideas are brought up during conversations regarding other components of PCK highlights the nature of PCK components being intricately related and interwoven.

At a more specific level, when discussing pre/post written tests and informal/formal questions, fellows seemed to embrace some of the potential formative uses of such tests. After conversations with the fellows, ideas such as using these assessment tests as "*barometers*" (i.e., to understand/gauge students' prior knowledge or level of understanding), or as "steering tools" (i.e., to change the angle and direction of the class) surfaced in progressive ways. The term formative assessment was not always used explicitly, however fellows implicitly referred to it when explaining the value of using pre/post tests and informal questions during class to guide the teaching and learning process. As mentioned previously, the use of these explanations seemed to be more prevalent in our interview dialogues towards the end of the program than towards the beginning.

Concurrently, some fellows demonstrated more in depth understanding of assessment than others. This was observed in Alex and Kate (second-year fellows) when they discussed issues related to assessment and in the way they presented their lessons. Kate and Alex asked more questions during class, paused, and used guided inquiry approaches and sign-posting, more often than Tyler and Chris (first-year fellows). The additional time Alex and Kate had invested in teaching and reflection with their mentors regarding these strategies could have contributed to this difference (Figure 6 & Table 5)

Finally, by the end of the program, Alex seemed to have embraced the central tenets of assessment more than any other fellow. This was evidenced by the way he discussed and reflected upon his assessment practices, and his critiques about Dr. T.'s lack of assessment. Both clearly showed an advanced level of understanding regarding assessment. Alex's ability to conceptualize central tenets of assessment may have been facilitated, in part, due to his mentor's centeredness on a curriculum design model (Understanding By Design), which is guided by assessment.

Since Alex spent a considerable amount of time with his mentor, relative to the other fellows (see Figure 6 & Table 5), it makes sense that his mentor's perspective regarding assessment may have influenced his perspective and appreciation of assessment as well.

Curriculum knowledge

Curriculum. Initially, Alex and Chris, had the idea that curriculum was synonymous with the number of biological concepts (content) to be covered in a science course. Nonetheless, towards the end of the program this idea seemed to have shifted. For instance, on the one hand Alex, after reviewing his case, commented that before MOSTEP he equated curriculum to content (personal communication, June, 2007). However, he also said that Understanding by Design had become like a toolbox that helped him plan his instruction (June, 2007). On the other hand, Chris said that curriculum did not mean anything to her and that content was the first and most important thing she thought about when planning a class or when teaching a class. Unlike Alex, Chris' idea of curriculum equated to content seemed to prevail. However, a review of her comments during the interventions reveals that as time progressed her notion of curriculum may have included ideas beyond content. In Kate's case there is not enough evidence to realize where she stands with regards to curriculum. What she does share is that some biological concepts, like DNA crossing-over, needed to be removed from the student's learning expectations. She believed that ideas like these required a higher level of maturity. Finally, and contrastingly, Tyler's seemed to have a better grasp of what a curriculum meant since the beginning of the program. This is probably the result of his

Table 5. Summary findings of case studies and background information (Part 1)

General Description	Specific Description	Biology Graduate Fellow (BGF)							
		Chris		Tyler		Alex		Kate	
Demographic	Age range	25-30		30-40		23-30		25-30	
	Sex	Female		Male		Male		Female	
Academic background	Degree's acquired	BS, MS		BS		BS		BS, MS	
	Degree pursued	PhD		MS		MS		PhD	
	Time in university	5-7 Yr		1-3 Yr		1-3 Yr		5-7 Yr	
Pedagogy (prior to MOSTEP)	Educational theory exposure	N		Museum Education courses		N		N	
Prior Teaching experiences	K-8	N		N		N		N	
	9-12	N		N		N		N	
	Undergraduate	Y (TA 2 Yrs)		N		N		Y (TA 2 Yrs)	
	Graduate	N		N		N		N	
	Informal Settings	N		Y (All ages, diverse audience)		Y (Tutoring)		N	
MOSTEP Years		1st Year		1st Year		2nd Year		2nd Year	
Mentor	Sex	Female		Male		Male		Female	
	Teaching experience	5-10 Yrs		15+		5-10 Yrs		5-10 Yrs	
Classroom	Grade allocated	Biology (Genera/honors)/ 9		AP Environmental/ Field Biology (10-12)		Biology (General/AP)/ 9 & 12		Biology (General/After school) 9-11	
Approximate Time (h) spent in MOSTEP Activities (Based on self reports)	Contact w/ Mentor	11.75		21.5		100.5		52.25	
	Observing Mentor	109		110		69.25		66.25	
	Planning lesson w/Mentor	24.5		4.25		97.25		24.5	
	Planning lessons alone	128.75		132		219.25		330.5	
	Teaching	25.25		48		138.25		73.75	
	Contact w/ students 1:1 or grp	13		6		117.75		87.75	
	Research Reflections	10		10		10		10	
Assessment (PCK)	Types (**NOTE**: Usually testing tools, and forms of classifying assessment)	**DF**: Prior Knowledge of Different tools and testing instruments (MCQ, short answer, essay, end of topic, writing research paper, hard tests, curves) (ESSAY was the best to know how much students knew)	•	**DF**: Like most fellows Tyler had heard about diff. types of tests (same as Chris) and was very much in favor of essays as the best way to test individuals.) He recognized the difficulties behind essay Q's, and disliked MCQ's because it did not work for him (2 strong discussions)	•	**DF**: Knowledge of different tools & question types (MCQ, Essay, Research papers, group projects). **CH**: Informal checks, hands-on, pre/post, journaling. Formal assessment and student-based assessment <words mentioned in his comments>	▲•	**DF**: Typical tools and question, **CH**: But mentioned hands-on assessment, alternative ass (index cards, questions, informal/formal), creative piece, multi approach and free-form. (Knowledge but not necessarily understanding)	▲•

Table 5. Summary findings of case studies and background information (Part 2)

General Descript.	Specific Description	Chris		Tyler		Alex		Kate	
Assessment (PCK) cont…	Use (**NOTE**: Depending on what information the teacher wants to obtain from the student)	**CH**: U.of-Pre/post test changed. Chronologically in Vig. Int. more detail was provided towards the end. **CH**: Formative Assess could have changed. 1) asking students Q's to gauge their U., and use questions to guide (Dif. in Vid.T. practices).	▲	**CH**: Pre/Post know. and formative assessment changed. He talked as time progressed of the use of formative assessment to: assess stud. prior know. (as a '*barometer*'), for curriculum/lessonplan '*steering*' tool to change angle and class direction. He did question the approach due to his statistics class. Talked about assessment to change practice w/o lowering the bar, which he did at the beginning and regretted.	▲▲	**CH**: Learned about formative assessment as a way to (surface prior knowledge, check for understanding of topic taught, engage & setting the stage, leveling up students, challenge prior knowledge, inform teaching, inform reaching students/ communication, way of introducing the topic, curriculum development). Understanding of uses of Pre/Post to do this also happened.	▲▲▲	**CH**: Informal assessment (random Q's, stops in presentation) as a formative tool to inform teaching and also as a way to surface prior knowledge. She called it assessing while going.	▲
	Basic knowledge (**NOTE**: General overall feeling, believe, knowledge, understanding of assessment)	**CH**: Overall concept of assessment just being a test vs. a way of getting information to improve learning and teaching	▲▲	**CH**: Overall concept of assessment just being a test vs. a way of getting information to improve learning and teaching	▲▲	**CH**: Overall concept changed. He also demonstrated know. integration between (Context, Assessment and Student)	▲▲▲	CH: Overall concept changed. Level of assessment integration a little less than Alex	▲▲
Curriculum (PCK)	Basic knowledge	**CH**: Idea of curriculum seemed to change from a basic plan to an elaborate idea that included other things but learning the content.	▲	**DF**: A curriculum for Tyler meant everything from the classes to the materials, to the goals (probably the idea was acquired during his museum experience and courses), assessment was not part of the curriculum <apparently>.	•	**CH**: Curric.-science content, but then changed to a more elaborate plan that includes multiple facts. From plan of content to UBD backward design (LP development, assessment.) Fellow thought that these ideas were now so engrained that he felt he had a toolbox in his head.	▲▲▲	**CH**: Implicit-curric. was about concepts to know in science, it changed to learning about NOS and critical thinking skills. Also, HS curriculum was to detail and dealt with concepts that were not necessary (GLE's have content objectives that are inappropriate) (SEE SCOPE)	▲
	Logical content sequence	**DF**: Believed in logical content going from simple to complex. (e.g., Pop. Bio.) Importance of building. Probably guided by the text book sequence as she reflected upon reading the document for interpretation verification.	•	**DF**: Logical sequence an important component from the beginning. Concepts should be taught in a logical order & lessons had to follow a logic. (Seen in planning and notes) He made contrast to mentor's more open ended approach/ less guided (didn't seem to like) this but tried to find the value.	•	**DF**: Believed in logic content sequence and integration of evolution throughout the curriuc. He also critiqued Dr T. concept linkage in the various vignette. Especially the evolution one.	•	**DF**: Content sequence was defined by strong SMK and probably textbook seq. Strong ideas of logic flow. Mention of a dichotomy approach as a way of sequencing and moving from broad to more specific.	•

Table 5. Summary findings of case studies and background information (Part 3)

General Descript.	Specific Description	Chris		Tyler		Alex		Kate	
Curriculum (PCK) cont…	Scope of content	**CH**: Developed sensitivity the idea of content coverage was challenged (Awareness of depth vs. breadth). Even in her reflections regarding the vignettes this view seemed to be constantly challenged	▲	**CH**: He commented that he seemed to have covered too much material at the beginning, and he commented that he became better at gauging. (Sometimes, he had internal debates as to how much he needed or not to break down the material)	▲	**CH**: Initially too much content in his first classes in HS but later gauged better. This sensitivity towards content was also obs. In the Vig. Int. reflections	▲▲	**CH**: Kate covered too much at the beginning (layering info. In her words) & then learned how to cover less in the HS setting. She seemed to take this to UG level. Built sensitivity and content rationalization	▲▲
	Goals and objectives	**DF**: Class goals & objectives was not a something that Chris discussed too much. One of her objectives in classes was to provide as many examples as possible for students. Expose stud. to multiple situations related to the concept. She became aware of state standards (GLE) but her familiarity with such guide was not evident. Her main objective in class was learn the content.	•	**DF/ CH**: Classroom sequences were guided by goals and objectives of the class. Example of trophic cycling idea guiding the lesson of things cycling in nature (life, materials). In other words OBJ & goals, guided students understanding, lessons and teacher. Some ideas about goals and objectives in relation to assessment were mentioned (changed idea). Discussed OBJ in state assessment and how one should teach depending on the goal of the assessment.	▲•	**CH**: Goals and objectives are critical to the UBD curriculum model. Time wise Alex spent way more time with his mentor working on curriculum building. He also became very familiar with State standards/frameworks to guide curriculum. These ideas are also brought to the university level discussions during the Vig. Int. interventions.	▲▲	**CH**: From her reflection Kate embraced the idea of learning objectives and goals (sign-posting), "she claimed that outlining her objectives and distinguishing between performance, content objective, and affective ones to was important. This for Kate is away to tell students, where they are going, what they need to know, and should not be hid from them. She also helped other fellows with LP object.	▲▲ ▲
	Material availability	**DF**: Textbook (HS and undergrad), science journals, ENSI, Pbs and google, sites. Learned about some of the sites like PBS and ENSI and Berkley.	▲•	**DF**: Very creative individual. Resourceful and original. Similar resources used by other fellows.	•	**DF**: Textbook, science journals, internet (PBS, U Stream, ENSI), own research experience. Maybe some of these sites were learned in MOSTEP but for the most part were mentioned.	•	**DF**: Draw ideas from internet, other graduate fellows (nature of her teaching club), outside organizations, undergrad - e.g. textbook + labs <tooth pick>	•
	Lesson planning	**CH**: Change in the understanding of the parts of a lesson plan. Although even towards the end she felt like she only had a better appreciation of inquiry based lessons. In her reflection about her case she pointed out at her being unsure	▲	**CH**: Tyler perceived he had changed in terms of lesson planning. He actually followed the LC during his enactment of classes and planning of such. Comments on having learned how to connect things	▲	**CH**: Clear change and preference for mentor's lesson plan format instead of programs LP. Very detailed and even reflective on lessons. Multiple times he would perfect the lessons after trying them in class.	▲▲▲	**CH**: 1st yr did not understand LP format. 2nd yr embraced it. She would talk about understanding its part and even helping other fellows. (Learned about the objective type, write one and edit one)	▲▲ ▲

Table 5. Summary findings of case studies and background information (Part 4)

General Descript.	Specific Description	Chris		Tyler		Alex		Kate	
Student (PCK)	Theories of learning	**DF/CH**: No explicit knowledge of theories but implicit knowledge or practical knowledge seemed to have changed. Showed practical uses of learning theories such as constructivist, prior knowledge, misconceptions, motivations and everyday life examples linked to this. Much like the other fellows. (**Note**: *This info has not been expanded to other fellows but it is assumed to avoid repetition)*	•	**DF**: Knew about learning theories and used them (multiple intelligence, Kolb, MBTI). He also implicitly talked about metacognition (best way to learn is learn how you best learn). Some of this theories were mentioned and used to explain some of his position regarding reflection on the rsrch interventions.	•	**CH**: Considered the importance of the NOS and student learning (EvoPI as an example), i.e. the importance of students not learning about NOS and with this in mind. Critical thinking was also discussed.	▲	**CH**: Learning of this theories: Multiple intelligence, NOS, Haberman pedagogy of poverty were triggered by MOSTEP. NOS more so than the other. The other were learned independently and complemented by psychologist friends	▲
	Metacognition	NA		**DF**: Implicit importance of metacognition of all fellows the only one. Self reflection and making sense based on prompted question from interventions. Claimed to have learn this due to his own learning ontology (museum courses, etc)	•	NA		NA	
	Constructing knowledge (**NOTE**: Related to Prior knowledge, Pre-requ. & hard concepts, providing examples familiar to students and applicable)	**CH**: Towards the end talked about students constructing knowledge for understanding rather than memorizing and talked about adding content to their existing mental framework. She also talked about seeing the larger picture so they can see where the concepts fit together.	▲	**DF**: Prior knowledge constructing knowledge analogous to a girder, connectors, connections into an armature, cumulative in nature, building on the previous concepts and being part of a framework. "Find those familiar concepts that will help you plug-in the information into your framework".	•	**CH**: The idea of critical thinking and students constructing knowledge (e.g. Food webs- moving from a chain to a complex mess, growth graphs- breaking it down and reflecting on the figure). Using their prior knowledge during his LP enactments. He believed this skill was strengthen by MOSTEP, but in his mind it sounded logical.	▲	**CH**: She had a different view but similar than other fellows. She talks about filling gaps with slats to allow classroom flow and a base start. Constructing knowledge on mental frameworks. She claimed that sometimes she thought teaching could be easier if students knew nothing. She talked about deconstructing any misperception, or adding to their current knowledge (Vig. Int.3) More elaborate description towards the end (MEDTE)	▲

Table 5. Summary findings of case studies and background information (Part 5)

General Descript.	Specific Description	Chris		Tyler		Alex		Kate	
Student (PCK) cont…	Prior knowledge (misconceptions, examples <e.g. human>, familiar animals <e.g. inv.sp>, and processes <e.g. landfill, pop.growth>)	**CH**: Learning about prior knowledge probably started unconsciously in TA, but she was made aware of it in MOSTEP and was "formalized" as she commented when reflected on reading her case. She learned more about misconceptions in EPI and reflecting on these with me in our classrooms, but was not sure how to use them for teaching advantage. She pointed towards other forms of competition (i.e. not only food but space <nesting sites, living space, mating territory, etc>)	▲	**CH**: The importance of its role changed. This is also discussed in Tyler assessment section (pre/post) It change from assuming a knowledge base to finding out about the prior knowledge and linking it to misconceptions especially in the area of black or white (where there is grey (e.g. generalist vs. specialist) Seemed to exploit the misconception knowledge different from other fellows (carnivores, herbivores, types of consumers, altricial, etc)	▲▲	**CH**: Using prior knowledge to inform teaching, provide framework for students, He also used expressions like "jogging student memory", he constantly used fictitious dialogues to explain how he would surface student's prior knowledge. Defined understanding of Misconception., especially when considering his EPI project.	▲▲	**CH**: After reflecting on her first year she said that she learned the importance behind prior knowledge and realizing that she had more SMK than what the students were coming in with, hence the disconnect at times. (Probing for Prior.Kn., having in-depth reflections about it during Energy in Food Web discussion, Invasive/non-invasive LP1 2yr <e.g. hybrid, sparrow, startling, def. non-inv, etc>, Landfills LP2 2yr] Assumption of blank slates she said she would avoid in the future (Ref. Int.). lack of U about NOS	▲▲
	Use of examples (**NOTE**: related to transfer of knowledge, prior knowledge, act.repr.)	**DF**: Provide students with multiple and diverse examples. A must to help in stud. und. abstract concepts. Indirectly Chris tried to provide multiple instances so that student's see e.g. happens in many occasions. In addition she is accomplishing this by trying to choose examples that they might be familiar in one way or another, or interesting (e.g. Soay sheep). This idea is related to prior knowledge	•	**DF**: Enjoyed using controversial examples (conflicting/ contradictory), use examples that were familiar with students (practical knowledge) Probably related to common sense and the fact that in life sciences and science in general the creation of discreet categories is relative an most of the times we always encounter shades of grey. Uses of known example (e.g. mutation ninja turtle, telegraph game)	•	**DF**: Using human examples, organisms examples that they might be familiar, everyday examples to their personal lives (No strong evidence of change, but it probably goes hand in hand with prior knowledge, and constructing knowledge)	•	**CH**: Provide more than one example. Students tend to think that it is the only example. She liked using examples that were context based and easy for her background but realized that was not the case for HS students, they need more and examples closer to them.	▲
	Pre-requisite/ hard concepts	**CH**: Learned about some of the difficulties students in HS may have (e.g. Osmosis, Meiosis, microscopy, competition and evolution)	▲	NA		**DF**: Build awareness of difficult areas in probed topics. Little evidence for this section.	•	Change in understanding. She tried to apply this concept during her teaching	▲

Table 5. Summary findings of case studies and background information (Part 6)

General Descript.	Specific Description	Chris		Tyler		Alex		Kate	
Student (PCK) cont…	Motivation and Engagement	**CH**: Learned that students could be mentally engaged even if not showing a physical engagement (e.g. Bell ringer). As such she believed that activity-based learning (as she called) it enhanced the chances of engagement. "I think it helps them learn"	▲	**DF/CH**: For Tyler motivation changed as one matures. He developed sensitivity and accepted that doing something fun can help to engage students, but still it did not feel like he was completely convinced about this notion. Clear distinction between university and high school level of motivations and how it should work in his eyes.	▲ •	**CH**: Alex Realized HS lack of motivation/ Unmotivated students. He actually learned how to confront the situation by trying to find out more about was causing the behavior.	▲	**DF**: Bothered the lack of motivation (She learned more about it) Her understanding changed regarding the demographics and backgrounds of her coming UG in the past.	▲
	Diversity	**CH**: Different perspective, and points of view, problems with diversity and classroom goals, moving from self-center to student centered. Conversation evolved from lack of interest to providing diff. perspectives, to how to deal with variety. Her level of understanding seemed to be more elaborate (she mentioned more aspects and characteristics of these)	▲	**CH**: Always having two perspectives (e.g. homogenous vs. heterogeneous classes), describing the advantages, later on describing the teaching approaches and implications, changing the approach in class, depending in the audience was his final message (College setting)	▲	**CH**: Attitudinal diversity, classroom diversity (1st, 2nd, 3rd), Diversity in terms of not race but learning too. Proposes alternative solutions to diversity issues. He seemed to have build certain level of understanding were non-motivated students would not frustrate him anymore.	▲	**CH**: Merged her understanding of the importance of student diversity from a teaching perspective to a student perspective. (ID diff.: interests <degrees>, diff. motivation, learning differences, gender, race, etc) Towards the end she was very keen to provide very detailed examples of how to deal with diversity, by asking certain questions in class, etc	▲
Instructional Strategies (PCK)	Act (Analogy, Simile and Metaphor & Examples) (**NOTE:** Related to Curriculum)	**DF**: Real life examples, good representations and creative (e.g. penguins & sci.methdo). Comment on understanding abstract concepts by using concrete examples. **CH**: Change from using activities and representations of what works for them rather than for me. Polished and refined.	▲ •	**DF**: Very creative activities, were he integrated many different ideas in promising ways (e.g. cycling lessons, evolution of beaks and classification <generalist vs. specialist>	•	**CH**: Showed ability to use activities and representations with strong arguments/ delineate activities weaknesses and strengths. He also showed inventiveness creating his lessons (e.g. Penguin alterations and invasive species).	▲ •	**DF**: Showed creativity to put lessons together/ especially manipulating pre-existing material. She used many analogies when teaching look at any video. Appropriateness depends	•

Table 5. Summary findings of case studies and background information (Part 7)

General Descript.	Specific Description	Chris		Tyler		Alex		Kate	
Instructional Strategies (PCK) cont…	Maj: Lecture	**CH**: Shared ideas of pro's/cons of lecturing, her views about lecturing (e.g. uses) were challenged. She seemed to change from "shear memorization" to an interaction where one would be carefully in not asking leading questions but questions to expose thoughts and enhance learning. Her internal deliberations- good to cover material, but incorporating other strategies somehow (e.g. bell ringers, hands-on, etc) " I think you need to stop, discuss, wait so students internalize what you are saying"	▲	**CH**: Ack- good approach for more content w/ less effort. If ground rules are set then lecturing is acceptable. Challenged and changed in terms of applying an outline to the approach, providing examples, contrasting examples, pick on non-talkers, engage them in discussion during the lecture. Change from "giving an answer" to "make them explore" . Change in how he approached his teaching in the video taped. 1st lecture then activity, 2nd exploration (activity) lecture, further exploration, summary (almost like following a LCycle model)	▲	**CH**: Upon further reflection regarding lecturing strategy, the idea was defined and consistent with additions of what he learned. No evidence was shared as how much he changed but in retrospect he commented that he changed.	▲	**CH**: Lecture views were challenged. She seemed to dislike lecture (desc. it's a reflex, shear memory, regurgitation, racing to keep up with prof) but also embrace it depending on circumstances. She said in follow up interview that she was "riding the fence" (hesitant to take a position). She reflected upon strength and weaknesses. Comment on specific PowerPoint approaches	▲
	Maj: Discussion/ Questioning (**NOTE**: Related to Communication section/ types of Q's, etc)	**CH**: Discussion ideas challenged. Init: It only happened in smaller classes and not large ones. Change in her understanding of not giving out the answers but waiting and guiding students towards and answer. Waiting enough time was a consideration too.	▲	**CH**: Change in his understanding of discussion seen through indirect evidence of his reflection on vignette2. He picked up more instance where Dr T did not address or engaged in discussion appropriately and finally he provided some insights into possible approaches. Upon reflection he said that he paid more attention to the outcomes of the discussion	▲	**CH**: Rephrasing, Socratic Dialogue, Leading Q's not providing answers, engaging students, more than one way to ask questions, no vague questions, appropriate wait-time, elaborate on student response and inform teaching (Discussed improvements and trade offs with regards to questioning)	▲▲▲	**CH**: From Vig. Int. At the beginning when discussing instances of Diss/Quest, she talked about lack of wait time. Upon further reflection she commented on assess., NOS, taking it by steps, she also seemed to prefer guiding students more towards the latter Video Taped. classes.	▲
	Maj: Collaborative learning	NA	NA	NA	NA	**CH**: Discussion of adding group work to lecture in Univ, idea of stud. Helping each other, probl. W assess at Univ. level, tackle shy students (discuss feature and trade-offs), create a safe environment for students to ask questions	▲▲	**CH**: She worked in groups as a student but the idea of Group work took a different place when obs. Mentor. The idea seemed to polished some of her pre-conceived ideas. She learned about Jig-saw for instance.	▲

Table 5. Summary findings of case studies and background information (Part 8)

General Descript.	Specific Description	Chris		Tyler		Alex		Kate	
Instructional Strategies (PCK) cont…	Maj: Inq and Hands on learning	**CH**: Initiate major experience with inquiry. Improved understanding of underpinnings & problems (e.g. longer, more thinking involved and correct questioning). Considered using inq-base in lecture. Inq.base learning students doing more by themselves and figuring things out. At times guided by the tchr.	▲	**CH**: In summary, Tyler inquiry-based knowledge changed from being an abstract probably not so useful teaching strategy to a possible strategy that would help develop individuals thinking capacity in mysterious ways and maybe "stick" longer in their cognitive schemas. He understood the trade-offs of inq-based instruction. Recognize that both approaches are important.	▲	**CH**: According to Alex his grasp of inquiry strategy changed. Practical knowledge changed. (related to NOS) too. This was further confirmed when doing a final read over his case.	▲▲	**CH**: Inquiry did not mean much to Kate initially. She did learn that guiding instead of telling, using the NOS (experimental design/ scientific method, etc). Inquiry is doable in lectures, labs & other strate-gies, it is hard, but I learned about it. She was interested towards the end in how to improve and change a normal activ. into inquiry.	▲▲
	Maj: Other and Summary	**CH**: Mention of graphic organizers and summarizing strategies. **Summary**: She said she thinks now more about the process of teaching instead of just spewing out info.	▲	NA	NA	**DF**: Talked about/mentioned mnemonic devices, graphic organizers, role playing.	•	**CH**: Some strategies were commented & added to Kate's repertoire of Tch.Strat. E.g. Role Playing and Sign-posting, lightening summary (did it in an u.grad. class) Discuss pros & cons.	▲ •
	Communication: general (**NOTE**: Related to discussion/questioning strategies)	**CH**: Emphasized the qualities of teachers in terms of communication & less in terms of providing good examples. "Being able to pay attention to whether they are picking up, how to adapt if not, and leading them appropriately"	▲	DF: From the beginning- an important quality of a teacher is comm. Questioning in general tightly related to making students think critically.	•	**CH**: More elaborate on his descriptions especially when discussing tchr qualities. Also during his thesis presentation, his way of pausing and reading the audience was evident. He perceived that his communication skills changed overall and were refined too.	▲	**CH**: She felt like her ability to communicate in public changed after MOSTEP. She said she could put complex words into simpler ones. She started evaluating presenters & teachers per-formance in regards to clarity of communication	▲▲
	Communication: Questioning strategy (**NOTE**: strongly related to discussion teaching strategy)	**CH**: Chris talked more about: level of complexity, encourage students to ask Q (get them to explain, wait), tone of voice, how one says things, stop & ask. Not necessarily learned but surfaced & discussed at different levels (this is similar to other fellows)	▲	**CH**: Fond of asking contro-versial questions (complexity, guiding to answ., encourage, bring forth prior knowledge, tone of voice, how you say things, non-verbal cues. (Claimed he became a better communicator in a scientific POV & at guiding students to an answer as in VSR2). Thesis defense a cue. Talks about asking questions that allow students to think critically.	▲	**CH**: He talks about: not asking vague questions, not answering yourself, ask Q that generate more Q, breaking complex concepts down through questioning, guiding students (help them infer relationships), rephrase, creating a safe environment, non-verbal cues (defined). This is also seen i n his practice & accepted as an important change	▲▲▲	**CH**: Guiding students to an answer, using questions. Also using Q's to bring forth prior knowledge using known examples. **DF**: Importance of non-verbal cues (she actually had a lengthy discussion about this)	▲ •

Table 5. Summary findings of case studies and background information (Part 9)

General Descript.	Specific Description	Chris		Tyler		Alex		Kate	
TRANSFER	Things that seem to transfer	**PT-(HS-UG)**: INST.STRAT. (e.g. bell ringers, hands-on), QUEST. STRATEGIES (guiding, asking not telling, waiting)		INST. STRATEGIES (Fun, engaging, inquiry-based, guiding students, misconceptions, STUD: make non-talkers participate, prior knowledge). Makes comment that he is still digging his heels in terms of old expectations of college education. More aware of how teachers taught in their classrooms like Kate and Alex.		**PT-(HS-UG)**: ASSESS, INST. STRAT (Questioning & Answ) formative assessment, lesson design and curriculum. Inquiry use in college as related to Socratic method in discussion section of lecture.		**PT-(HS-UG)**: INST. STRAT. (Group work<team building-mixing group>, Role-playing, inquiry, L.cycle) STUD. (Multiple intelligences, NOS) ASSESS. Formative assessment **PT-(UG-HS)**: INST.STRAT. (PPS quest. During lecture, probe for understand,)	
Potential sources of PCK	OUT side MOSTEP	Scientific presentations, lab meetings, student (college n HS), TA experience, Reflection of own learning	•	Presentation from past job, college student XP, military XP, Ref.Own learning, teaching in informal settings, intuition	•	College student, HS student, Refl on own learning	•	Scientific research, workshop-seminar-books/papers, journals, students background (k-16), TA experience very influential, own reflection	•
	In MOSTEP	Other fellows (e.g. Tyler, Kate, JPS), Education specialists, Mentor, **Refl. On research instruments**.	•	Other fellows, meetings, edu specialist and scientist, mentor, **Research interventions**, teaching at MOSTEP	•	Other fellows (Tyler, Noah), classroom mentor, **Reflections due to research process**.	•	Educational specialist big difference (lack of teacher initiative but fellow motivation look for another source of knowledge), Mentors effect minimal (lost respect), **Research process reflection**, MOSTEP in general/meetings bi-weekly	•

KEY Abreviat.	**Descriptions**
DF	Defined
CH	Changed
U.of	Understanding of-
NA	Not Applicable

KEY Symbols	**Descriptions**
▲	Some evidence of change
▲▲	Changed
▲▲▲	Big change
▲ •	Uncertain or partial change
•	position defined

KEY Colors	**Descriptions**
	Changes in general
	Changes most likely related to length in program

experiences with museum courses related to pedagogy. For instance, he would talk about using appropriate goals, sequences and classroom objectives from the beginning when discussing Dr. T.'s case study (Vig. Int.1) or from discussing ways of teaching food webs in our first interview. However, the inclusion of assessments as part of the curriculum seemed to escape his definition as it did for all the other fellows in the beginning.

Interestingly, as time passed, ideas such as: a) the importance of developing understanding of the nature of science along with content, b) teaching students about the scientific method and c) thinking about goals and objectives, and making assessments an integral part of the curriculum seemed to be incorporated more frequently in further conversations with fellows. For example, every fellow agreed that teaching the nature of science was important. They said that it was something that students needed to know and that teachers should focus. This perspective was probably biased because of the emphasis from the different PI's of the program in their roles as resource scientists in the high school classroom. However it is consistent with what was found in other GK-12 project evaluations (Trautmanm & Krasny, 2006).

Curricular goals. In terms of major curricular goals, all fellows became aware that, unlike higher education courses, there were science grade level expectations (GLE) that needed to be met when teaching high school biology courses. In universities faculty tend to determine what content is covered in their subject. In high schools, especially public schools, the state or government tends to dictate what needs to get covered in a science course. The GLEs represent this state standard and needs to be used and targeted by teachers in the US public school system. It is not clear from the data what level of understanding regarding GLEs BGF had. However, awareness of the existence and need to use such a document was gained. This gain in understanding was observed during our bi-weekly MOSTEP meetings. Moreover, second year fellows, Alex and Kate, incorporated the idea of GLEs, and learning objectives in general, more often than first year fellows. For instance, Kate will constantly quote the GLEs when having discussions in our biweekly meetings, and Alex will use the GLEs to compose lesson plans enduring understandings (big ideas) and essential questions (driving questions).

Scope of Curriculum. Fellows developed certain sensitivity towards coverage of content (i.e., scope). Apparently, when the fellows were teaching in their high schools, at one point or another (usually at the beginning of the program), they covered much more content/material than students could handle in one class. For instance, during some of their first teaching enactments, fellows such as Tyler and Kate took more days to complete their class than anticipated. For example, Tyler planned to teach the basic tenets of evolution, using beaks as a model, in one class period and at the end took more than one class period to accomplish this. Kate had a similar experience in her first video taped class about photosynthesis. She tried to cover too many concepts at once, and realized days later, that students did not grasp many of the concepts she taught that day. As she reflected: “I never realized how I was just layering information” (Ref. Int.). Unlike Tyler and Kate, Alex and Chris where asked by their mentors to adjust (shorten) their lesson before they taught it. For Chris this happened in her scientific method lesson and population ecology lesson. Chris had initially planned to use multiple examples (too many) for her scientific method lesson and had to cut down the number of examples. For Alex this happened in his invasive species lesson. Alex mentioned in one of our conversation that by the fifth round teaching the same lesson, he and his mentor had removed and improved several aspects of the lesson, like the graphing section. As a result of these experiences, all fellows realized that covering fewer concepts in their classes could have been more beneficial and if they were teaching them again, they would reduce the amount of content that they tried to cover. Fellow’s commented that expressions shared by education specialist during our biweekly meetings, such as, “coverage is your enemy” (Kate’s case) and “teaching one concept at a time” (Tyler and Chris’ case), started ringing bells as the program advanced.

When fellows were asked to reflect on the undergraduate case studies (e.g., using vignette) most of them (all except Chris) initially failed to acknowledge that Dr. T. was covering too much material, which was the case. By the time the fellows examined additional vignettes the idea of covering too much material was brought up by all fellows. It is evident that fellows’ sensitivity towards coverage of content changed. Alex made comments such as: “It is inconceivable that he was able to cover it [all]” (Vig. Int.2). Kate made comments comparable comments: “As you plan the entire course, you know, [you] don’t want to do too much at once [cover too much content]” (Vig.Int3), when discussing the pro's and cons of Dr. T.'s class. Similarly, Chris and Tyler commented more often about the potential problems covering too much content could generate.

In spite of these reflections and conversations regarding coverage Tyler and Chris felt that undergraduate preparation should still have a strong focus on content than high school should. Both agreed that changing some of the teaching strategies would be okay if they did not compromise content. Concurrently, Kate and Alex also agreed with this notion, but they seemed more inclined to use alternative teaching strategies (i.e., inquiry) that would most likely include a little content.

The four fellows struggled with the idea of depth vs. breadth. The challenge to their previous position regarding the importance of content could be a consequence of them having to reflect about this issue in two different contexts. Questioning our beliefs is the beginning of internal growth that could help either resolve, clarify or further question ones understanding of the nuances and intricacies behind such issues (depth vs. breadth) (Pajares, 1992, Crawford, 2007). Nevertheless, one would expect that most fellows, coming from a strong science background and from teaching assistant experience at a university level, would bring to the table a know all, study all archetype. Having fellows reflect about the trade off between depth vs. breadth of content provides a vehicle for change.

Content sequence. All fellows seemed to agree that teaching should move the student from simple concepts to more complex ones. They acknowledged that content sequence was an important factor in student learning. In the classroom, all fellows demonstrated an almost cookie cutter approach where according to them one concept logically flowed into the other one. For example, after discussing factors affecting population growth, one should begin with the simplest population growth curve (i.e., exponential) and then a more complex one (i.e., logistic), ending with a mathematical model for both. In their enacted lessons, a logical flow prevailed among their lessons and across them. Most of this logic flow, more likely than not, represented a textbook flow.

Lesson planning. All fellows experienced a change in their understanding of lesson planning. Alex took lesson planning very seriously. He mentioned that he had a much better grasp in his second year of how to use assessment to guide his planning, and in general how to use the Understanding by Design backward model (Wiggins and

McTighe, 1998) to write his lessons. He shared that his understanding of lesson planning changed completely due to his mentor and his high school curriculum policy.

Kate also embraced the overall idea of good lesson planning. However, she said that it would be unlikely for her to use Madeleine's Hunter (MH) lesson plan model [cite] (the recommended lesson plan format for the program) in a university setting, because it would take too long for her to prepare for a class. She added that getting to understand the different components of MH format (anticipatory set, affective and psychomotor objectives, etc) expanded her understanding of lesson planning beyond presenting concepts. She said these ideas could be used in a college setting. Kate served as "lesson plan" mentor for fellows like Chris and others fellow outside this study. She demonstrated, certain expertise regarding the different sections of MH lesson plan. In particular, she had an understanding of the different kinds of objectives (affective, psychomotor and cognitive).

Tyler and Chris claimed that they learned some lesson planning, but that there were still parts of MH lesson plan that were not clear to them. This incident of not understanding MH lesson plan model was also observed during Alex and Kate's first year. A two-year examination of Alex and Kate's lesson plans revealed that some learning had occurred in year one, but not at the level observed in the second. This is another example of the effect of program exposure over multiple years.

Every fellow demonstrated a certain degree of creativity when designing lesson plans and modifying activities. For example, Chris developed a Taxonomy activity where students had to classify penguins based on morphology, then DNA and finally the concept of phylogeny was introduced. Tyler, developed a story about "Stubby and Curvy" to summarize the concept of evolution by natural selection. Alex developed an invasive species activity based on his recent experience at the Galapagos Islands, and Kate was good at modifying activities. This result is consistent with the GK-12 findings from other projects (NSF, 2005). In retrospect, the time a fellow could invest in creating a lesson plan, and his background knowledge, determined the uniqueness of the activities developed by the fellows.

Student knowledge

Students' prior knowledge. All fellows seemed to have learned or become more aware of the importance of considering student prior knowledge when planning for instruction. Some of the ways in which fellows demonstrated change in their understanding of prior knowledge was by showing understanding of how student's pre-conceptions, naïve conceptions or misconceptions about science affected learning. Another way was by using instruments like pre/post assessments to surface student's prior knowledge, and by also by using familiar illustrations with which students were familiar.

Not all fellows developed the same in-depth understanding about prior knowledge. For instance, Chris claimed that MOSTEP helped her formalize the concept of prior knowledge in her mind (personal comment made after member check, July, 2007). She embraced teaching strategies that helped her surface student's prior knowledge when teaching and she acknowledged the importance of doing so especially during her final reflections "…I think if they [students] are able to put… a new concept… to things that they already understand, then it's easier for them to learn it" (Vig. Int.3). Chris instinctively tackled common misconceptions. During her population biology and species classification lessons she would ask students for clarifications and she would challenge student's naïve conceptions of just using morphology to classify organisms. When asked why she did this, she said that she was not aware of it, but in retrospect she said that it made sense. This same instinct was shown when she constantly advocated the use of real and tangible examples to in her eyes enhance students learning. Chris intuitively used the students' prior knowledge to guide her teaching. Reflection on practice allowed her to name what she was doing.

Other fellows like Tyler, focused on the use of assessments such as pre/post tests to gauge students prior knowledge of the topic to be taught. This enabled him to use the information from the assessment to steer his planning. Tyler also liked using what he viewed as common misconceptions, in his teachings. He liked to point out the fact that in biology things rarely are black or white (e.g., generalist or specialist, primary consumer or secondary consumer), that there are most of the times shades of grey. He made the following comment to his students during his first video taped lesson: "this is what we call a continuum, it's a gradation. It's not an all the way specialist or all the way generalist (VSR1)." When further asked, why he said this he said that he had observed this before with the concept of altricial and precocial (VSR1). A similar issue was argued about mutation and developed more in depth in chapter 4.

With experience, Alex became more and more adept at using classroom strategies of formative assessment through questioning to elicit students prior knowledge. He used these findings to determine the changes while teaching and to plan for future lessons. The importance of determining prior knowledge was a major focus of Alex's mentor and was adopted by Alex during the program.

Like all fellows Alex also advocated the use of real examples that considered students prior knowledge, as an important component in his teaching. The idea of student misconception was one that Alex included as an important component of his Evolution Plug-in project indicating that misconceptions were something he thought was important. Kate reflected that probing for prior knowledge and having in-depth reflections about it, was one of her teaching goals for her future career as a teacher. In her second year of the program, she also used more prompts to explore prior knowledge than the first year of MOSTEP.

Understanding the importance of prior knowledge is a conduit towards understanding knowledge construction. All fellows' ideas on the construction of knowledge seemed to have been formalized and fine-tuned during the program. Towards the end of the program all fellows talked more about students constructing knowledge rather than memorizing for a deeper understanding of content. For example, Kate talked about filling knowledge gaps by facilitating the accommodation of knowledge slats into a knowledge base. One of her justifications for doing this was to ensure that when new and more complex knowledge was taught the teacher would know that all students started on the same place. Tyler, Chris and Alex discussed the idea of making students add concepts to a mental framework, where connections were made and re-made as the information was being processed. In Tyler's case, the idea of mental frameworks was present since the beginning of the program. However, with time he refined some of these ideas. In his final reflection he said: "the best way [for someone] to learn is to find those [familiar concepts] that will help you plug that [new information] into your mental framework in a way that it will stick with you" (Ref. Int.).

Chris ideas evolved in similar ways to Tyler's. They moved from filling gaps in a puzzle, to putting information into a mental framework while being aware of the student's prior knowledge. For example, towards the end of the program she said that if students "…are able to put [new information] into a framework, or link it to things that they already understand" then it will become easier for the student to learn such concept (Vig. Int.3). These ideas are consistent with what Donovan and Bransford (2005) refer to in their Principle #1: Engaging Prior understanding; "new understandings are constructed on a foundation of existing understandings and experiences (p. 4)."

Finally, when Alex was questioned about his position regarding knowledge construction he said that, the idea of constructing knowledge made sense to him from the beginning. He said that it made sense when it was explained by the educational specialist and afterwards by his mentor. In a way he added that the idea of constructing knowledge was strengthened in MOSTEP (personal communication, July, 2007).

Student engagement and motivation. All fellows acknowledged the "lack of motivation" in their high school science classrooms. This experience was probably the most shocking to the fellows because they all have a deep interest in and commitment to their subject area. A common theme emerging from the fellows' comments was their frustration based on a lack of student motivation. Most fellows moved towards understanding the lack of motivation and engagement and tried to address it. For example, Kate and Alex (second year BGF), who were taken aback by this lack of motivation during their first year, much like Tyler and Chris, were more proactive about tackling and learning the causes behind this lack of motivation. They inquired further as to what was causing this behavior, and how they could overcome it and get students excited about studying science or maybe even becoming a scientist. Kate took the initiative to read some papers related to pedagogy, motivation and poverty to try to understand the lack of student engagement. She also shared that after her second year her understanding of motivation in teaching and learning environments changed. She felt that this experience in itself would probably make her a better undergraduate instructor because she will have a better idea where her students will be coming from.

Alex learned how to deal with these behaviors in his own teaching. He now (as a practicing teacher) mentally asks himself, “What is causing this behavior?” How can I help them or help my class in general be more motivated? For Chris, the impact was somewhat different. When she saw students lying down apparently not paying attention or with their heads down and not taking notes (unmotivated), she believed, at the beginning that students were not learning and did not care. However, upon further experience in her mentor’s classroom and through some reflection she realized that even though students seemed like they were not engaged, they were actually learning something.

The lack of motivation threw Tyler off from the start. He said that this characteristic of his class made him lower his expectations, but towards the middle/end of the project he reflected that if he had to do this again he would never underestimate what his students could learn. Coming from a very strong position of the importance of content over process, Tyler seemed to have a hard time adjusting to this reality. Nevertheless, even though he said he lowered his expectations cursory analysis of the tapes of his classes showed an appropriate level of student engagement.

Understanding of diversity. Fellows are divided in their analysis of the costs and benefits of addressing diversity in the classroom. Their experiences and reflections about different levels of student motivations, different student learning ability, different student backgrounds and different prior knowledge seemed to have sensitized BGFs to the need to factoring diversity into the teaching and learning process. Toward the end of the program, when fellows reflected about diversity issues, all fellows seemed to have shifted from pointing out the characteristics of a diverse classroom, to discussing the implications of diversity in the teaching and learning of science. In addition, they talked more about diversity from a student-centered point of view (i.e., how students could benefit from this situation, how considering diverse examples that drew from students backgrounds could be incorporated) and less from a teacher-centered perspective (i.e., harder to teach because they all have different backgrounds and are not at the same level). For instance, all fellows said that having a diverse classroom in a science class would allow the teacher to pull from different experiences to enrich the classroom content. Overall, all fellows moved from describing diversity in terms differences among students to using their understanding of diversity to enhance a learning environment. For example instead of describing that students came to class with different interests they discussed ideas about the teacher using his/her understanding of diversity to customize his/her classroom to enhance and enrich the learning environment.

Instructional Strategies knowledge

Later in the program, during the analyses on teaching and learning strategies fellows tended to reflect in a more coherent and detailed manner analyzing the strengths and weaknesses of various teaching strategies. Fellows thought that the idea that lecturing strategies were suitable to convey knowledge, was challenged. For example, when reflecting upon the first vignette intervention, fellows like Tyler and Kate, would comment that Dr. T. delivered science content in adequate ways. However, in follow up vignettes, all fellows made parallel comments that Dr. T. could stop more often to assess his student's level of understanding to get a picture of what was going on the class and tailor his class accordingly.

Almost every fellow dealt with the lecturing issues in similar ways. For instance, Kate's comments throughout the study reflect a constant debate between using and not using lecture-based teaching approaches. She refers to her state of being as "riding the fence". Tyler, on the other hand, argued that using lecture was fine as far as the ground rules were set. That is, if students knew that the teacher's mode of teaching was lecturing and were warned about this at the beginning of class, students then need to adapt to this way of teaching to succeed. However, towards the end of the program he commented that integrating some inquiry and good questioning might be appropriate.

Chris reported that she had heard that lecture was bad. However, she used lecture in her first teaching experience even when encouraged to do an activity-based lesson. When questioned why, she answered that it made sense to her to do this based on the nature of the class. Lecturing was probably one of the teaching strategies she felt more comfortable with and most familiar with. This comfortableness was implied in one of her comments during our introductory interview "I mean just standing up there and talking…think of all the stuff you can get through in just 45 minutes." Maybe what she said was not as important as how she said it. In addition, when asked how she would teach a food web class in high school she basically described a lecture approach claiming that this is what she knew (Gen. Int.1). Despite all this predispositions towards lecture, later in the program Chris made comments of adding anticipatory sets to the lecture and adding inquiry activities. She also became more reflective of the weaknesses and strengths of the strategy. A degree of change was observed.

Alex from the beginning proposed making changes in Dr. T.'s lecturing approaches. He talked about managing discussions, using guiding questions and constantly assessing students. He also demonstrated awareness of the strengths and weaknesses of lecturing.

Toward the end of the research intervention during the final vignette exercise, all fellows included these comments about lecture during teaching: a) ideas of questioning students during class "appropriately" to elucidate their thought processes, b) guiding students by providing relevant and exemplar visual models, and c) assessing formatively students level of understanding, that is, check their ongoing and prior level of understanding and whenever possible consider the information gathered to change the practice or else include another teaching strategy in the mix. Combined with their reflection on weaknesses and strengths of lecturing, these characteristics may be valuable when involved in teaching or presenting at the college level.

Worth noting is that some of these observed changes could be attributed to BGF's familiarity with the instruments used in the research. The use of the vignettes and similar processes surrounding its use within one content area could result in BGF's anticipation of appropriate answers. Veal (1997), plants the same argument. However if this were the case I would say that BGFs would most likely provide less details in their accounts and be more broad in their explanations as repetition of the event occurred. On the contrary, the level of detail and further reflection in discussions were more detailed and articulated. In addition, as the program progressed, other MOSTEP experiences were provided by the BGFs as supplemental explanations to their reflections and discussions.

Discussion strategies. All fellows agreed that their biggest change was in the area of questioning strategies. All fellows agreed about the importance of not giving the students the answer to a prompted question. Instead one should guide students towards an answer and wait enough time for them to answer if needed. In spite of this discussion, fellows like Chris and Tyler still showed some impatience during teaching when students did not provide an immediate answer to their question and ended up giving the answer. On the other hand, Kate and Alex were more patient and managed their wait time differently. Philosophically all fellows seemed to understand the importance of wait time following a question.

Some fellows offered more examples of appropriate discussion strategies. Alex provided more detailed explanations about formative assessment. He was also able to discuss in depth some of the trade-offs of such an approach. Alex was one of the fellows who had had almost double the amount of teaching hours and mentoring time. Experience in the program could be a possible explanation for his depth of understanding of questioning strategies (see Figure 6 & Table 5)

Tyler, said that his recent learning experiences in the classroom had been valuable in shaping his views regarding discussions. For instance, during the vignette exercise, Tyler said that he started questioning the effectiveness of the instructor's discussions in the vignette. He further reflected on how Dr. T. should interact with his students to improve his students' learning. Finally, Chris' level of understanding regarding discussions shifted, from a back and forth dialogue of presentation of facts to a rich interaction between teacher and students, where asking appropriate questions and guiding student thinking should be more the norm. Chris had never thought about the level of complexity behind discussion learning.

Group learning. Kate and Alex were the only fellows out of the four who made any comment regarding group learning. Kate mentioned that she learned about the jigsaw strategy in her mentor's class and added that she would advocate group work even in large lecture rooms in order to enhance student learning by promote student-centered approaches. When and where she learned about the specifics of group work were not clear.

Alex understood the use of group work at multiple levels. He was able to look at group work from an assessment perspective, a student perspective and evaluate the pro's and con's behind using such approach. He used group work, more often than Kate during his taped lessons.

Inquiry. All fellows finally seemed to accept that inquiry teaching strategies, and learning about scientific inquiry, were important in science teaching and learning. All fellows seemed to have struggled with using inquiry at the beginning of their first year in MOSTEP. Chris said that inquiry meant nothing to her but asking a question until she met with the mentor teachers during one of the summer workshops. Even after this summer workshop the idea of inquiry teaching took some time to form in Chris' mind. Toward the end of the year-long intervention she demonstrated basic uses of inquiry when teaching and during discussion/reflection sessions she was able to articulate the weaknesses and strengths of inquiry teaching. All fellows expressed knowledge about inquiry's strength and weaknesses. For instance, Chris mentioned that "a weakness [in inquiry] is it takes really long. You have to have a lot of time for them to come up with what they're doing. But I think it's more meaningful to them because it is more personal (VSR2)." Tyler made the following comment, "An inquiry-based approach is going to be a lot more scattered and not as efficient [as lecture], and not as focused" if you need to cover the material. Similar comments were made by Alex and Kate.

For Tyler the idea of inquiry first seemed more synonymous with playing than investigating. After being involved in the culture of teaching science, the word inquiry seemed to metamorphosize for Tyler into a positive thing and potentially a valuable approach to teaching science. This was a conditional change because at some point Tyler added that if the context was a university classroom considering the use of inquiry teaching would be contingent on the teacher's ability to cover the intended content. In one of his last vignette analysis, he did acknowledge that he embraces inquiry because it engages learners in more critical thinking and a holistic manner as opposed to students memorizing terminology.

Kate was one of the few fellows who acknowledged that inquiry could be done at any level and circumstance in the education continuum. She said that "it was just a matter of knowing how to guide and asking the right questions" at the appropriate time. She acknowledges that her constant reflection on prior university practices, when being a TA, could have had an effect on this. Unlike Tyler, she did not hesitant to consider the use of inquiry in a university/college setting. She embraced the idea of inquiry and demonstrated this by making it an important tenet of her teaching philosophy and goals.

Alex comments indicated that he embraced inquiry. One of his last comments, made outside of our regular discussion sessions was that he had really learned what it means to teach using inquiry and about inquiry (personal communication, July, 2007). Not only did he feel confident saying this, but his video taped enactments demonstrated a good use of inquiry in his classroom.

All fellows seemed to have learned the main underpinnings behind inquiry teaching. They also seemed to have a basic grasp of the potential difficulties and trade offs with regards to implementing inquiry. They would talk about inquiry taking up more time and about inquiry jeopardizing the amount of content covered. Concurrently, they all recognized the importance of learning about scientific inquiry. However, this was a position adopted from the beginning of the program mostly likely as a result of the education specialists and project PI's emphasizing the role of BGS as scientists in residence.

Transfer of PCK

Biology graduate fellows (BGF) seemed to consider that certain knowledge and practices about teaching and learning, experienced in their high school setting, had the potential to be applicable to a higher education setting, and vice versa. For instance, Chris favored the use of bell ringers (anticipatory sets) in university/college settings. She mentioned that Dr. T. could use this strategy during his class as a way of improving his way of teaching. Alex mentioned multiple times the inclusion of diverse assessment strategies in the university/college learning environment to enhance student learning. Kate advocated group work and the idea of splitting large lectures into sub-units during class to accomplish more cooperative learning. She also demonstrated how some strategies she learned in higher education settings were applicable to high schools. This was the case with the 5 slide assessment question strategy during PowerPoint presentations. It was also the case for the use of sign-posts to build student awareness of difficult sections within a unit. Tyler said that he could teach his high school evolution beak activity to an undergraduate class, but he would expect students to come prepared for class, that is having read the chapter on evolution, and not shy away from technical terminology and more advanced concepts (VSR2).

Kate also considered that some activities used in undergraduate science classes could be used in high school contexts. Because of her previous teaching experience in college, as a TA, we could argue a form of backward reaching transferred (BRT) occurring (Woolfolk, 2001). One of the activities she used was modified from a general ecology lab on natural selection she used for an undergraduate class. Contrastingly, when fellows where asked to create an undergraduate class, Chris and Alex up-scaled a lesson they had previously taught or prepared for their high school class. Chris scaled up his Hardy-Weinberg class and Chris the penguin taxonomy class. These behaviors could be interpreted as an indication that BGF were considering the potential uses of strategies learned in one context applicable to the other context.

All fellows considered the potential of using some form of inquiry, either in complementary labs, discussions or lecture sessions as a potential change in their teaching approach when teaching in a higher education setting. They also considered the use of appropriate questioning strategies. For example, not telling answers but guiding students towards an answer, waiting enough time for students to process ideas, and using the information gathered as a guiding tool or barometer for their class.

Overall, ideas such as: prior knowledge, strategies such as bell ringers, appropriate questioning, designing lessons and using appropriate goals and objectives, and in general using formative assessment have been considered by fellows as having the potential to transfer across contexts. However, a follow-up study on how this strategies get used or not, and how they get implemented by each fellow if they teach in academia would most likely provide a complete picture of the transferability of these strategies from a high school setting to a higher education setting.

As pointed by the NRC (2000), "the degree to which the situations share common elements" (p. 73) will greatly enhance the chances for teaching ideas and practices to transfer across contexts. At times if similarities are not made visible through appropriate reflection, then *forward reaching transfer* (FRT) (Woolfolk, 2001) may not occur. The fact that fellows were forced to think outside the high school context through the use of: vignettes and higher education floating questions embedded in interviews, had an important role in making these types of connections more visible and relevant.

Sources of PCK

There were many factors that contributed to the fellow's development of PCK. Factors were separated into those sources of PCK related to experiences prior to MOSTEP and those related to the MOSTEP experience per se. For instance, Tyler experience with museum pedagogical courses and Chris and Kate experience as TA's in undergraduate science classes will be considered experiences prior to MOSTEP. Conversely, comments made by educational specialists, teaching experiences in the high school classroom, comments made by other fellows and scientists, and professional development teaching conferences (e.g., NSTA) attended during their MOSTEP experience are examples of what was considered an experience related to MOSTEP. For example, during a biweekly meeting, one of the scientists recommended Tyler to change the order of his beak evolution class to give his class an inquiry twist. After listening to this idea Tyler did so and successfully.

Other sources of PCK related to MOSTEP were: observations and comment made by their teacher mentors; reflecting on case studies and teaching practices; and attending PD seminars and reading research papers in education to complement ones knowledge of the teaching and learning processes. Although not every fellow experienced all these interventions, the combined effect of such sources provided a mechanism for fellows to question, change, define, challenge, or maintain their views regarding teaching and learning processes as scoped by PCK.

Evidence shows that fellows were exposed to different sources of PCK in different ways, and for different amounts of time. Some fellows taught more often, others observed more often, while others planned lessons more often (see Figure 6). As a result, their understanding of PCK developed in mosaic ways. Some fellows learned more about assessment, while others learned more about inquiry. Some learned ideas about teaching and learning more in-depth, and others did not learn at all. Like previously mentioned, these differences in levels of understanding is most likely related to the amount of exposure to certain practices fellows might have had, the amount of reflection and relevancy they found with regard to each question asked, each situation presented and its application to their future.

Finally, the level of mentorship was probably influential in fellows learning and further understanding of PCK. All fellows agreed that the reflective exercise they did while being part of the research had a major influence in their understanding of teaching and learning processes. For example, every fellow agreed that reflecting on their practice (VSR), talking about the vignettes, and critiquing various instances of teaching and learning due to the research interventions, allowed them to further learn and understand a little more about teaching and learning processes (member check comments made by all fellows, July, 2007).

CHAPTER 6

Discussion of Results and Implications

Introduction

In general, university faculty have limited exposure to issues related to teacher preparation. Similarly, prospective faculty have little to no access to issues associated with effective teaching and learning (Dobson 2001; Elton, 2000; Norman, 1999; Nowlis, Clark & Rock 1968; Park & Ramos, 2002; Wulff & Austin, 2004). As a result, a series of ineffective teaching and learning strategies are pervasive in university classrooms. The creation of centers for teaching and learning at universities, and programs such as NSF GK-12 (e.g., MOSTEP) address this issue. However, the lack of preparation of prospective faculty remains an issue that needs immediate attention. Therefore, a more in depth analyses of the impact of such programs, in the understanding of teaching and learning processes of prospective faculty, is needed. These analyses would facilitate the characterization and replication of successful program practices in an effort to increase the likelihood of future professors becoming teacher scholars.

Defining change in understanding of teaching and learning processes in science is not easy. However, the construct of pedagogical content knowledge (PCK), introduced by Shulman (1986) and embraced as a knowledge base for teaching by the education community (NRC, 1996), provides a suitable construct for analysis of change in this study. In addition, a constructivist perspective of learning and transfer theory, in relation to changes in understanding of PCK, informs my findings and clarifies patterns of change in biology graduate fellows (BGF, i.e., prospective faculty).

The National Science Foundation (NSF, 2005) found that supported programs, such as MOSTEP, have increased or changed prospective faculty communication and instructional skills. At the communication level, the report claims that prospective faculty in these supported programs, spoke clearer and in a more concise manner, had increased teaching confidence, and were better able to gauge the audience response. At the instructional skill level, NSF reports that prospective faculty in the supported program developed creative lesson plans that were age appropriate and addressed different learning styles. The report mentioned that prospective faculty were challenged to think beyond lecture as the primary mode of instruction. These findings from the NSF report are consistent with findings in this dissertation study. While the NSF focused upon broad concepts, this study explores particular changes of prospective faculty understanding of teaching and learning processes in science as a function of PCK and the potential of transfer of these components across contexts. The findings in this study, suggest that specific components of PCK were challenged, changed and refined in addition to affecting instructional skills and communication strategies.

This chapter is presented in two sections. The first section contains a discussion of findings in relation to the research questions. The second section covers the implications of the research for science education research and future faculty education.

Findings in relation to research question

Change in understanding of teaching and learning processes in science (PCK)

While exploring the change in understanding of teaching and learning processes in science, two questions kept reoccurring. First, what did I mean by understanding? And second, what did I mean by change? Wiggins and McTighe (1998) talk about different levels of understanding. They proposed that for a person to truly understand a concept, an idea or a process, that person needs to be capable of explaining the concept, interpreting the concept, applying the concept to different contexts, exploring the concept from multiple perspectives (i.e., see and hear points of view from critical eyes), empathizing (i.e., finding value in what others might find odd), and having self knowledge related to the individuals knowledge and understanding about the concept (i.e., awareness of ones prejudices, knowledge gaps and biases)[12].

Examining understanding through these multiple facets allows for analysis of depth of understanding. An analysis of three teacher's (i.e., Teacher A, B and C) level of understanding of assessment, might begin by asking these teachers: How will you assess student's understanding of a concept (e.g., natural selection)? Depending on their answer, one could determine the level of understanding each particular individual has with regards to assessment as compared to each other. For example, if **Teacher A's** answers

[12] For further description of what each category implies see Appendix A. Readers unfamiliar with Wiggins and McTighe's work should note that these concepts build on notions originally proposed in Bloom's (1956) taxonomy.

lists a variety of testing tools (such as multiple choice, short answer questions and essays) to get a grade and nothing more is said, then one could argue that Teacher A has a basic level of understanding. If Teacher B's answer discusses using a battery of tests that are aligned to pre-established classroom goals and objectives (i.e., it is tied to the curriculum), where the tests are given before, during and after the content has been taught (i.e., tied to an instructional strategy) and s/he claims to use the student's answers to guide his teaching (i.e., uses formative assessment strategies) and to accommodate differential learning (i.e., it is customized to target student diversity in the classroom), then one could argue that Teacher B has an expanded level of understanding of assessment as compared to Teacher A. Finally, if Teacher C's answers includes the concepts expressed by Teachers B's answers and s/he mentions the strengths and weakness of the specific tests and assessment approaches (i.e., s/he has a perspective and self-knowledge) sharing how s/he uses such assessment approaches in other instances (i.e., can apply), while demonstrating awareness of some of his/her biases towards using certain strategies over others in certain situations, then one could argue that Teacher C has the greatest depth of understanding in comparison to Teacher A and B.

In other words, as individual teachers provide a more thorough explanation of assessment, with stronger and better supported arguments for the use of such assessments, the more likely his or her response represents a greater depth of understanding of assessment. If the explanation of how to assess the concept is also aligned with Wiggins and McTighe's characterization of understanding (see Appendix A, p. 1), then greater understanding has probably been demonstrated. Level of understanding, in this respect can be seen as a continuum. Moreover, the comparison just presented among teachers A, B and C could also be extrapolated to a situation where A, B and C represent the same individual moving through different stages in his/her understanding of assessment.

In this study, this method of analyses was used in a systematic way to guide interpretations of fellows' depth of understanding regarding components of PCK as they relate back to teaching and learning within and among fellows. Through comparative analysis and an inductive approach, differences in understanding were determined. For example, all fellows acknowledged that prior to MOSTEP they considered assessment as end of topic tests that provided a grade for the student as a measure of his/her achievement. After MOSTEP, all fellows explicitly and/or implicitly shared that assessment meant more than giving a grade. It meant constantly prompting students with questions during class to “jog their memories” (e.g., Alex), or asking questions before class “a barometer” (e.g., Tyler) to surface student prior knowledge and “steer the class curriculum.” In this respect, the fellows' general level of understanding about assessment shifted from a basic level to an enhanced or in-depth level. Thus, their knowledge of assessment changed and therefore their understanding of PCK changed. Despite the fact that all fellows’ concept of assessment changed, some changes were more obvious than others and some conceptualizations of assessment were more elaborate than others. For instance, Alex provided a succinct and detailed explanation of types, uses, weaknesses and strengths of assessment. Alex and Tyler discussed assessment in relation to curriculum, individual student, and instructional strategies. Chris’ comments related back to a definition and some uses of formative assessment instruments.[13]

So, what is change and how can it be observed? Change in PCK can be observed, and was observed, as a variation in biology graduate fellows' (BGF) behavior, knowledge, and self perception with respect to their prior understanding of PCK. Hence, considering BGF prior knowledge about PCK is important in order to understand change.

Shifts in BGF understanding of teaching and learning processes in science, as a function of PCK, occurred at different levels. For example, when an idea changes (e.g., knowledge about lecturing strategies shifts), it moves from state A to state B <A→B>; or is refined (i.e., moves from <A→A’>); or is maintained after being challenged (i.e., stays the same <A→A>), one can assume that change has occurred, i.e., the individual has undergone learning.

All fellows experienced some degree of change in this study. At one level or another, BGF understanding of teaching and learning processes in science as a function of PCK changed. All fellows refined and learned new strategies of how to teach science (e.g., inquiry). That is, their knowledge of instructional strategies, a component of PCK, changed. All fellows, also learned more about assessment and the value behind formative

[13] In Chapter 4 and Chapter 5 further comparisons in regards to changes in understanding of PCK have been provided. Table 5, in particular provides a synopsis of theses change, where symbols (see Key) determine, based on a subjective judgment, differences in levels of understanding as expressed by change.

assessment (e.g., probing student understanding during the class) which indicates that their knowledge of assessment, another component of PCK, changed. All fellows became more knowledgeable about ways of improving their lecturing and discussion skills (e.g., using anticipatory sets to start the lecture and using guiding questions to surface students prior knowledge), to help their audience (students) be more engaged and to increase learning. Concurrently, BGF became more critical of teaching at the university level as they reflected upon potential uses of different strategies and knowledge in other educational contexts. That is, they reflected on their knowledge of assessment, student learning, and instructional strategies, and how these components of PCK interact to provide a meaningful learning situation. They explored the potential, of using the strategies that they had learned in other contexts. The fellows' understanding of the different components of PCK had changed.

All fellows acknowledged that reflecting upon the research interventions, allowed them to challenge prior understanding of specific components of PCK. It helped them refine and better understand better the intricacies of teaching and learning science, specifically in relation to biological sciences. The finding, that reflection is crucial for enhanced understanding is consistent with the idea of reflective practitioner or reflective practice described by Schön (1983) and with transformative learning described by McGonigal (2007). For all of the participants, this study was their first experience with reflective practice related to pedagogy. In this sense, this study was similar to what Lenze & Dinham (1994) described in their study of PCK of college faculty new to teaching. Polman (2007, pers. comm.) said that if we do not reflect on our learning it is very unlikely that changes will happen, or refinement of existing knowledge will occur.

Overall, changes in components of PCK, by default, result in an overall change of PCK. In retrospect, this could be interpreted as a change in understanding of teaching and learning processes in science. Figure 2 and 3 (p. 12 & p. 13) shows the relational models of Magnusson et al (1999) and Veal and MaKinster (1999) proposed for PCK. The links between components and PCK implies that a change in any component of PCK will have a direct effect in PCK. Additionally, Figure 1 (p. 10) shows a hypothetical model of differential influences of knowledge bases in the development of PCK. One could assume that most BGF fall under Teacher A model, where probably most of BGF prior understandings of PCK was influenced by subject matter knowledge (SMK). One could argue that after the MOSTEP program, the influence of pedagogical knowledge (as related to PCK) changed for each fellow. In that sense, the influence of pedagogical knowledge (i.e., assessment, instructional strategies, curriculum and student learning knowledge) had a greater impact on BGF understanding of PCK. Therefore, a larger box would be depicted in the diagram (Figure 1, p. 10) for pedagogy, if BGF were to be used as a model teacher. In addition, differences between BGF's understanding and changes in understanding of PCK are probably associated with the fact that fellows are learning information from different sources: they have different mentors; they are being involved and exposed to different practices for different amounts of time; and, they had different prior experiences in relation to teaching and learning. Consequently, investigating how prior knowledge and sources of PCK influenced this study is also important.

Sources of PCK and learning theory

Grossman (1990) identified 4 main sources that affected an individual's development of PCK. These sources were: 1) apprenticeship of observation, 2) classroom experience, 3) subject matter knowledge and 4) teacher education. In one form or another, biology graduate fellows in this study were exposed to each of these sources (see Figure 6 & Table 5).

When developing a lesson or teaching a lesson, BGF were exposed to a classroom teaching experience or went through what Woolfolk (2001) calls enactive learning. As Jarvis (2004) points out, "learning always begins with experiencing" (p. 93). When BGF observed their mentor teach (i.e., apprenticeship of observation happened) or interacted with their mentor on a one-on-one basis (i.e., reflection and informal teacher education), the potential to learn more about PCK was present. I say the potential because observational learning, as described by Woolfolk (2001), requires someone to be active and reflective on what is going on so that a cognitive shift may occur.

According to Woolfolk (2001), observational learning also requires paying attention, retaining the information, and using the information in practice which includes reinforcement of correct practices. Only with these actions will someone gain this knowledge or skill. At times, one might learn about a skill through observation, but not necessarily use it. In this study some of the fellows, observed a skill as a potential teaching strategy but did not visibly use it. Kate observed the jig-saw instructional strategy but did not use it in her classroom. However, the idea surfaced as "an interesting strategy to use" during our conversations. This phenomenon could also be interpreted as evidence of the presence of declarative knowledge without procedural knowledge (Anderson, 1981). Thus the change in PCK happened because of a gain in knowledge of a new instructional strategy.

In other cases, the teaching strategy was observed and then was encouraged to be used by the mentor. After observation of inquiry Tyler's or Alex's attempted to incorporate it. Tyler was very skeptical towards using inquiry in his class. He argued at the beginning that it did not seem realistic to use inquiry. He also said that this strategy was something he would not use in a college setting. However, with time that included observation and constant encouragement from his mentor and education specialists, Tyler developed and enacted a couple of lessons where inquiry teaching was used to guide the lesson. Learning about scientific inquiry was also an important aspect of one of the lessons. Tyler eventually agreed that some inquiry could and should be used in college settings. Alex observed inquiry being used by his mentor, who encouraged him to use inquiry during his teaching enactments. Alex's knowledge of curriculum design and lesson planning was impacted resulting in his recognition that inquiry could and should be used in college. Other cases in which PCK was affected were observed with the bell ringers in Chris' instruction and with the stop and assess every 15 minutes PowerPoint strategy that Kate used. All fellows were observed using guiding questions to help students reach an answer, instead of telling them the answer.

Without reflection, observational learning could remain in a behavioral state. When a certain behavior (e.g., stopping every 15 minutes) is imitated by a fellow, without reflecting on the purpose of the behavior it may remain in a stage of "must be done for some unknown reason", instead of "it should be done" because of a strong pedagogical support behind the behavior. One possible reflection could target the idea of allowing the teacher to pace him or herself, by formatively assessing students or by giving students some down time to allow concepts to "sink in." The ability to transfer such skill to another context, or situation, requires the learner to use a cognitive process that requires reflection. If this kind of learning (i.e., I imitate what I am observing without thinking about it, much like TA's do with senior TA's or professors) happens without adequate reflection, the observed strategy will most likely lead to the use of ineffective teaching and learning strategies or use of effective teaching and learning strategies ineffectively.

Figure 6, shows that fellows were exposed to different sources of PCK, in varying degrees, as denoted by the number of self-reported hours they devoted to such activities. For instance, if we look at Figure 6 (section Prep.LP.HSFac.) we observe that, overall, Alex spent more hours with his mentor preparing lesson plans than any other fellow. In contrast, Chris, Kate, and Tyler spent more time preparing lessons by themselves (i.e., no contact with their mentor) than did Alex. Considering that findings from this study suggest that Alex developed a more in-depth understanding of lesson planning and curriculum planning than any other fellow, I would argue that preparing lessons with someone to help you reflect on your mistakes and conundrums (mentor) will most likely result in the development of a more in depth level of understanding regarding lesson planning. Thus one might assume that something similar with regards to other components of PCK will follow through. Additionally, the more hours one spends doing and reflecting upon certain tasks (e.g., teaching using inquiry or preparing a lesson), the higher the chance that individual will understand better that skill or teaching and learning process. Hence, this differential use of MOSTEP hours resulted in differences among changes observed in BGF level of understanding of teaching and learning processes, as a function of PCK.

So far I have discussed and provided examples of BGF changes in understanding of teaching and learning as a function of PCK. I have also discussed instances of change as related, to identified sources of PCK. Concurrently, reflection was identified as a necessary practice for fellows to consolidate the ideas about teaching and learning. All fellows recognized that this metacognitive practice helped them clarify, refine and/or change their views about teaching and learning in science. However, most of these reflections happened through the research interventions (some happened via the high school mentors as discussed earlier). In the end, modifications in BGF understanding of PCK was discussed as a result of BGF's prior knowledge being challenged, refined and changed. At this point I believe that looking at conceptual change theory and constructivism, as they relate to prior knowledge, in a more in depth manner, will provide the reader with a better understanding of what fellows may have experienced in MOSTEP.

A person learning, consciously or unconsciously (i.e., active or passively), how to teach science (e.g. pre-service teacher <teacher intern, student teacher>, in-service teacher <beginning teacher, master teacher>, prospective university teacher <TA, BGF>, or in-service university teacher <professor, lecturer>) is in essence a learner. Therefore, learning theory can be equally applied to teachers, as it is applied to students, when learning how to teach[14] (NRC, 2000; Loughran, 2007; Woolfolk, 2001**)**. In this particular case, biology graduate fellows (i.e., prospective faculty) fall in this cluster.

Ausubel (1968) believed that the most important and influencing factor affecting one's learning is prior knowledge. If change is going to happen, prior knowledge needs to be challenged (see previous discussion). With this in mind, a table was created, to provide the reader with a tentative outline of the potential sources of prospective and beginning teacher's prior knowledge, regarding the understanding of teaching and learning processes in science (see Table 6). The goal behind constructing this table was to provide the readers with a general and comprehensive, common sense, framework to help them situate the context of how BGF understanding of teaching and learning could have happened. Teacher B, provides and example of a beginning high school science teacher without educational training. Most likely, teacher B's prior knowledge regarding teaching and learning will be the result of his/her observations, and images, kept from his/her experience as a high school student. Therefore, in a scenario where this individual is going to start teaching at a high school, s/he would draw on his/her past experiences as a high school student. Additionally, experiences in his/her undergraduate science classes might have an effect also, but most likely this effect will be at the level of content knowledge. However, this possibility cannot be ruled out. The likelihood of transferring a teaching approach observed as a student in high school is probably higher than transferring an approach from an undergraduate experience because transfer is a function

[14] Once a comfort zone is reached in terms of teaching, that is, the in-service teacher (university or high school alike) reaches a level of satisfaction with his/her teaching material and enactment, maintaining the status quo requires little effort. Interestingly, from an outside perspective learning how to teach seems to stop. Nevertheless, based on ones beliefs and work ethics it is subject to change as the practitioner reflects and updates his/her content or learns and implements new strategies.

of similarity (NRC, 2000). A prospective teacher will be more inclined to use certain strategies if s/he had seen it used successfully in a similar environment, with similar materials, with a similar set of students. Thus, the more similar a situation is to the present one, the more likely transfer will occur. Although a case can be made for a combination of sources affecting one's prior knowledge about teaching and learning, this breakdown allows the reader to acknowledge this situation and keep in mind the diversity of possibilities.

Biology graduate fellows fall into different categories within this table depending upon the circumstances surrounding the teaching experience and individual experience. From a high school teaching experience, fellows would most likely fall under Teacher B model. However, Tyler could be an exception because informal interactions with high school students during his zoo educational programs. From an undergraduate teaching experience, all fellows will fall under teacher model C with prior knowledge most likely coming from a combination of sources. This combination could include column 1 and 2, but would be less likely to include column 3, due to the degree of similarity among contexts. This five teacher model provides a broad picture of the potential origins of prospective faculty and, in retrospect, the potential sources of PCK.

Constructivist theory supports the idea that learners construct and deconstruct meaning when they are learning. This process involves constructing and deconstructing knowledge using prior knowledge as base knowledge to work on. BGF had certain prior knowledge of teaching and learning before MOSTEP. Between MOSTEP and my research this knowledge was challenged, refined and changed via construction and deconstruction of existing teaching and learning paradigms. Most fellows assumed they knew little about teaching and learning. However, not knowing the educational jargon or thinking that one knows nothing about teaching and learning does not mean a person does not understand what teaching and learning is. “Those learning how to teach tend to be unaware that they may have learned more about how to teach science than about science and scientific concepts while they were studying science in school and university classes” (Russell & Martin, 2007, pp. 1151-1152). In addition, beliefs and experiences are deeply intertwined and hard to change and can make the process of change difficult. When Tyler talked about undergraduate education and applying some of the skills he observed and learned in high school during the first two-thirds of the program, he stuck with his position that one is responsible for one's own learning and as far as the teacher laid the ground rules students should abide. Towards the end of the program, he acknowledged that there might be some value in implementing some of the strategies like inquiry even in lectures. Chris had a similar non-changing point of view with essay questions. All fellows had a strong non-changing opinion regarding logical content sequence of a curriculum. Saying does not mean embracing completely, but it means considering: therefore consideration to apply certain teaching strategies involves a challenge to one prior conception and in essence the first steps for change.

Like many other learning processes (i.e., learning to play basketball, learning about evolution or learning about drawing and art), learning how to teach involves: 1) surfacing and challenging one's prior knowledge, 2) building on this existing or changed knowledge, 3) reflecting throughout ones learning, and 4) trying out what is learned in different situations using multiple examples in a variety of contexts. In this way transfer of gained knowledge is enhanced. For some fellow's in this study, their level of understanding of components of PCK, seemed to have progressed through all four stages; others seemed to have progressed through two or three stages only. This progression through stages was not necessarily a linear process, nor was their homogeneity among fellows background regarding understanding of teaching and learning processes. Whatever changes could or need to happen, "conceptual change is central to learning and teaching science and to learning how to teach science" (Russell & Martin, 2007, p. 1153). However, one must remember that prior knowledge and beliefs are critical components in the change process, as is constructivism.

Table 6. Tentative outline of the potential origins and sources of science teacher’s prior knowledge regarding the understanding of teaching and learning processes in science.

		Where could prior knowledge, on how to teach come from? Where is it **more likely** for a science teacher (mainly beginning) to draw ideas about teaching and learning from?		
	Source	Various	University	High School
	Experiences (Time perspective)	Most RECENT experience---> Less RECENT		
		[Prior Knowledge] Teaching/Classroom experience in relation to job (i.e. most common sources of PCK)	General courses taken at university that could affect PCK and teaching. (PK, PCK, SMK)	
Science teacher description	(HS) beginning science teacher (e.g. with teacher education training) Teacher Model A	(***) *Classroom experience: during pre-service, teacher internship & other school teaching experience (e.g. virtual visit)* -Observation of cooperating teacher -Experience teaching in the classroom -Reflection on teaching	(**) *Education courses* -Education Foundation courses (Gen) -Specialized education courses -Science methods (Inst.) *Science courses* -Observation of teacher -Gain in subject matter knowledge (SMK)	(**/ *) *HS student experience.* –Observation of HS teacher.
		[Prior PCK for these experiences most likely comes from UG courses and high school experience as a student]	[Prior PCK for these courses most likely comes from HS student experience]	
	(HS) beginning science teacher (e.g. w/o teacher education training) Teacher Model B	( ) *Classroom experience* (None)	(*) *Education courses* (None) *Science courses* -Observation of teacher -Gain in SMK	(***) *HS student experience.* –Observation of HS teacher (e.g. what worked in class that helped him/her learn, what s/he remembered from HS teachers activities and experiments)
		[Prior PCK: NA]	[Prior PCK: NA]	

Undergraduate (UG) beginning science teacher (*aka* Faculty or lecturer) Teacher Model C	(***) *Classroom experience: as a Teaching Assistant (TA) maybe lecture replacement for advisor* -Observation of senior TA or lab/lecture teacher -Observation of lectures taught by faculty -Experience teaching as a TA in (Lab/recitations or lecture)	(**/ *) *Education courses* (None) *Science courses* -Gain in (SMK) -Obs. Graduate science courses (Unlikely)	(*) *HS student experience.* –Observation of HS teacher.
	[Prior PCK for these experiences most likely comes from observation of UG courses]	[Prior knowledge: NA]	
Graduate (GR) beginning science teacher (*aka* Faculty) Teacher Model D	(***) *Classroom experience: as a Teaching Assistant (TA)* -Observation of graduate faculty -Observation of senior TA or lab/lecture teacher -Observation of lectures taught by professor -Experience teaching as a TA -Graduate teaching experience (unlikely)	*Education courses* (None) *Science courses* -Obs. Undergrad. courses/ Gain in (SMK) -Obs. Graduate science courses (SMK)	*HS student experience.* –Observation of HS teacher.
	[Prior knowledge for these experience most likely comes from observation of UG courses]	[Prior knowledge: NA]	
High school (HS) science teacher (e.g. in-service or master teacher). Teacher Model E	(***) *Classroom experience:* -Past teaching experience -Professional development (e.g. workshops, seminars, conferences) -Graduate courses (if any)	*Education courses* -Education Foundation courses (Gen) -Specialized education courses -Science methods (Inst.) *Science courses* -Graduate science courses (Unlikely)	*HS student experience.* –Observation of HS teacher.
	[Prior knowledge for these experience most likely comes from observation of UG courses]	[Prior knowledge: NA]	

(***) The number of asterisks represent locations based on the table model where it is most likely the described teacher will draw information, experiences to conceptualize, discuss or get involved in teaching

Note: How far one goes to get ideas about teaching and learning is unknown. Most likely the "newer" stuff, which is more latent, will probably be the first choice. An evaluation of similarities will also occur to match the relevancy among contexts. The model teacher's are assumed to be prospective teachers. Teacher model E is the exception. It has been provided as a contrasting reference.

Potential of Transfer

“Learning in context has very positive benefits; however, it also has limitations. Our learning becomes quite context specific, and we must actively work at being able to transfer that learning to new situations” (Mann, 2002, p. 71). This study examined the potential of knowledge transfer, specifically the transfer of pedagogical content knowledge (PCK), from a high school context to a university context. Conversely, evidence of transfer of PCK from university to high school was also observed, in rare cases, as a byproduct of the different research interventions.

According to Mann (2002) learning can become “quite context specific” (p. 71) and the more similar a situation is to the target context the more probable it is that transfer will occur (Driscoll, 1994, NRC, 2000; Singley & Anderson, 1989). In contrast, the less similar the two situations or concept are, the less likely it is that transfer will occur (Bjorl & Richardson-Klavhen, 1989). Thus, transfer is not a “yes” or “no”, but a continuum. Thus, the expectation of biology graduate fellows (BGF) transferring PCK from a high school context to a university context could be rather challenging. For the most part BGF spent the majority, if not all, of their time in a high school classroom with high school students teaching high school content. Therefore it would be more likely, and probably expected, for BGF to transfer more readily their PCK to a similar high school situation than a university one. Nonetheless, by constantly situating the BGF in a university context, through the use of vignettes portraying university science classrooms and challenging fellows with questions related to higher education contexts (embedded in interviews), the potential of transfer of PCK could be noted as well as potentially encouraged. By having BGS reflect actively (indirectly or directly) on the feasibility of transfer of PCK among contexts, the likelihood of them using their gained understanding of PCK in high school settings to explain or discuss teaching and learning situation in a university settings was present. Interestingly, evidence suggests that when fellows were exposed to vignettes and asked to reflect on the case study, they explained student behaviors and critiqued teaching and learning strategies occurring in the vignette by using some of their high school teaching and learning experiences or some of their gained understanding of PCK. However, in some instances, when talking about high school situations, Kate, Tyler and Chris used part of their university experiences (as students and TA's) or adult learning experiences to explain and justify actions taken in their high school classrooms or positions taken during the interview.

Additionally, when BGF were asked to prepare an undergraduate or graduate lesson plan all fellows chose to use the proposed lesson plan, based on Madeleine Hunter's model, despite the fact that they were encouraged to use their own format. Concurrently, some fellows, like Chris and Alex, accommodated a previous high school lesson plan into a university lesson plan. The differences among both lesson plans were more at the content level and the difficulty of the questions asked rather than the sequence of events to happen. Some fellows such as Chris, seemed to have used part of the vignette sequence to teach her population biology review at the high school level, but it could well be related to following a text book approach. Nonetheless, the vignette could have potentially affected the way Chris acted in the high school classroom.

These observations suggest that transfer at a philosophical level had occurred from a high school context to an undergraduate context and were most likely facilitated by the use of vignettes and reflective practices. Veal (1997) used a similar case study strategy to perform research on pre-service science teacher's development of PCK. For the most part his vignettes portrayed a High School classroom environment. Therefore it acted as an additional source to observe the development of PCK among and within these teachers.

One of the NSF GK-12 objectives is to enhance the learning skills of prospective faculty. This is assumed to occur naturally, however the findings in this study imply that situations where BGF are not required to think outside their high school context, as is the case with a number of GK-12 programs, will only result in temporary changes that are less likely to transfer to the next level. While this assertion is not definite, the nature of the situation implies that it is a strong possibility.

Implications for science education research and Implications for prospective faculty education

To the best of my knowledge not many studies have explored, in depth, the changes in prospective science university teachers' (i.e., prospective university faculty/

scientists') understanding of teaching and learning processes in science, as a result of an interaction with a high school science teacher. What has been done in the past either tackled this interaction broadly (NSF, 2005), or described the benefits for the teacher rather than the scientist (Haakonsen, Tomala, Stone, Hageman, 1993), and commented in an anecdotal manner, some potential benefits to the scientist (Drayton & Falk, 1997, 2005; Melber & Cox-Petersen, 2005). Seldom has what happens to the university teacher's (i.e., scientist's) understanding of the actual teaching and learning processes as a result of this interaction (NSF, 2005) been examined. Discussions of how scientists' pedagogical content knowledge was affected after the interaction with a high school teacher have been partially neglected. Additionally, little evidence exists of a longitudinal approach to the study of the effects these partnered interactions have in the classroom context. The idea has been proposed by NSF (2005), but to my knowledge it has not yet been conducted. I believe that many research avenues could be explored and additional studies are needed to add to the body of knowledge of helping scientist develop a better understanding of teaching and learning processes in science. Only then will the understanding of this the phenomena related to this topic be clarified and enhanced. Some potential future studies follow:

1) A similar study to the one conducted could be completed where other treatments, such as TAs with no interventions (control group) and TA's with intervention from the university's center for teaching and learning programs, compared against a year long partnership with a high school teacher. In that study, all groups would be exposed to the same instruments: interviews, vignettes and surveys. In other circumstances, this same model could be applied in situations that investigate first-year university faculty who have been exposed to similar treatments. In similar ways comparisons could be done across treatments, within treatments and across studies.
2) A second study could involve comparing the results of this study with results of other studies in which similar analyses occurred with other groups of prospective science teacher including pre-service high school, middle school and elementary teachers (Veal, 1997). In this way, similarities shared between and among groups, and differences between and among groups could be explored and potentially

result in a better understanding of the nature of learning how to teach in different contexts and individuals.

3) A third study could involve deepening the understanding of the actual changes in level of understanding each fellow went through. This strategy might require the construction and use of a quantitative scale, based on Wiggins & McTighe (2001) that has been adapted to serve as measuring instrument of degree of change. In addition a quantitative analysis of their teaching could be performed and compared more thoroughly with other findings. And finally, fellows could be asked to teach in a pre and post fashion classes at the university while being involved in the GK-12 program.
4) Based on Crawford's (2007) findings, where evidence from their study strongly suggested that

> the most critical factor influencing a prospective teacher's intentions and abilities to teach science as inquiry, is the prospective teachers' complex set of personal beliefs about teaching and views of science. A prospective teacher's personal view of teaching science as inquiry, comprised of his or her knowledge of scientific inquiry and of inquiry-based pedagogy and his or her beliefs of teaching and learning, is a strong predictor of a prospective teacher's actual practice of teaching science (p. 636)

another study could be conducted to explore the notion of beliefs more in depth.

5) A final approach would be a longitudinal study that follows people involved in GK-12 or similar programs into their professional lives. In this way a better appreciation of the effect of such interaction could be noted and the degree of transfer, between what was learned during these interactions in a high school, and what is performed in a college setting, could be observed, analyzed and discussed more thoroughly. The NSF (2005), in their draft report, also made this recommendation.

Variations of the mentioned studies are possible and very much encouraged. By no means is this an exhaustive list of studies that could be performed in this area. Teacher education, and in particular understanding and studying teacher education in relation to faculty (i.e., university teachers), is a topic left largely unexplored, or maybe it has been left untouched purposefully. What is true is that it is an area that raises many controversies, and remains an area in need of further research. Many questions persist about faculty and the synergy or lack of it in their academic/teaching roles (i.e., scholarship of teaching vs. scholarship of research). Arguments vacillate between the importance of each role and questions are raised as a result of this intellectual debate: Should faculty focus on research more than teaching? Should tenure be weighted more in terms of their awards, publication and grant money or should teaching be the driving variable? What is the right balance? If we need to make a name for our university, how do we make our name, by hiring better researchers, better teachers, better research-teachers? Does that individual exist? Is it reasonable to conjure an individual with those characteristics? Is graduating capable individuals with the ability to think critically, to be self-learners and problem-solvers the main goal of a university? If so, who makes this possible, who creates this opportunity? Is it a good researcher, or a good teacher? All these questions are good questions. Some of them have answers, some of them have been explored, and some of them have been primers for more intellectual debates in academia. The purpose in recalling these questions lies in understanding that teaching, as much as it has been a secondary characteristic of faculty needs, should be reconsidered as a critical one. The more research done on avenues of teaching as related to faculty or future faculty the better and more informed decision could be taken in the near future as to how best to accomplish excellence in educating future generations. For new and practicing faculty it is a search for understanding of those competencies for which thou should strive to learn and which will allow them to provide a learning environment where diversity is more the norm rather than the exception and where imitating predecessors might not be enough training for addressing teaching circumstances in the near future.

Analogous to biology, in particular natural history, this study provides a base line, in the form of an in depth description, of what changes future faculty undergo when exposed to situations like the one NSF GK-12 programs advocate. It is one way of exploring those skills and practices that might be valuable for prospective faculty in the future. The richness in the descriptions and the verbal accounts of each BGF could potentially lead to an enhanced understanding of this phenomenon. Although GK-12 project provides us with a framework the results could be superficial in some respect while particular in another. This study adds to this line of inquiry by delving more in depth into understanding of what happens at a finer and more individual scale. It opens another door into enhancing and understanding the development of faculty and future faculty teaching abilities and knowledge related to the processes of teaching and learning in science. It also adds and reinforces the idea that faculty members, and in particular future faculty, need more than a swim-or-sink approach to develop their teaching skills. In other words, they need a more in depth understanding of teaching and learning processes in science, so that they can provide a quality education to the future professionals, formation for which they are responsible. Programs like GK-12, initiatives of different centers of teaching and learning and institutions such as the Pew Charitable Foundation and Carnegie need to stay in place to accommodate the need for improved training of future faculty and to provide for in-service of current faculty.

However, based on my findings, and in a complementary fashion with NSF GK-12 results, I would recommend considering the following ideas in order to increase the effectiveness of programs that target the development of understanding of PCK in prospective science faculty.

A) If the program has no GK-12 funding available:

1) *Make it mandatory (part of their degree program) for graduate students to take at least two college level courses that specifically address teaching science in higher education settings.* These courses should include activities like: writing a science teaching philosophy (pre/post); discussion of case studies (much like in business and medicine) related to the teaching of science (i.e., similar to my vignette intervention); discussion of components of PCK in relation to science teaching and learning; observation of multiple faculty members in the science department teaching core, major/non-major and advance graduate level courses; teaching sections of science courses that vary in size (i.e., large lecture, small lecture, diverse classrooms, discussion) and type (e.g., lab, discussions, seminars, and recitations); and finally it is imperative that constant reflection, while performing these different activities, occurs via the mediation of a team composed of an expert pedagogue, an active science faculty member, and the group of prospective faculty being trained.

2) Emphasize the importance of such requirement (taking courses and performing the activities). Ensure that the majority of faculty (advisors in particular) endorse the idea of teacher-scholar and not one or the other. In other words, create a culture where teacher scholars are applauded instead of undermined. Stress the importance of taking the courses in science pedagogy instead of seeing them as a hurdle in the program. In addition, factor into faculty duties and responsibilities time invested in mentoring students in their teaching. If time is not available, develop partnership with Colleges of Education on campus and have doctoral students in science education work together with prospective science faculty.

3) Ask fellows to plan a unit for a class and teach it. Providing experiences like these allows fellows to gauge needs to be done in order to plan, develop, and implement a successful science related class. In addition, it provides prospective faculty with prior knowledge for when they start working as faculty.

B) If the program has GK-12 funding available:

1) Emphasize the importance of reflection. Make sure that prospective faculty encounter situations where they are forced to think about the applications of what they are learning in one context (high school or grade school) in the higher education context (Forward thinking transfer). Provide multiple occasions to reflect on this and practice this.

2) Mandate fellows to visit and observe other school settings. By doing this fellows will have a broader perspective of what is out there in terms of effective strategies related to teaching and learning environments in science. For example, if you always observe the same teacher that you consider a good teacher, with out asking and reflecting on this teaching moment, you may miss out on strategies that may be very effective, and maybe more appropriate, for your teaching context.

3) Make fellows take college level courses in pedagogy of science (See previous sections). Ask fellows to focus purposefully on applying what is learned in these classes to a higher education setting.

4) Ensure that mentor teachers have multiple student teacher experiences in their classroom. The quality and commitment of a high school mentor is key to enhance the success and development of PCK in fellows.

5) Require fellows to teach a certain number of hours inside the school and at the university as part of the program. Doing this will increase the likelihood of transfer among contexts and therefore likelihood of future faculty using what was learned when teaching in higher education contexts.

Overall, program implementation should include active reflection, guidance by an expert science pedagogues, and support of the department.

I have heard scientists say that there is no science behind learning how to teach. Conversely, from the context and descriptions shared during their conversations about pedagogy they often times seem to focus more on teaching and little on learning. "You learn to teach by doing it," they say. "That is how I learned and it worked for me," they add. Others have said that science implies knowing about the scientific method and describing phenomena with analytical eyes and rational thought. Most of the times, I have heard these arguments from scientists who have been old-schooled, that is, they have learned to teach by observing their: advisors, mentors, senior TA's or fellow TA's. In other words they have used an apprenticeship of observation approach to learning how to teach. They were thrown into the water (i.e., teaching situation) to see if they would sink (i.e., fail) or if they would swim (i.e., succeed). Most likely these same individuals will mentor and model teaching through this same example to their protégés. Clearly, a perspective change is needed, and fast.

REFERENCES

AAAS. (1993). Benchmarks for Scientific Literacy. New York: Oxford University Press.

Abell, S.K. (2007). Research on science teacher knowledge. In S.K. Abell & N.G. Lederman (Eds.), Handbook of Research on Science Education (pp. 1105-1149). Mahwah. NJ: Lawrence Erlbaum.

Abell, S.K., & Lederman N.G. (Eds.). (2007). Handbook of Research on Science Education. Mahwah. NJ: Lawrence Erlbaum.

Anderson, J. (1982). Acquisition of cognitive skill. Psychological Review, 89(4), 369-406.

Anderson, R.D. (2007). Inquiry as an organizing theme for science curricula. In S.K. Abell & N.G. Lederman (Eds.), Handbook of Research in Science Education (pp. 807-830). Mahwah. NJ: Lawrence Erlbaum.

Appleton, K. (2003). How do beginning primary school teachers cope with science? Toward an understanding of science teaching practice. Research in Science Education, 33(1), 1-25.

Association of American Universities (AAU). (1998). Committee on Graduate Education Report and Recommendations. Retrieved 01/30/2005. AAU Reports. http://www.aau.edu/reports/GradEdRpt.html.

Austin, A. (2002, Winter). Creating a bridge to the future: Preparing new faculty to face changing expectations in a shifting context. Review of Higher Education, 26(2), 119-144

Ausubel, D. (1968). Educational psychology: A cognitive view. New York: Holt, Rinehart & Winston.

Bandura, A., Ross, D., & Ross, S. (1963). Vicarious reinforcement and imitative learning. Journal of Abnormal and Social Psychology, 67, 601-607.

Becher, T., & Trowler, P. (2001). Academic tribes and territories: Intellectual enquiry and the culture of disciplines (2nd ed.) Buckingham, United Kingdom: The Society for Research into Higher Education & Open University Press.

Bell, G. (2001). Reflective Journal writing paired with inquiry based science instruction: Effect of elementary pre-service teachers’ science and science beliefs. In:

Proceedings of the Annual Meeting of the Association for the Education of Teachers in Science (Costa Mesa, CA, January 18-21, 2001). (ERIC Document Reproduction Service No. ED 472911).

Berg, B. (2000). Qualitative research methods for the social sciences. Needham Heights, MA: Allyn and Bacon

Bjork, R., & Richardson-Klavhen A. (1989). On the puzzling relationship between environment context and human memory. In C. Izawa (Ed.), Current Issues in Cognitive Processes: The Tulane Flowerree Symposium on Cognition (pp. 313-344). Hillsdale, NJ: Erlbaum.

Bloom, B. (1956). Taxonomy of Educational Objectives, Handbook I: The Cognitive Domain. New York: David McKay Co. Inc.

Boyer, E. (2000). Scholarship reconsidered. Washington, DC: The Carnegie Foundation.

Bransford, J. & Schwartz, D. (1999). Rethinking transfer: A simple proposal with multiple implications. Review of Research in Education, 24, 61-100.

Buskist, W. (2000). Common mistakes made by graduate teaching assistants and suggestions for correcting them. Teaching Psychology, 27(4), 280-282.

Cazden, C. (2001). Classroom discourse: The language of teaching and learning (2nd Ed). Portsmouth, NH: Heinemann.

Clermont, C., Borko, H., & Krajcik, J. (1994). Comparative study of the pedagogical content knowledge of experienced and novice chemical demonstrators. Journal of Research in Science Teaching, (32), 419-441.

Cochran, K., King, R., & DeRuiter, J. (1991, April). Pedagogical content knowledge: A tentative model for teacher preparation. Paper presented at the annual meeting of the American Educational Research Association, Chicago, IL, April 3-7.

Cochran, K., DeRuiter, J., & King, R. (1993). Pedagogical content knowledge: An integrative model for teacher preparation. Journal of Teacher Education, 44(4), 263-272.

Counts, M. (1999). A case study of college physics professor's pedagogical content knowledge. Unpublished doctoral dissertation, Georgia State University. AAT 9926040.

Crawford, B. (2007). Learning to teach science as inquiry in the rough tumble of practice. Journal of Research in Science Teaching, 44(4), 613-642.

Darling-Hammond, L., Ancess, J., & Falk, B. (1995). Authentic Assessment in Action: Studies of schools students at work. New York: Teachers College Press.

Deel, S. (2004). Finding my teaching voice. The Stanford University Center for Teaching and Learning. Tomorrow's professor (SM) mailing list. PT Msg. #598. Received 10/14/2004 from owner-tomorrows-professor@lists.Stanford.EDU.

Denzin, N., & Lincoln, Y. (Eds.). (1994). Handbook of qualitative research. London: Sage.

Dewey, J. (1910). How we think. Boston, MA: Health.

Dobson, C. (2001). Career advice for life scientists: Teaching and learning- the scholarship of teaching. The American Society of Cell Biology- Women in Cell Biology. Chapter 2, 15-23. Retrieved 02/05/2005 from http://www.ascb.org/

Donovan, M., & Bransford, J. (2005). Introduction. In M. Donovan & J. Bransford (Eds.), How students learn science in the classroom (pp. 1-30). Washington, DC. National Academies Press.

Driscoll, M. (1994). Psychology of learning for instruction. Boston: Allyn and Bacon.

Duggan, D. (2005). Content and pedagogy: Intersection in the NSTA Standards for Science Teacher Education. Retrieved 02/05/2005 from www.msu.edu/~dugganha/PCK.htm

Ebert, C., & Risacher, B. (1996, April). Alternative pathways to Teaching: An investigation of the factors that influence the acquisition of pedagogical content knowledge for traditional and non-traditional teachers. Paper presented at the annual meeting of the American Educational Research Association, New York, NY. (ERIC Document Reproduction Service No. ED 424204.)

Elton, L. (2000). Turning Academics into Teachers: a discourse on love. Teaching in Higher Education, 5(2), 257-260.

Educational Testing Service. (2004). Study Guide: Principles of Learning and Teaching (2nd ed.). Princeton, NJ: ETS Publications.

Falk, J., & Drayton, B. (1997, March). Dynamics of the relationships between teachers and scientists in an innovative mentorship collaboration. Paper presented to American Educational Research Association, March 1997.

Fernandez-Balboa, J., & Stiehl, J. (1995). The generis nature of pedagogical content knowledge among college professors. Teaching & Teacher Education, 11(3), 293-306.

Fisher, R., & Taithe, B. (1998). Developing university teachers: and account of a scheme designed for postgraduate researchers on a lecturing career path. Teaching in Higher Education, 3 (1), 37-50.

Fortus, D. (2003). How to use design as a framework for developing environments that support the construction of new science knowledge and real-world problem solving skills. Unpublished dissertation, College of Education- Michigan Ann Arbor, MI.

Gabel, D. (2003). Enhancing the conceptual understanding of science. Educational Horizons, 81(2), 70-76

Gess-Newsome, J. & Lederman, N.G. (1999). Examining pedagogical content knowledge: The construct and its implications for science education (vol. 6). Boston, MA: Kluwer.

Gross, B. (1993). Collaborative Learning: Group Work and Study Teams- From the hard copy book Tools for Teaching by Barbara Gross Davis; Jossey-Bass Publishers: San Francisco. Retrieved 03/15/2007 from http://teaching.berkeley.edu/bgd/collaborative.html.

Graff, J., Pruitt-Logan, A., & Weibl, R. (2000, April). Building the faulty we need: Colleges and Universities working together. Washington DC: Association of American Colleges and Universities and the Council of Graduate Schools.

Graaff, E., Andernach, T., & Klaassen, R. (2006). Learning to teach, teaching to learn the impact of a didactic qualification programme on university teachers careers. Proceedings of the 10th IACEE World Conference on Continuing Engineering Education (WCCEE) April 19-21, 2006, Vienna University of Technology, Vienna, Austria.

Grossman, P. (1989). Learning to teach without teacher education. Teacher College Record, 91(2), 191-208.

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

Gudmundsdottir, S. (1990). Values in pedagogical content knowledge. Journal of Teacher Education, 41(3),44-52.

Kogan, M. (1994). Teaching and Research: separation, co-operation or integration. Report of the multilateral workshop, Kaunas, 20-22 October 1994, Multilateral Workshop No. 5. (Strasbourg, Council of Europe)

Kreber, C. (2002). Teaching excellence, teaching expertise, and scholarship of teaching. Innovative Higher Education, 27(1):5-23.

Haakonsen, H., Tomala, G., Stone, A. H., & Hageman, S. (1993). Enhancing teaching excellence through a scientist-science teacher collaborative process. Journal of Science Teacher Education 4(4), 129-136.

Hammerness, K. (2002, April). Looking for learning in practice: Examining the teaching practices of graduates. Paper presented at the Annual meeting of the American Educational Research Association. New Orleans, LA 2002. (ERIC Document Reproduction Service No. ED 475355).

Hickok, E. (2006, March 10). Higher education needs reform, too. The Chronicle of Higher Education- School & College, pp B48, B49.

Higher Education Research Institute. (1999). The American college teacher: National norms for the 1998-99 HERI faculty survey. Los Angeles: University of California, Los Angeles.

Hogan, K. & Pressley, M. (1997). Scaffolding student learning: instructional approaches and issues. Cambridge, MA: Brookline Books.

Hoz, R., Tomer, Y., & Tamir, P. (1990). The relations between disciplinary and pedagogical knowledge and the length of teaching experience of biology and geography teachers. Journal of Research in Science Teaching, 27(10), 973-985.

Lenze, L. & S. Dinham. (1994, April). Examining pedagogical content knowledge in faculty new to teaching. Paper presented at the Annual meeting of the American

Educational Research Association. New Orleans, LA. (ERIC Document Reproduction Service No. ED 375139).

Lincoln, L. & Guba E. (1985). Naturalistic inquiry. Beverly Hills, CA: Sage.

Lortie, D. (1975). Schoolteacher. Chicago, IL: University of Chicago Press.

Loughran, J. (2007). Science teacher as learner. In S. Abell & N. Lederman (Eds.), Handbook of Research in Science Education. Mahwah, NJ: Lawrence Erlbaum.

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

Lunetta, V., Hofstein, A., & Clough, P. (2007). Learning and teaching in the school science laboratory: An analysis of research ,theory, and practice. In S. Abell & N. Lederman (Eds.), Handbook of Research in Science Education. (pp. 393-441) Mahwah, NJ: Lawrence Erlbaum.

MacDonald, D. (1992). Novice science teachers learn about interactive lesson revision. Journal of Science Teacher Education, 3, 85-91.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources and development of pedagogical content knowledge. In J. Gess-Newsome & N.G. Lederman (Eds.), Examining pedagogical content knowledge (pp. 95-132). Dordrecht, The Netherlands: Kluwer.

Major, C., & Palmer, B. (2002). Faculty knowledge of influences on student learning. Peabody Journal of Education, 77(2), 138-162.

Mann, K. (2002). Thinking about learning: implications for principle-based professional education. The Journal of continuing education in health professions, 22, 69-76.

McGonigal, K. (2005, Spring). Teaching for transformation: From learning theory to teaching strategies. Speaking of Teaching, Vol. 14, No.2. Retrieved from http://ctl.stanford.edu/Newsletter/

McMeniman, M., Cumming, J., Wilson, J., Stevenson, J. & Sim C. (2000). Teacher knowledge in action. In The impact of educational research. (pp. 381-533). Retrieved 12/12/2007, from http://www.dest.gov.au/archive/

Merriam, S. (1998). Qualitative Research and Case Study Applications in education. San Francisco: Jossey-Bass.

Mellado, V. (1998). The classroom practice of preservice teachers and their conceptions of teaching and learning science. Science Teacher Education, 82, 197-214.

Mervis, J. (2000). Sharp jump in teaching fellows draws ire from educators. Science 288:21.

National Center for Education Statistics. (1999). 1999 national study of postsecondary faculty, data analysis system. Washington, DC: U.S. Department of Education.

National Academy of Sciences. (2000). Attracting Science and Mathematics Ph.D.'s to secondary school education. Retrieved from http://www.nap.edu/catalog.php?record_id=9955.

National Research Council (NRC). (1996). National Science education standards. Retrieved from http://www.nap.edu/catalog.php?record_id=4962.

National Research Council (NRC). (2000). How people learn: Brain, mind, experience and school: Expanded Edition. Retrieved from http://www.nap.edu/catalog.php?record_id=9853

National Research Council (NRC). (2002). Scientific Research in Education. Retrieved from http://www.nap.edu/catalog/10236.html

National Science Foundation (NSF). (2001). NSF graduate teaching fellows in K-12 education (GK-12). Retrieved 11/10/2004 from NSF updated on 08/20/2007. Education and human resources (HER) section on Graduate teaching (DGE) http://www.nsf.gov/

National Science Foundation (NSF). (2004). Science and Engineering Indicators. Retrieved 10/06/2007 from NSF. Division of Science Resources Statistics (SRS) http://www.nsf.gov/

National Science Foundation (NSF). (2005). Final Report on the Evaluation of the National Science Foundation's GK-12 Fellowship Program: Volume I. Final draft rev.2. Washington, DC: National Science Foundation.

National Science Teachers Association (NSTA). (1998). CASE draft standards for the preparation of teachers of science. Retrieved from http://wolfweb.unr.edu/homepage/jcannon/ejse/baird.html.

Norman, D. (1999). Prepare for a shock. Times Higher Education Supplement, 3 September, p.14.

Nowlis, V., Clark, K., & Rock, M. (1968). The graduate student as teacher (American Council on Education Monograph). Washington, DC: National Science Foundation.

Pajares, M. (1992). Teachers' beliefs and educational research: Cleaning up a messy construct. Review of Educational Research, 62(3), 307-332.

Park, C., & Ramos, M. (2002). The Donkey in the Department? Insights into the Graduate Teaching Assistant (GTA) experience in the UK, Journal of Graduate Education, (3), 47-53.

Patrick J., & Smart, R. (1998). An empirical evaluation of teacher effectiveness: The emergence of three critical factors. Assessment and Evaluation in Higher Education, 23(2), 165-178

Piaget, J. (1950). The psychology of intelligence. Translated from the French by Malcolm Piercy and D. E. Berllyne. London: Routledge, & Paul

Pruitt-Logan, A., Gaff, J., & Jentoft, J. (2002). Preparing future faculty in the science and mathematics: A guide for change. Washington, DC: Council of Graduate Schools and the Association of American Colleges and Universities.

Reis, R. (2004). Lack of experience in teaching: Lesson from quick starters. Tomorrow's professor (SM) mailing list. PT Msg. #600. Received 10/20/2004 from owner-tomorrows-professor@lists.Stanford.EDU.

Rowland, S., Byron, C., Furedi, F., Padfield, N., & Smyth, T. (1998). Turning Academics into teachers? Teaching in Higher Education, 3(2), 133-141.

Russell, T. & Martin, A. (2007). Learning to teach science. In S. Abell & N. Lederman (Eds.), Handbook of Research on Science Education (pp. 1151-1178). Mahwah. NJ: Lawrence Erlbaum.

Salomon, G., & Perkins, D. (1989). Rocky roads to transfer: Rethinking mechanisms of a neglected phenomenon. Educational Psychologist, 24, 113-142.

Schön, D. (1983). The reflective practitioner: How professionals think in action. New York: Basic books.

Shkedi A & Horenzyk, G. (1995). The role of teacher ideology in the teaching of culturally valued texts. Teacher and teacher education, 11(2), 107-117.

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

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

Shulman, L. (2000). Teacher development: roles of domain expertise and pedagogical knowledge. Journal of Applied developmental psychology, 21(1):129-135.

Shulman, L. & Grossman, P. (1988). Knowledge growth in teaching: A final report to the Spencer Foundation. Stanford, CA: Stanford University.

Singley, K., & Anderson, J. (1989). The transfer of cognitive skill. Cambridge, MA: Harvard University Press.

Smeby, J. (1998). Knowledge production and knowledge transmission. The interaction between research and teaching at universities. Teaching in Higher Education, 3(1), 5-20.

Spivey, N. (1997). The constructivist metaphor: reading writing, and making meaning. San Diego, CA: Academic Press.

Stark, J. (2000) Planning introductory courses: Content, context and form. International Science, 28, 413-438.

Strauss, A. & Corbin, J. (1998). Basics of qualitative research: Techniques and procedures for developing grounded theory (2nd ed). Thousand Oaks, CA: Sage.

Swami, R. (2002). Perceptions of physical science faculty at the College level about teaching introductory level science courses. Unpublished doctoral dissertation. University of Cincinnati, Cincinnati.

Tellis, W. (1997, July). Introduction to case study [68 paragraphs]. The Qualitative Report [On-line serial], 3(2). Retrieved 2/5/2005 from http://www.nova.edu/ssss/QR/QR3-2/tellis1.html

Trumball, D., & Slack, M. (1991). Learning to ask, listen, and analyze: using structured interviewing assignments to develop reflection in preservice science teachers. International Journal of Science Education, 13(2), 129-142.

Tsai, C. (2002). Nested epistemologies: Science teachers' beliefs of teaching, learning and science. International Journal of Science Education, 24(8), 771-783.

Van Der Valk, T., & Broekman, H. (1999). The lesson preparation method: A way of investigating pre-service teachers' pedagogical content knowledge. European Journal of Teacher Education, 22(1),11-22.

Van Driel, J., Verloop, N., & De Vos, W. (1998). Developing science teachers'pedagogical content knowledge. Journal of Research in Science Teaching, (35), 673-695.

Veal, W. (1997). The evolution of pedagogical content knowledge in chemistry and physics prospective secondary teachers Unpublished Doctoral Dissertation, University of Georgia, 1997. AAT 9807136.

Veal, W. & MaKinster. (1999). Pedagogical content knowledge taxonomies. Electronic Journal of Science Education, 3(4), 1-17. Retrieved 2/19/2005.

Vygotsky, L.S. (1978). Mind in society. Cambridge, Mass: Harvard University Press.

Woolfolk, A. (2001). Educational psychology (8th ed.). Needham Heights, MA: Allyn and Bacon.

Wiggins, G., & McTighe, J. (1998). Understanding by design. Alexandria, VA: Association for Supervision and Curriculum Development.

Wulff, D., Austin, A., & Associates. (2004). Paths to the Professoriate: Strategies for enriching the preparation of future faculty. San Francisco, CA: Jossey-Bass.

Wulff, D., Austin, A., Nyquist, J., & Sprague, J. (2004). The development of graduate students as teaching scholars: A four-year longitudinal study. In D. Wulff, A. Austin & Associates, Paths to the Professoriate: Strategies for enriching the preparation of future faculty (46-74). San Francisco, CA: Jossey-Bass.

Yin, R. (2003). Case study research: Design and methods (3rd Ed.). Beverly Hills, CA: Sage Publishing.

APPENDICES

Appendix A. Framework used to guide analysis of data

RESEARCH TITLE: Understanding of Teaching and Learning Processes in Science
Science: Science is limited to the body of knowledge and processes involved in doing science. I focused exclusively in the life sciences.
Understanding (from Wiggins and McTighe, 1998, p. 44):
When we truly understand we:

1) Can explain: provide thorough, supported, and justifiable accounts of phenomena, facts and data.
2) Can interpret: tell meaningful stories; offer apt translations; provide historical or personal dimension to the ideas; make it accessible through images, anecdotes, analogies and models. (*PCK- Good analogies and examples, experiences*)
3) Can apply: effectively use and adapt what is known into different contexts (*transfer*)
4) Have perspective: see and hear points of view from critical eyes and ears; see the big picture.
5) Can empathize: find value in what others might find odd, alien or implausible
6) Have self-knowledge: perceive the personal style, prejudices, projections, and habits of mind that both shapes and impede our own understanding; we are aware of what we don't understand and why understanding is hard. (*beliefs, biases*)

Note: Some areas of understanding might be more developed than others in an individual. It is more like a multidimensional continuum. People move from a novice to an expert level.

An example of understanding at different levels (Science Concept and Science Ed

Area of Understanding			
Science Discipline	Topic: Population growth patterns		
Subject is able to:	Recognize the J and S Shaped curves [Note: Essentially this is like a rubric for understanding. Subject can sort of explain, little interpretation, application probably just to the few examples presented, no perspective, no value found since it is just something to learn.]		Explain with basic math and clear classic examples both curves. S/he understands how regulatory factors affect growth patterns in different contexts including the human socio-economic context.
Level of Understanding	Novice	------------------------>	Expert
Science Education	Topic: (PCK- Knowledge of Assessment in Population Growth)		
Subject is able to:	Design multiple test sets only, basically MC. No consideration of student background is taken into account.		Incorporates multiple types of assessment (open-ended, performance based, case studies, recall, short answer) Takes into consideration background and goals and objectives of the topic covered. Relevant to the topic.
Level of Understanding	Novice	------------------------>	Expert

Teaching and Learning Processes: What does a teacher need to <u>know</u> and <u>do</u> so that adequate learning takes place in the classroom? [E.g., Best instructional practices <based on knowledge of *instructional strategies and orientations*> for a particular topic <based on *content knowledge*- e.g., population grow patterns>, to make sure that students understand and meet the objectives of the lesson <based on *curricular knowledge* and *student knowledge*> by providing meaningful examples, analogies, experiences and discussion <*context knowledge, student knowledge, instructional strategies knowledge*>. Finally, assess their understanding of the topic. Teacher provides continuing evaluation to be able to modify the teaching strategies and plans accordingly <*assessment knowledge*>.]

Note: You cannot really divide these two into teaching processes and learning processes since they are dependant on each other.

Q1: How does the experience of participating in MOSTEP change BGF understanding of pedagogy and practice of pedagogy?

- How do BGFs pedagogical content knowledge (PCK) change as a result of their participation in MO-STEP?

1) <u>Understanding of Pedagogy (Q1.1 in Dissertation)</u>
    a. Subject matter Knowledge (SMK) (Content Knowledge in Science Area)
        i. Importance of concept
        ii. Evolution of subject-matter knowledge (Historical account HOSC, NOS?)
    b. Pedagogical Knowledge (PK) (Content Knowledge in Education Area)
        i. Assessment Knowledge
        ii. Context knowledge
        iii. Curriculum knowledge
        iv. Instructional Strategies knowledge
        v. Student knowledge
        vi. Educational Policy and Procedures
    c. Pedagogical Content Knowledge (Intersection of PK & SMK)
        i. Assessment knowledge
        ii. Context knowledge
        iii. Curriculum knowledge
        iv. Instructional strategies knowledge
        v. Student knowledge
        vi. Orientation or Purpose

        SMK
    d. Pedagogical Practices (or teaching practices) (Q1.2 in Dissertation)
        i. Lesson plan development (based on PK, PCK)
        ii. Actual classroom teaching (based on PK, PCK)
        iii. Teacher as a reflective practitioner
    e. <u>Practical Knowledge</u> (Knowledge of how to do Lesson plans, actual teaching, reflection. (This probably relates to knowledge in PCK too)

Pedagogical Content Knowledge

Definition: Pedagogical content knowledge is the ability to **translate** subject matter to a **diverse** group of students using **multiple** strategies and methods of **instruction, curricular approaches** and **assessment** while understanding the **contextual**, **cultural**, and **social** limitations within the learning **environment**. (Grossman, 1989; Veal & MaKinster, 1999; Magnusson, et al, 1999)

Note: Science-Topic **Population growth (Specific growth curves J & K**), PCK- Based on personal experience and what I believe is a good way to teach the topic considering the standards.

Subject matter knowledge: *E.g., Population growth patterns (exponential vs. logistic), and how density independent and dependant shape growth patterns. ** (Out of the analysis)*

1. Orientation or Purpose:
   a. **Perceptions of science as an enterprise and as a subject to be taught an learned** (NSES, 1996)
   b. **Classification of orientation** according to Magnusson, Krajcik and Borko (1999)
      i. *Process*: help develop science process skills. (Students engage in thinking process used by scientist, NOS) *E.g., How scientist use and interpret growth curves in certain environments to determine best course of action regarding an invasive species.*
      ii. *Academic rigor*: represents a particular body of knowledge. (Demonstrations, Problem based and activity problems) *E.g., Using simulations to demonstrate what a variation in birth rates or death rates affects population patterns or how carrying capacity plays a role in leveling population.*
      iii. *Didactic*: transmit facts. (Lecture, discussion, or questions). *E.g., Defining logistic and exponential growth using a powerpoint presentation, examples and questions.*
      iv. *Conceptual change*: develop scientific knowledge by challenging naïve conceptions by confronting it. *E.g., Understand that exponential growth curves can only hold true for a limited amount of time.*
      v. *Activity driven*: Students be active with materials. (Hands on). E.g., *Students manipulate variables in a simulation program to predict outcome of duckweed experiment and Azolla.*
      vi. *Discovery*: Students on their own discover targeted science concepts. *E.g., Students are given the above experiment and are asked to explore and come up with ideas as to why they obtained the results they did after 4 weeks. Try to get them to concepts of competition, density dependant and independent factors and competitive exclusion principle.*
      vii. *Project-based science*: involve students in investigating solutions to authentic problems. *E.g., there is a problem of honey suckle in a state park. How would you come up with a solution to control or eradicate this invasive species using your knowledge of population growth patterns and other concepts of population ecology.*
      viii. *Inquiry*: Science as inquiry, guided inquiry. (Scientific method and modeling this method and nature of doing science) *E.g., for PBL and*

discovery come up with an experiment write-up following the scientific method and coaching students as they go along this.

2. Assessment knowledge. What's the impact of state and national assessments in the school?
    a. **Types of assessment** (What battery of tests will be most appropriate for a topic such as population growth curves? Why?)
        i. *Standardize test, norm-reference or criterion reference*. (Difference in how content is selected and how results are interpreted) NRT used to classify student base on achievement. CRT see how student achieves and accomplishes class objectives there is a criteria (Linda, B. 1996). (E.g., driver's license test). *E.g., using Life Science GLE's to meet state objectives as far as process and knowledge goes regarding Population growth.*
        ii. *Achievement tests*
            1. Seen test and unseen test. (E.g., take home, or in class)
            2. Open book test, Multiple Choice (Pre/ Post test)
        iii. *Structured observations*: When instructor is looking for particular actions, results, behaviors, in a systematic way, etc written down before hand. *E.g., Looking for misconception cues as far as population growth goes.*
        iv. *Anecdotal notes, observations*
        v. *Assessment as prior knowledge*: Pre-test, Pre-quest. *E.g., is this a required assessment based on the number of misconceptions students bring regarding population growth?*
        vi. *Student response during lesson*: Classroom performance systems ("clickers"), IRE, orally, interventions.
        vii. *Portfolios*: A compilation of artifacts, test, presentations, projects that a student makes or has as a result of being in the class. This is assessed in its entirety.
        viii. *Essay*
        ix. *Journals* (Notebooks)
        x. *Self-evaluations and peer evaluations*
        xi. *Performance assessment & projects*: Practical tests (doing it), Individual or group project
    b. **Uses of assessment**
        i. *Formative evaluation*: ongoing assessment during class, notebook, quiz usually to help the student learn.
        ii. *Summative*: end of topic test, quarter level exams, semestral or final exam how much has the student learnt. Based on unit goals and objectives.
        iii. *Diagnostic*: Pre test
        iv. *Guide curriculum writing & Lesson planning*

    Note: Between formative and summative assessment is more like a continuum
3. Context knowledge

a. **Student family circumstances** (E.g., single mom, parents are both working full time jobs, etc) *E.g., Do you have adoptive children? How will they feel if you start talking about paternity? Should you be concerned?*
b. **Community expectations and characteristics** (E.g., an involved community, parents are very active and supportive of the administration, etc)
c. **Health and economic conditions** (E.g., Poverty area, poor health services, etc) *E.g., does the science department budget cover basic kit, experimental expenses?*
d. **Availability of outreach resources** *(E.g., science centers, zoos, theme parks, outdoor centers, state parks, national parks, etc)*
e. **Administrations goals. (**E.g., Is the school interested in actual student learning or is it in place just to keep students out of the streets? What is their main goal?**)** *E.g., Is science an area that the school emphasizes?*

4. Curriculum knowledge
   a. **Planning Instruction**
      i. *National and State Standards* (*E.g., NSES, Missouri GLE for Science, AAAS)*
      ii. *State and local frameworks and guides* (*MAP, GLE's*)
      iii. *Scope and sequence*: see below *(E.g., what comes before and after Population growth?) How much do you cover? Depth vs Breadth?*
      iv. *Organization of the course*: Units and lessons and how topics link to each other (Like the AAAS benchmark maps)
      v. *Class Objectives and goals* as part of the unit, lesson, year
         1. Behavioral (affective, cognitive, psychomotor)
         2. Learner objectives and outcomes
      vi. *Curriculum (***Def**.: (i) as a range of courses offered by an educational institution,(ii) a specific learning program where the curriculum describes the teaching, learning and assessment materials available for the course- in this case science. Curricula base their objectives, goalsand learning outcomes on State or Nation standards. E.g., Biology Curriculum = 7 modules/units, School Curricula = (2) Science, (1) Math, etc.)
         1. Emergent: *(Def.: departing from the idea that everything is defined to the idea of everything is developing. It is experiential, creative and life based, Yule PDF.)*
         2. Anti-bias: Doesn't favor gender, racial groups or other of the sort
         3. Webbing: A central theme, and ideas web out from the theme
         4. Hidden: Underlying implications of the written curriculum
      vii. *Lesson planning* which could include
         1. Activating prior knowledge, anticipating preconceptions
         2. Encouraging exploration and problem solving
         3. Building new skills on previous
         4. Predicting
         5. Modeling (E.g., Thinking, Manipulation,)
         6. Guided Practice
         7. Independent work and different context applications

viii. *Knowledge of teaching materials available* for:
1. Basic classroom management (journals, cards, etc). *E.g., science notebooks, question boards, bell ringer/ work.*
2. For Subject area. *E.g., Simulation programs like Netlogo or Vortex for population growth, simple to use classroom experiments or science notebook to write up the experiment, internet sites that talk about population ecology.*

5. Instructional strategies knowledge (i.e., **strategies & methods,** comm.. techniques, classroom management, variation in instruction)
   a. **Major Methods of instruction** (Major Categories Praxis II, p. 22)
      i. *Direct instruction*: Madeline Hunter's "Effective teaching model", Advance Organizers (D. Ausbel), Mastery Learning (Bloom), Demonstrations, Mnemonics, Note-taking/ Lecture, Outlining, Use of visual aids. (See Joyce & Wells, 2004 for all)
      ii. *Inquiry method (SCM)*: Scientific Inquiry, Learning Cycle (Karplus), GLM (Osborne & Freyberg)
      *iii. Discovery learning (SCM) (*J. Bruner*):* Students wrestle with questions and controversies, explore, manipulate and perform experiments.
      iv. *Whole group discussion (SCM)*: Getting all the class involve in scientific discussion or question discussion in science.
      v. *Questioning*: Related to appropriate communication techniques *
      vi. *Independent study*: Internet search, classroom independent work questions
      vii. *Interdisciplinary instruction*: Across subjects (*E.g., 1: Evolution in geography-fossils and rocks, chemistry-radioactive dating and biology-evidence for evolution; E.g., 2: Population growth in mathematics-graphs and algebra, geography- human population growth*)
      viii. *Cooperative learning (SCM)*: Pair share, jigsaw, teams, games, competition (science fair, envirothon, science Olympiads)
      ix. *Concept mapping (SCM)*: concept development, attainment and mapping (Jonassen D.)
      x. *Project Work (SCM)*: Project base learning (Polman)

   Note: (SCM) = Student Centered Models
   b. **Methods of enhancing student learning**
      i. *Computers, internet resources, web pages*: Powerpoint, Simulations
      ii. *Audio visual*: DVD, CD, tapes, audio
      iii. *Local and National Experts*: In subject area
      iv. *Field Trips:* Relevant to subject area
      v. *Libraries:* Relevant to subject area
      vi. *Service Learning:* Relevant to subject area
      vii. *Primary documents and artifacts*: Papers, pictures, historical books
      viii. *Labs and hands on*
   c. **Other**

i. *Topic-specific (or Topic Specific PCK) strategies for science. Best activities and representations, their strength and weaknesses, also the ability to invent representations.*
    1. Examples of **representations**: illustrations, examples (e.g., good because they are classical or because they hit on prior knowledge), models, or analogies (e.g., human example could be used as an analogy, population growth linked to human population growth). (E.g., simulation of heart circulation (model) after diagrammatic representation, graphing population growth of deer (example, illustration) to understand exponential and logistic growth,)
    2. Examples of **activities**: problems, demonstrations, simulations, investigations, or experiments.
    3. Creating connectiveness to prior knowledge , to with-in subject and among subject

d. Communication Techniques

i. *Wait time:* *E.g., Some areas in biology (logistic growth questions) may require longer wait times.*

ii. *Questioning Strategies to stimulate discussion and responses*
    1. Helping students articulate their ideas and thinking processes
    2. Probing learner understanding (Formative assess. related)
    3. Paraphrasing
    4. Promote risk taking and problem-solving
    5. Encourage divergent and convergent thinking
    6. Asking peers to translate

iii. *Verbal and non-verbal communication*
    1. Nodding, looking at the person, moving around the classroom
    2. Engaging everyone with there movement of his/her body and eye contact
    3. Shows enthusiasm (Fun & Excitement
    4. Calls student by their first names
    5. Clear communication, word appropriate phrases and ideas
    6. Changing tone of voice
    7. Understands student verbal + non-verbal communication, when they don't understand ** (Student cues)

e. Classroom Management

i. *Behavioral management*
    1. Getting closer to off task student
    2. Talking in a gentle but authoritative voice
    3. Punishments
    4. Modeling Conflict resolution and anger management

ii. *Space management* (Classroom space, location, etc)
    1. Conducive for labs
    2. Conducive for discussion and group work

iii. *Daily Class Routines/ Time management*
1. Using natural and logical consequences
2. Daily procedures and routines
3. Clear class rules
4. Positive guidance
5. Timely feedback
6. Parent communication
7. Maintaining accurate records

6. Student knowledge
a. **Student development**: Physical and psychological (emotional, social)
i. *Major progression in each developmental domain*
1. Development in one domain may affect performance in another domain

ii. *Impact of physical, social, emotional, moral and cognitive development on learning*

Important Theorists
1. **Piaget**: *theory of cognitive development*. Certain ways of thinking that are simple for an adult are not so simple for a child. Biological development, activity and social transmission.
2. **Maslow**: *Hierarchy of needs*. First is survival then is self-actualization.
3. **Bandura**: Individuals learn by observation and modeling. (Social learning theory)
4. **Vygotsky**: importance of language and social interaction for cognitive growth. *Zone of proximal development* and scaffolding.
5. **Erikson**: *Psychosocial theory of development*. The eight ages of man.
6. **Kohlberg**: theory of moral development. People were presented with situations where they had to make difficult decisions. (Based on males study)
7. **Gilligan**: work on ethics of care used to challenge Kohlberg's theory.

b. **Learning processes** (how students construct knowledge, acquire skills and develop habits of mind):
i. *Learning theory*

Important Theorists
1. Piaget: Children need to construct and re-construct knowledge while having rich opportunities to interact with the world
2. Maslow: See above
3. Bandura: Modeling after what is seen. Organize, rehearse, adopt it if it results in outcomes individuals like.
4. Vygotsky: Scaffolding
5. Dewey: Hands on

6. J. Bruner: People interpret the world in terms of its similarities and differences (Categorization)
7. Gardner: Multiple intelligence
8. B.F. Skinner: behaviorism- negative and positive re-enforcement.

<u>Terms used or proposed by different theorists</u>

1. Transfer: (Bransford & Schawrtz, 1999, Woolfolk, 2001; NRC, 2000)
2. Scaffolding: Series of supports to help students move beyond their Zone of Proximal Development (ZPD).
3. Constructivism: Building on knowledge on top of knowledge. Not a blank slate. Piaget
4. Metacognition: thinking and reflective about our own thinking.
5. Readiness: Being active.
6. Schemata (Schemas): Mental maps of how concepts interconnect to each other. Novice schemas vs. Expert schemas.
7. Bloom's taxonomy: Bloom
8. ZPD: Vygotsky
9. Intrinsic and extrinsic motivation

ii. *<u>Differences in the ways student learn and perform</u>*
1. Learning style: 70 total learning styles. Most known Kolb's learning style inventory (Concrete, observation/experience, abstract), Fleming's VARK, NLP. Dunn & Dunn
2. Multiple intelligences: Gardner, Dunn (Diverse learners)
3. Gender differences: *E.g., Female role in science, minorities' role in science.*
4. Cultural expectations and styles

iii. *<u>Knowledge of exceptional learners</u>*. (ADD, behavioral disorders, developmental delays, etc)

iv. *<u>Student Prior knowledge</u>* (pre-conceptions (simple), misconceptions): Student learn best when their prior knowledge is surfaced, challenged, and built upon (Hamermass, 2000). *E.g., misconception of populations following exponential or logistic growth.*
1. Requirements a student needs to understand a particular concept or run a particular experiment. *(E.g., population growth, stud. Need algebra, graphing skills, for Evolution- need to know about populations, genetics, community interactions, etc)*

v. *<u>Knowledge of concepts students may find hard or need to understand concept</u>*
1. *Abstract vs. Concrete (related to learning theory)*
2. *Pre-requisite knowledge*

vi. *<u>Approaches for accommodating different learning styles</u>*
1. Differentiated instruction
2. Alternative assessment
3. testing modifications

7. Educational Policy and Procedures
    a. **Legislation and institutional responsibilities**
        i. *American Disability Act* (ADA)
        ii. *IDEA*
        iii. *Individual Education Plan* (IEP)
        iv. ***Others*** (Family involvement)
    b. **Procedures of how to handle experiments in science labs.**

NOTES 1:
Professional Growth (Change): Is defined as changes over time in the behavior, knowledge, images, and self perception of BGF.

Assumption in the project

Assumption 1: Because fellows operate from the beginning in a science classroom we can assume that what's going to be developed, as far as knowledge of pedagogy, is going to be some form of PCK (generic, specific, topic)

Pedagogical Practices (Or teaching practices, or pedagogy) (Q1.2)

Definition: The act of teaching in a classroom. How a participant teaches a particular topic, what s/he does, how they move, how they interact with the students and how they use different instructional strategies. (Hammerness, 2002)

1. Lesson plan development (based on PCK)
2. Actual classroom teaching
    a. Communication
3. Teacher as a reflective practitioner
    a. Resources available (Professional literature, colleagues, professional associations, PD activities)
    b. Personal reflection on teaching practices. (Video, peer obs., admin. obs., self reflection)

NOTES 2:
Categories have been built based on the researched literature (Balboa & Stiehl, 1995, Grossman, 1990, Hamermass, 2000, Magnusson et al, 1999, Shulman, 1986, Veal & McKinster, 1999) and the ETS Praxis Principles of learning and teaching handbook that is itself aligned with the National Standards and adopted by the Interstate New Teacher Assessment and Support Consortium (INTASC).

Appendix B. Lesson Plan Model (Madeleine Hunter's Model)

ECOLOGY-EVOLUTION-SYSTEMATICS & CONSERVATION

Topic
Concept
By
Your Name
School
School Address

I. MECHANICS
A. **Title**:
B. **Time**:
C. **Target Audience**:
(Student population, description, grade level, demographics, and other important characteristics significant to teaching this concept)
D. **Resources**:
E. **Safety Concerns**:
(*Note- Safety is an important category. Please be thorough in listing safety and hazardous waste disposal issues.)

II. ANTICIPATORY SET
A. **Motivational Device to be Used**
(e.g., discrepant event, challenge, rhetorical question, relevant story or scenario, etc)

B. **Introduction to topic**

III OBJECTIVES AND PURPOSE
A. **Concept**:
B. **Objectives**
1. ***Cognitive Domain*** (all levels of Bloom Taxonomy)
2. ***Affective Domai****n*
3. ***Psychomotor***

(Note: Show me standards link)
C. **Purpose**

IV. INSTRUCTIONAL INPUT
A. **Prior Knowledge**
B. **Problem Areas**
C. **Strategy**
1. ***Overview***
2. ***Procedure***
    a. Starting/ Exploration

b. Concept Formation
c. Concept Application- Applying
d. Summarizing

V. MODELING

VI. CHECKING FOR UNDERSTANDING
A. **Informal**
B. Formal

VII. GUIDED PRACTICE

VIII. INDEPENDENT PRACTICE

IX. CLOSURE

X. REFERENCES

XI. NOTES

XII. APPENDED COMPONENTS

Now you need a section for all your appendices that compliment your lesson plan. These may include, but are not limited to:

Drawings
Protocols
*Student Lab
Sample Data
*Grading guide
Expanded references for student use
*Answer keys
*Pre/Post Measure for assessment
* Essential components of learning cycle packet

XIII. What will be the next concept you want to teach?

Appendix C: Weekly Time Allocation Sheet. Online Survey

MOSTEP- Time Allocation by Fellows (Weekly Survey)
Please fill out this survey as accurately as possible. All questions must be answered. If you did not spend any time on a particular task leave it blank. By default if you leave any option BLANK it will be assumed as zero time. Thanks in advance for your time. Don't forget to complete this survey on a WEEKLY basis.

1. Fellow Initials (E.g., John Brown will be JB)

2. Week ending (E.g., Sep 3)

INSIDE THE CLASSROOM (Note: Please round 30 minutes to the nearest hour, i.e. if you teach 2h 30min this should be noted as 3h, 2h 25min as 2h)								
How many hours of the week did you spend doing the following tasks?		Time in hours						
		0-30min	30min - 1h	1-2	3-4	5-6	7-8	9+
3.	Observing the teacher							
4.	Teaching (Taking the leading role in the classroom, i.e lecturing, conducting labs, facilitating a class discussion, etc)							
5.	Preparing Lab materials (e.g., making solutions, setting up experiments, cleaning up, etc)							
6.	Working on a one on one basis with either a group of students or a single student (Discussion)							
7.	Preparing Lessons with High School Faculty							
8.	Writing Curriculum with the teacher							
9.	Grading (In the classroom formal or informal)							

10. Other (Write down any other activity you have done that is not mentioned above and include the number of hours invested in this activity)

OUTSIDE THE CLASSROOM (Note: Please round 30 minutes to the nearest hour, i.e. if you teach 2h 30min this should be noted as 3h, 2h 25min as 2h)								
How many hours of the week did you spend doing the following tasks?		Time in hours						
		0-30min	30min - 1h	1-2	3-4	5-6	7-8	9+
11.	Tutoring							
12.	Professional Development Meetings or Workshops							
13.	Departmental Meetings							
14.	Personal Meetings with High School Faculty							
15.	Field Trips							
16.	Preparing Lessons							
17.	Searching for Teaching materials (E.g., Information in the internet, lectures, equipment)							
18.	Writing Curriculum							
19.	Grading (OUTSIDE the School)							

20. Other (Write down any other activity you have done that is not mentioned above and include the number of hours invested in this activity)

Appendix D: Semi-structured interview protocol for Pre and Post interviews

COMPLETE INTERVIEW PROTOCOL
Data Collection Item for BGF
(D.1) Pre Interview Questions (Interviewer version)
(D.2) Post Interview Questions (Interviewer version)

SYNOPSIS

The following interview protocol will be used for all semi-structured interview, that is pre-interview, post-interview, VSR interview and Vignette inteviews. The same questions will be delivered to 1st yr fellows and 2nd yr fellow. The difference is that for a first year fellow the reflection part of the interview was not done (Reflection part of the interview has been highlighted).

Materials: (Fully charged) iPod, iPod Charger, iPod MIC, Tape Recorder (back-up), Extra Batteries, At least 2 Tapes, Notepad for extra notes (Date/Time, Fellow Initials, Place)

Procedures:

BEFORE

1. Find a Location (ICTE default, if possible outside Bio dept. <Woods Hall, Library, MSC, etc>) It has to be a quiet place. Background noise is a problem when transcribing.
2. Send Interview Questions (attached to an email) to all fellows in advance and remind them about making an appointment for the interview. (Not all questions were placed in the attached set of questions)
3. Make sure all materials are ready.
4. Record Fellow names, date and time before interviewee is in the room.

DURING

1. Offer Coffee and/or snacks if available to break tension.
2. Ask interviewee about how the day is going so far for them.
3. If it is the first interview of this kind, explain fully what the interview will be about.
   EXPLANATION
   - *"Some questions will be about your last year at MOSTEP other will be about your background and,"*
   - *"Some questions will be about teaching and learning ,and some about your past MOSTEP experiences"*
   - **<PAUSE>**
   - *"Shall we start?"*
   - *"By the way please feel free to interrupt me at anytime throughout the interview."*
   - *"If at anytime you wish me to stop the recording let me know."*
   - *"Alright, let's begin"*
   - **<TURN THE RECORDER ON, Make sure it's recording>**

5. Proceed with Interview questions in a relaxed way
6. Make sure that if a question is composed of multiple questions (why? ,etc) give time for the fellow to answer.

AFTER
1. Make a backup copy of MP3 File./ Transcribe verbatim. /Copy interview to NuDIST, NVivo and do a content analysis.
2. Code interview according to PCK component and add any emerging category.
3. Patience ☺

(D.1) PRE-INTERVIEW QUESTIONS: Interviewer Version

GENERAL
1. How did you decide to become a biologist? What moved you in this direction?
2. What do you feel your strengths in biology are? (**CKN**)
3. Which areas in biology you would not feel comfortable teaching? Why? (**CKN**)
4. What do you see yourself doing once you graduate?
5. Tell me about the best teacher you ever had. In your eyes what made him a good teacher?
6. How about the worst? **(PCK**)

PAST YEAR MOSTEP (REFLECTION)
- "Reflecting on this past year"
1. How will you describe your past MOSTEP experience? (EXPAND)
2. Could you describe briefly the way you worked with your mentor teacher? How did this relationship evolve? How often did you guys meet? (EXPAND)
3. What was your main role in the classroom? What else did you do? How often did you teach? (EXPAND AS MUCH AS YOU CAN PCK, TRANSFER)
4. When you taught. What was your most rewarding experience you had? (**PCK**) **EXPAND**
5. What was the most frustrating experience? (**PCK**) **EXPAND**
6. How about the teaching dynamics. How will you describe the main teaching and learning environment? Do you think this will work in a University classroom?
7. Do you remember or recall any instance when it felt really good of being in your mentor's classroom? When was this? What happened?
8. How about an instance where you felt frustrated?
9. Did you encounter any roadblocks or hurdles when interacting with kids while teaching or being a co-teacher in the class? What were they? Can you elaborate on this?
10. "Going back to the overall experience." How do you think the experience may have been improved?

PCK

1. If you were asked to teach ecology in an undergraduate class, with what topic would you start your class? Why? What other MAIN topics might you include? Why will you choose this topic? How will you assess your students? (**PCK**)
2. What do you think it means for someone to be knowledgeable in <your field of expertise>? How about a knowledgeable teacher? (**OTS, CKN**)
3. Have you ever taken a class (subject) where you were engaged in it and learned a lot? Can you elaborate on this? Do you recall how the class was taught?
4. How would you describe the main way professors teach undergraduate classes? Do you think this is a good approach? How about graduate classes? (**IST**)
   (**IF IT IS THE SAME TEACHER ASK IF THIS WAS HIGHSCHOOL OR UNIVERSITY AND ASK THE QUESTION WITH THIS BACKGROUND IN MIND**)
   - *"Now I will ask you some specific questions about two topics in ecology, are you ready?"*
   PAUSE. SHOW DIAGRAM.
5. If you where going to be teaching energy transfer across food webs. What do you think would be important for your students to learn? What would be your teaching approach? What considerations would you need to take when teaching this topic? Why? How will you assess learning in this topic? (**PCK**)
6. What is the most common misunderstanding/ misconception in Evolution? How could you overcome this problem? What would you do?
7. How about a common misconception in your field of expertise?

PEDAGOGICAL PRACTICES

- "Going back to teaching."

1. In your mind what qualities must a good teacher have? How does good teaching look like?
2. What will be, in your mind, bad qualities in a teacher?
3. How will you say is the best way for a student to learn something?

TRANSFER

1. What differences will you say exist between teaching in a University and teaching in a high school?
2. From your experience in a High School teaching and learning environment is there anything you've learnt that could be applied at a University Setting?
3. Do you think good teaching looks different in university compared to high school? How so?

FINAL

1. Have your teaching practices changed as a result of being in MOSTEP? How?
2. What helped you to change? Can you give me some examples?

3. Why did you join MOSTEP in the first place? What do you see yourself taking home once the program finishes for you? How do you think this might help you in your professional career?
4. Do you see yourself teaching at academia? How about teaching in other environments?
5. Will you mind if I look at your transcripts to collect some information on the courses you took while doing your undergraduate and graduate studies? How about your CV…in this way I will get an idea of your work experience.

(D.2) POST-INTERVIEW QUESTIONS: Interviewer Version

GENERAL

- How will you describe your overall MOSTEP experience? (EXPAND)
- Could you describe briefly the way you worked with your mentor teacher? How did this relationship evolve? How often did you guys meet? (EXPAND)
- What was your main role in the classroom? What else did you do? How often did you teach? (EXPAND AS MUCH AS YOU CAN PCK, TRANSFER)
- When you taught at your school: What was your most rewarding experience you had? (**PCK**) **EXPAND**
- What was the most frustrating experience? (**PCK**) **EXPAND**
- How about the teaching dynamics: How will you describe the main teaching and learning environment in your classroom? Do you think this will work in a University classroom?
- Do you remember or recall any instance when it felt really good of being in your mentor's classroom? When was this? What happened?
- How about an instance where you felt frustrated?
- Did you encounter any roadblocks or hurdles when interacting with kids while teaching or being a co-teacher in the class? What were they? Can you elaborate on this?
- "Going back to the overall experience." How do you think the experience may have been improved?

PEDAGOGICAL PRACTICES

- "Going back to teaching."

- In your mind what qualities must a good teacher have? How does good teaching look like?
- What practices would you recommend someone to avoid when teaching?
- How will you say is the best way for a student to learn something?

TRANSFER

- What differences will you say exist between teaching in a University and teaching in a high school?
- From your experience in a High School teaching and learning environment is there anything you've learnt that could be applied at a University setting?
- Do you think good teaching looks different in university compared to high school? How so?

FINAL

- Have your teaching practices changed as a result of being in MOSTEP? How? Why didn't they?
- What helped you to change? Can you give me some examples?
- What are you taking home from this program?

Appendix E: Video Stimulated Recall Protocol and an example of interview questions

Protocol

1- Send email to fellows giving enough time to plan a lesson and teach it in their schools
2- Request lesson plan/ outline and materials (pps, handouts, etc) (fellows discretion no format required) before enacted lesson
3- Video tape session focusing only in the fellow and it's interactions with the students.
    a. Try to put a Lavaliere Microphone so that if the fellow engages in a one on one discussion with a student, sound can be recorded at that level. For the most part I will use the built in Mic of the Canon Video Cam ZR50.
    b. When going to video tape I need to make sure to arrive with enough time, batteries, DV cassettes, and all equipment ready.
    c. I tell the fellow or mentor teacher to tell students that fellow will be the one that the video camera is going to record.
    d. I will follow the fellow during class. If using presentations (OHP) or PPS try to take a shot at the PowerPoint to be able to come back during interview if needed..
4- Ask the fellow for a convenient date within a week from the taping session to debrief about the lesson.
5- Download movie from DV to iMovie.
    a. Burn movie to a CD and make a hard copy for storage.
    b. Save the video on Laptop computer to analyze later.
    c. Hand a copy of the video to fellow. Allow for a chance before interview for fellow to look at their practice.
        i. I-Movie best set-up. Step by step.
            1. File>Share> Quicktime> Expert Settings> Share> Export (options)
            2. Video:
                a. Compression (Sorenson 3)
                b. Quality (Medium)
                c. Frame rate: 15
                Current
                d. Key frame rate: 24 (*)
                e. Limit data rate: 90
                f. Data Rate: Automatic
            3. Audio:
                a. Compressor (Qualcomm PureVoice)
                b. Rate (44.100KHz) (32.000KHz)
                c. Size (16 bit
                d. Use (Mono)
            Uncheck Prepare Internet Streaming

4. **One hour video gets effectively converted into 300MB of space**

6- Schedule date for interview
7- Prepare questions for interview based on portions of the recordings.

Materials for interview

iPod <mic-charger> (charged), Pen-Notepad, Second tape recorder. Laptop charged and a quiet environment, speakers to enhance audio from video.

Before the interview:

1- Select portions of the video that I liked to analyze with fellow to get some feedback as to why they make one choice over another (Decision making). I will try to hit on relevant portions of video that relate implicit or explicitly to the components of PCK.
2- I will try to pick (2 curriculum related sections, 2 assessment sections, 2 student knowledge section, 2 strategy sections,
3- Prepare probe questions to bring up the best out of the fellows decision making process as related to PCK (explicit thinking):
    a. Stop video (significant event or decision making part)/ ask probe question/ try to identify why this was done and also id where this knowledge came from. Explore as deep as possible into fellows Professional Development as a teacher.

During Interview

1- Tell them how the interview will be.
2- Video could be stopped by the fellow at their leisure if they have any insight in their teaching that they want to share. Tell this to the fellow.

-"I guess you know the drill, let's just get started."

4- Try to keep interview at 30 min or 40 min maximum.

(E.1) VIDEO STIMULATED RECALL: Example of analysis sheet used for interview questions

Explain to fellow what's going to happen:

This interview is using what we call in education VSR, which allows us to go back to the enactment of your lesson and learn more about your teaching. For this I will need your help to let me know if while we are watching parts of the video you get some flashbacks and what you thought or where thinking by asking one question, or behaving in one way or another, etc. I will be asking questions myself about points in the video that interested me and points in the video where I thought you were making some decisions. Are we good to go? OK let's start.

Alex

Activity Presented: Invasive species in Guam Islands. A re-introduction of what students did this week and last week. And a follow up of the Brown Tree snake Presentation.

Teaching: Powerpoint presentation with an activity sheet that has graphs, tables, predictions and

Notes: Think about IRE (Initiation, Response & Evaluation), Take instances where they might be critical of their practice and ask them how would they do it differently? Try to question instances where they seem to be thinking about classroom practices, etc.

Opening questions: (*This were almost the same for each fellow*)

1- Did you take a peek at the CD I burnt with your video in it? Just curious
2- Before we move to our interview. I would like to know a few things about the lesson you prepared. So, (Name) what were the main goals of this lesson? What did you want to achieve with this lesson?

Table with an example of a Video Analysis

Portion of Video	Transcription of parts of the video. Description and Questions	Observations & Theories	Special Notes
00:30-1:14	Q: What were you talking with your teacher? It seemed like you were talking about the class.		
4:30-4:49 4:50-5:10 5:15-5:28 5:40-6:00 6:00-6:20 6:22-6:50	T; At the end of yesterday you guys had the task to put together a food web. What were we talking about yesterday? **Q: Why do you start the class like this? Where did you learn about doing this?** T: In this class we are going to answer why were we counting hawks? S: Population. Yeah we were going to look at the population but today we will go into this deeper. **Q: Why did you acknowledge de students answer in this way?** We are going to talk about invasive species how many of you remember the video about invasive species? Organisms slide- **Why did you use this slide at the beginning of your presentation?** Food Web discussion. 6:37 T: (After student said oh	Initiation, Anticipatory Set present	

7:00-7:13	no) Well it might be different? You might be missing a few arrows. **Q:Why did you say this?** S: Mine look like (up and down movement) T: Are your arrows pointing in each other way? S: No.		
8:10-8:35	T: I have a question. What would happen if new animals and plants where brought to Guam? **Q: What was your idea for setting up this question slide?**		Inquiry? Follow up questions, not giving answers.
9:40-10:05	Definition of Invasive Species. **Q: What effect do you think your slide had on the students?**		
20:05-20:15	….Work with the neighbor too. **Q: Why do you encourage this?**		Collaborative Learning. Think pair share?
41:28-42:05	Conversation with the student. **Q: What happened here? You invited the student to draw the graph. Q: Why did you do this?**		
GENERAL Q:	**Q: Why do you mention the word ecologist a lot during your presentation?** **Q: Why did you decided to ignore those two students at the back?** **Q: How would you do things different with Anna, when she asked you a question about differential reproduction as a strategy to out compete native species?**		

Closing Questions

1. What teaching strategy did you use in your class?
    a. Why did you choose this strategy?
    b. What do you think are the strength and weaknesses of such a strategy?
2. Where did you get your ideas to develop this lesson?
3. Where did you get your examples? Why did you choose these examples?
4. In what ways do you think you met the goals of the lesson?
    a. How might you change the class if you were to teach it again? I saw you did some changes to the worksheet. Why did you do (point at each change) these changes?
    b. What will you keep if you had to teach again?
5. How will teach this topic to an undergraduate class? How will you teach it to a graduate class?
6. One last question. How much did you prepare for this class?
7. Did you prepare this class by yourself? Have you taught this class before?
8. Was this the first time you taught this lesson? What did you teach before this? What are you planning to teach after this lesson?

Additional Probing Questions

What's going through your mind at this moment? I'm wondering what might you be thinking about?
What does understanding mean for you?

Appendix F: Vignette Protocol and an example of one case (Population Biology)

VIGNETTE #1: POPULATION ECOLOGY
Population Growth and Limiting Factors

INSTRUCTIONS

Please read the following vignette and **complete the questions** at the end. Some snapshots of the professor's power point slides have been added to the text to assist you during the reading.

THE CASE: WHAT'S GROWING?

Note: All characters are fictitious any resemblance with real life is just a matter of coincidence.

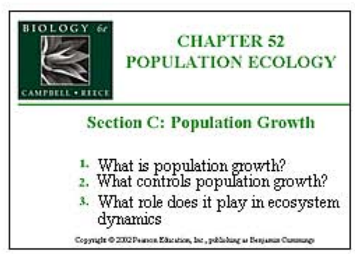
Ecology (102) was part of the core courses at the University. Most people took Ecology during spring semester, but it was offered all year round. Dr. Thomas (Dr. T.), a fairly new faculty member in the science department, was the leading instructor for this year. His background was in ornithology and he had published several papers in well known peered- review journals.

Sarah, Djuan, Lisa and Pedro were students in this class. Sarah came from a Co-Ed prep-school. She always liked animals so she decided to study biology with the idea of eventually pursuing a Ph.D. in animal behavior. Djuan had studied in an urban public school. He liked technology and was inclined to pursue a degree in computer science. He was offered a basketball scholarship by the university. Lisa was a single mom pursuing her degree in science teaching. And Pedro came from one of the best high schools in the country. He had decided to pursue medicine but first he needed to have a B.S. in a science area and he chose molecular biology.

PART 1: Population Growth

The hall had space for 80 students but during fall the class was rarely full, at best 1/2 of the class seats were taken. It was past mid-semester and finals seemed to be just around the corner. Djuan and Sarah arrived to Dr. Thomas' class just in time. Upon arrival Djuan asked Sarah, "What did you guys do last week?" He had been absent due to a basketball game and wanted to get some bearings before class started.

PRESENTATION SLIDES



Slide #1

Sarah replied, "Not much, something about population characteristics and life histories. He covered a lot so I don't remember. I'll need to check my notes". Sarah laid her backpack on her seat, and while pulling out the pre-quest * she thought, "*I hope he reviews some of the concepts before moving to our next topic especially **fertility** and **fecundity***". [* Pre-quests' were questions about the last and the coming chapter that Dr. Thomas posted online. They needed to be answered and handed in before the beginning of every topic/ chapter. They were an important part of the grade.]

Sarah was the kind of student that would not ask questions in class. She would wait for someone else to ask them in order to clarify any concept not grasped. She didn't want to look dumb. It was a very competitive environment.

It was one minute past the beginning of class and people were still arriving and chatting about yesterday's baseball game. Suddenly Dr. T turned on the projector. He was ready to start. The title of his power point was- **Chapter 52- Population Growth** [See slide #1]. People started taking seats and the noise gradually faded. Dr. T. began, "If you look at the chart I gave at the beginning of the semester, the one that outlines how the different topics in this course relate to each other, it makes sense to look now at population growth in order to understand the interplay between this and life histories". He turned back to his slides and said with a loud and clear voice, "So…, what is population growth? ... What controls population growth? " He stared intensely at his students. A few seconds later, while passing to the next slide [See slide #2], he continued "Population growth refers to the rate of change at which a particular population varies in number of individuals. In other words how the size of a population changes over time." Pointing at the slide, he added, "There is two basic models that ecologist use to describe patterns of population growth. One is an exponential model or J-curve and the other is a logistic model or S-curve". He continued, "In the exponential model we see the following [pointing at a graph of whooping crane population in the next slide #3] a leveled population for the first few generations and then a sudden increase, called a geometric growth, forming sort of a J shaped curve"

"Mr. T", asked Lisa while raising her hand. "Does this mean that a population would grow indefinitely?"

Mr. T seemed surprised by this question. He thought the graph was self explanatory. Nevertheless he continued by answering to Lisa. "Not exactly" he said, while taking a panoramic view of the entire class. "What do you all think some assumptions for this model must be?" No one answered. Dr. T added, "Well, we must assume that there are no restrictions on the abilities of individuals to harvest energy, grow, reproduce…etc."

(…) *<The discussion continued for 4 more minutes>*

After this, Dr. T. went on to explain the basic mathematical model that described the change in population size over time [$\Delta N/\Delta t = B - D$]. In this part he showed the students how to derive the formula $dN/dt = rN$ from the word equation that described the first formula [See Slide #4].

"You know", Sarah said to Djuan. "I don't get it when he moves so quickly through the equations". "Don't worry we can ask Pedro at the end of the class to give us a hand" said Djuan.

Dr. T did a similar explanation for the logistic model providing the class with another example. The difference was that he talked about the concept of carrying capacity (K). Then he derived another formula for the students but this time he included K as part of the equation [$dN/dt = r_{max}.N.(K-N)/K$]. Most of the questions he asked during this explanation were answered by Pedro.

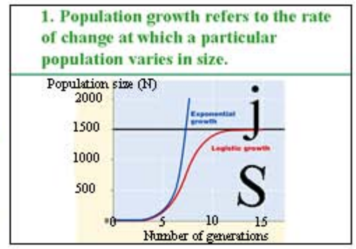
After he posted one more example for each type of growth pattern he moved on and asked: "OK now… It is easy to plug in numbers to equations, but how do you go about finding the number of individuals in a population?" He crossed his armed and sat on the table.

"You do a census" Lisa said.

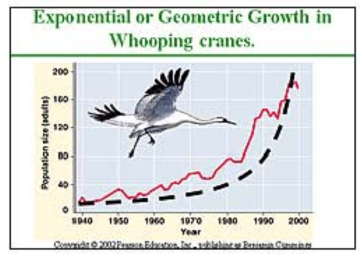
"What do you mean a census?" asked Dr. T curiously.

"You know when you count all the individuals in a population, much like a state census" said Lisa somewhat unsure.

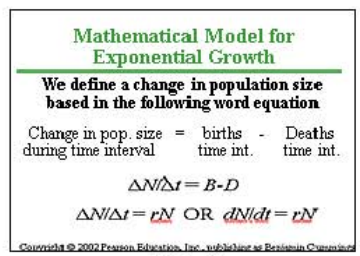
PRESENTATION SLIDES



Slide #2



Slide #3



Slide #4

"OK. Let's say you are an entomologist. How will you do that with a population of fire ants in the middle of a rain forest? Or else, if you were an ornithologist like me, how will you do that with a population of blue birds in the state of Missouri?"

After a few seconds Lisa replied. "I don't know, I'm not sure"

"Anybody" said Dr. T making eye contact with the rest of the audience.

"I would think that you can count the total number of individuals in a known area and multiply that that by the total area they occupy" said Pedro.

"Do you mind expanding on that thought Pedro" said Dr. T.

"Let's say we find the number of birds in a known area- 1 km^2. We know that geographically this birds' home range is about 100 km^2. We could assume that one hundred times the number of birds will give as a fairly good estimate of the total bird population" said Pedro very confidently.

Dr. T. smiled a little and said, "No, that's not what I meant. What I meant is how will you count that initial sample? How will you know you have counted all of the birds? How do you really know?"

(...)

<The discussion continued for 10 more minutes. At that time Dr. T. moved to the next part because he was running short on time.>

<u>PART 2: Factors that control populations (Limiting factors- density dependant & density independent)</u>

"So moving on…" said Dr. T while clicking to the next slide [See slide #5], "Why do all populations eventually stop growing? What environmental factors prevent a population from growing?"

"Food supplies" interrupted Lisa.

"Correct", said Dr. T. "But it's not only food" he paused.

Then he added. "In order to understand why populations cease growing we need to look at the effects that an increase in population size might have on a limited area."

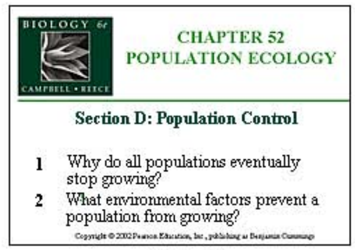
"What do you mean?" asked Djuan.

"Basically, what immediate effects will an increased population density have on the population birth and death rates for example" said Dr. T. turning to the next slide.

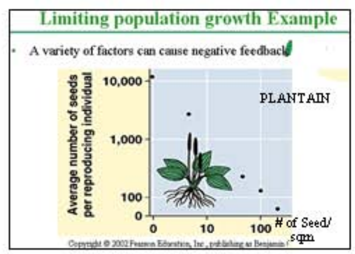
The slide was showing a graph about song sparrows and plantain seeds [See slide #6, #7]. He added "Bearing in mind this idea of resources, and looking at these graphs what can you guys tell me about them?" No one answered. After waiting for 3 more seconds he said. "More individuals in a particular area will mean more pressure on resources which translates into higher rates of intra-specific competition. Hence reduce number of births. For example, in this plantain graph, plantains with fewer nutrients result in smaller plants which result in a smaller amount of seeds being produced!"

Dr. T. tilted his head a little and while looking at the class at the same time he was looking at the graphs he said: "Can you tell me what is happening in this other graph (pointing at the sparrow graph- Slide #7)?"

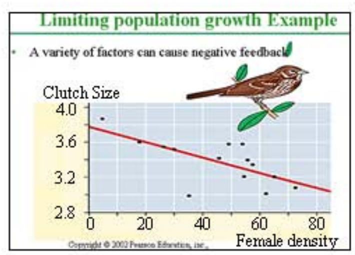
<u>PRESENTATION SLIDES</u>



Slide #5



Slide #6



Slide #7

(…) *<The discussion continued for 6 more minutes>*

PART 3: Wrapping up.

The class finished brainstorming and discussing how other factors like predation, health and disease, tornadoes and temperature affected population growth.

At the end of this section Dr. T. said, "Population dynamics reflect a complex interaction of biotic and abiotic factors. Some populations fluctuate erratically. Other populations' express regular boom-and-bust cycles. Just like we saw with the Dungeness crab (*Cancer magister*) and the snowshoe hare and lynx respectively"

He then added as a closing remark "Basically populations can be controlled by density-dependent factors, that is biotic factors, and density-independent factors, that is abiotic factors."

Dr. T turned around to turn off the projector and close his power point. He added, "Make sure you look at those graphs before next class and if you have any questions we'll try to answer some of your doubts. That's it for today, you are dismissed"

Everybody started standing up. Lisa asked in the middle of the commotion, "Dr T. what will next weeks exam consist of?"

"It will be 30 multiple choice questions on the topic of evolution, same as the first exam."

"What if we had any questions", said Pedro.

"Well you can set-up a meeting with me during my office hours or else talk to Dianne [Class T.A. for one of the labs]" replied Dr. T.

Sarah asked Djuan, "What is our Pre-lab about?"

"Lemna sp. and Azolla sp. (Growth and Interactions between Duckweeds and Water ferns)" said Pedro from afar.

The class cleared.

REFERENCES

- AAAS. (1993). Benchmarks for Scientific Literacy. New York: Oxford University Press.
- Campbell, N. & Reece, J. (2002). Biology 6th Ed. Pearson Educational Inc. publishing as Benjamin Cummings. San Francisco, CA.
- Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources and development of pedagogical content knowledge. In J. Gess-Newsome & N.G. Lederman (Eds.), Examining pedagogical content knowledge (pp. 95-132). Dordrecht, The Netherlands: Kluwer Academic Publisher.
- Miller, K. & Levin, J. (2004). Biology. Pearson Educational Inc. publishing as Prentice Hall. Saddle River, NJ.
- National Research Council- NRC (1996). National Science education standards. National academy Press, Washington DC.
- Veal, W. (1997). The evolution of pedagogical content knowledge in chemistry and physics prospective secondary teachers Unpublished Doctoral Dissertation, University of Georgia, 1997. AAT 9807136.
- Veal, W. & MaKinster. (1999). Pedagogical content knowledge taxonomies. Electronic Journal of Science Education, 3(4), 1-17. Retrieved 2/19/2005.

REFLECTION QUESTIONS FOUND NEXT PAGE

INITIALS : ___________________	DATE : __________________

Questions for Reflection (Adapted from Veal, 1997)

1- Comment on what you liked and what you disliked about the class described in the vignette.

2- How would you describe the teaching approach Dr. T. had? Do you think this is an appropriate one? Why? How will you do things differently?

3- How do you think the teacher might start his class next time? What makes you think this? If you were the teacher how would you start the class?

4- What did you like best about what the teacher did, and why?

5- Please rate the teacher on a scale from 1-10, one being poor, ten being a great teacher. Why did you rank the teacher as such? Please list your criteria

6- How long did it take you to answer these questions (Give an estimate)?

Note: *Last vignette (III- PBio) had a Qs.0: Completing a discussion section of choice.*

Interview questions that will follow after the Vignette has been completed- The format will be more open ended trying to hit on all the components of PCK if possible. Transfer will be a particular focus.

Materials

iPod <mic-charger> (charged), Pen-Notepad, Second tape recorder.

Before the interview:

5- Read Vignette responses before starting the interview.
6- Prepare specific questions about their vignettes.
7- Check participant background information if possible.
8- Find a quiet place (Woods Hall or MSC 3rd Floor, or ICTE offices)

During Interview

1- "Thanks for coming" Start with a casual question. Offer coffee if available, water or cookies. Talk about what the person has been up to. (2-3 minutes)
2- Tell them how the interview will be.

-"I guess you know the drill, let's just get started."
-"Do I need to read your rights? Just Kidding"
-"At any time feel free to tell me if you don't want something to be recorded, I'll turn off my iPod."
"Shall we start?"

9- Start with the first question only and then ask about specific questions from their answers. Then move on to questions submitted to them before the interview and finalize with questions about specifics lines in the vignette. Try to touch base in a few sections of PCK. Don't ask everything
10- Try to keep interview at 30 min or 40 min maximum.

POTENTIAL QUESTIONS FOR VIGNETTE

PCK and Practices

1. What did you think about the vignette? Why?

Move to specific questions about their answers. See suggested follow up questions

-Why do you suggest doing this?
-Where in the Vignette made you think this? Expand.
-Which part of the text made you say that? Expand.

----

2. How would you teach a topic like population growth and factors affecting population growth? (Strat., Curric.)
3. What do you think is the purpose of teaching this topic? Why do you think people should learn about it? (Orient.)
4. Do you have in mind any labs that could help strengthen this concept? Do you think this lab is appropriate for this level? (Curric., Strat.)
5. What do you think will be a fair way to test students? (Asses.)
6. What do you think about the slides Dr T. used in class? (Strat.)

7. What can you tell me about the students? (Stude.) Do you think that having a diverse group of students matter? How come? Will this change if all of them wanted to pursue biology?

Content

8. How familiar did you feel with the content? Did you have to look up some of the concepts?
9. Based on your own understanding, did you feel the content presented in the class was "scientifically correct"?
10. What concepts do you think students need to know before coming to the class?
11. Anything you may want to add at this point?

Looking at specific portions of the vignette: ONLY BOLD

1- **(L50-52) What do you think about this particular section?** (More specific for later: How will you do things differently? Why and when will you do things the way he did?)

2- (L78-79) What do you think about this section?

3- **(L64) What do you about this section?** Why is it important for a teacher to direct their questions to others?

4- **(L123-128) What do you think about this section?**

5- **(L36-39) What do you think about this section?** Where the prequest's a good idea or not? Why or Why not?

6- **Can you look at slide one?** What can you tell me about this slide?

7- **(L150-151) What do you think about this section?** What's the point of doing this?

Thank you so much for your time.

Note: During the last vignette the following question was added to the interview

What pointers would you give me if I have to teach a lecture? I ask, you what should I do [fellow]? I'm teaching next semester…

Pedagogical items (Practices and PCK)	
Context	
General	Teacher did not show variety in the way he taught.
[L 59,60]	On top of using the typical example in nature instructor could've used a local example. Maybe human population growth.
[L 15-21, 40-43]	Diverse community of learners, therefore different examples could be used to make things more relevant to all the audience
Strategies for teaching and Teaching practices	
General	(Strat.) Teacher Centered-model- Lecture-base method.
[L 47-49]	(Strat.) Advance organizers used to outline concept inter-relatedness.
[L 50-52,108,119, 120]	Too many questions at the same time were asked. People tend to answer the last question and forget the previous ones. It gives them enough leverage to answer what they want and not link concepts.
[L 108]	Question was not stated clear enough for the students to answer appropriately
[L 88-107]	Guided inquiry. Questioning used to scaffold student thinking. To come up with an answer
[Slides All]	(Pract.) Slides where simple, not too crowded with words and phrase and a good mix of images.
[L 31-33]	Teacher seemed more worried about breadth rather than depth
[Slide #1]	Follow the text book
[L 78-79, Slide#4]	Cutting steps and moving too quickly through abstract mathematical concepts.
[Slide #2,#3]	Whooping crane example- Well known example. Using Graphs with letters to show correspondence
General	Explanations are too vague. There is no link to real cases in nature as often as it might be.
[L 45]	(Class management)- turning on the projector to start class and stop the chatting.
[L 36-39]	(Class management)- Pre-quests, and office hour's allocation. Pre-quest given as a revision for the previous chapter and a precursor for the next.
[L 47-49, 50-51] [L 40-44]	Linking the content, somehow to the previous concept. Starting the class with some opening questions, lecturing and then summarizing the concepts at the end of class.
[L 40-44]	Summary was very superficial and did not cover all the topics lectured during class.
General	Training students to a routine of what to expect. Starting the class topic by handing in a pre-quest worksheet. Then starting lectures with a powerpoint, a series of questions, and summarizing at the end, then dismiss.
[L 108]	Negative response to a badly phrased question.
General	No monitoring of student understanding occurred.
[L 50, 51, 67, 90, 99, 133]	Eye contact and trying to include all participants and constantly looking at the audience. Clear voice.
[L 50-52, 68]	Teacher answered his own questions. Related to wait time.
[L 50-52, 68]	(Wait time) Too short. Teacher needs to leave more time for students to participate and think longer.
[L 64]	Need to ask questions of more students. Pedro seemed to answer most of the questions. Students tend to lay back and wait for an answer instead of thinking.
[L 53-53, 123-128]	Re-verberating. Phrasing an explanation in a different way to improve understanding

	of the concept. Putting complicated concept in simple terms.
Assessment	
[L 150]	Main exams multiple choice. A focus on concepts rather than process.
[L 36-39]	Pre-quests as a mode of reflecting on the subject before coming to class and as a way of revising the concepts already learnt (re-conceptualizing Cazden book)
[L 68, 85, 95-97]	Informal assessments while questioning students
Curriculum	
[Slide #1]	Curriculum based in teachers textbook.
[Slide #1]	A well known general biology book is being used (Campbell 6^{th} Ed.)
General	One could speculate that course is taught in a compartmentalized way. Little does the teacher do to use examples from real life situations or connect the subject to other subjects (e.g., farmer concerns of weed growth in his fields and ways to control this).
General	(Not mentioned) Pre-requisites to take this class.
Student	
[L 15-21,25,40-43]	Knowledge about students (Know about student backgrounds)
[L 73-86, Slide #4]	Mathematic background of students is important, especially when deriving mathematical formulas. (Graphing, Algebra, Calculus- Pre-requisites)
[L 73-86, Slide #4] [L 57-59]	Abstract concepts like those represented in the mathematical formula, apparently were not explained properly
[L 150-151]	Teacher generated misconception about density dependant and independent and their relationship with biotic and abiotic factors.
[L 57-59]	Students are sometimes better teachers than other students. Working in similar Zones of proximal development.
General	An assumption that students know the content like the professor does.

Content items	
[L 35-36]	(Fecundity and fertility) Hard concepts for students.
[L 73-77, Slide#4]	(Migration) Not considering migration as important factors for population growth
[L 53-55 Slide #2] [L 52]	(Population Growth, Birth and Death Rate) Defined properly in simple terms (Birth and Deaths). Teacher should've at least mentioned that Migration is important too. Assumptions of the model (Additional, nest sites, shelter, territory, etc)
[L 127-128]	(Population Density)
[L 58-71 Slide#2, #3, #4]	(Exponential Growth, J-curve, geometric) No clear explanation about the fact that exponential growth only occurs in an idealized population where resources are unlimited.
[L 81-86]	(Logistic Growth, S-curve, Carrying Capacity-K)
[L 150-151]	(Density dependant Factors) Predation- Top-down regulation
[L 150-151]	(Density independent factors)
[L 135]	(Intraspecific competition)
[L 95-107]	(Field methods in ecology)
[L 121, 131-138]	Factors controlling populations
[L 49]	(Life Histories) Just mentioned but related to the topic.

Content Knowledge: Population Ecology and Limiting Factors

AAAS	NSES	MO-Frameworks (Know and Do)	UMSLB12/ Campbell 6th Ed.	Misconceptions (TIEE)	Multiple Choice Exam
•Ecosystems can be reasonably stable over hundreds or thousands of years. As any population of organisms grows, it is held in check by one or more environmental factors: depletion of food or nesting sites, increased loss to increased numbers of predators, or parasites. If a disaster such as flood or fire occurs, the damaged ecosystem is likely to recover in stages that eventually result in a system similar to the original one.•Like many complex systems, ecosystems tend to have cyclic fluctuations around a state of rough equilibrium. In the long run, however, ecosystems always change when climate changes or when one or more new species appear as a result of migration or local evolution.•Human beings are part of the earth's ecosystems. Human activities can, deliberately or inadvertently, alter the equilibrium in ecosystems. •At times, environmental conditions are such that plants and marine organisms grow faster than decomposers can recycle them back to the environment. Layers of energy-rich organic material have been gradually turned into great coal beds and oil pools by the pressure of the overlying earth. By burning these fossil fuels, people are passing most of the stored energy back into the environment as heat and releasing large amounts of carbon dioxide.• The amount of life any environment can support is limited by the available energy, water, oxygen, and minerals, and by the ability of ecosystems to recycle the residue of dead organic materials. Human activities and technology can change the flow and	•Energy flows through ecosystems in one direction, from photosynthetic organisms to herbivores to carnivores and decomposers. •Organisms both cooperate and compete in ecosystems. The interrelationships and interdependencies of these organisms may generate ecosystems that are stable for hundreds or thousands of years. •Living organisms have the capacity to produce populations of infinite size, but environments and resources are finite. This fundamental tension has profound effects on the interactions between organisms. •Human beings live within the world's ecosystems. Increasingly, humans modify ecosystems as a result of population growth, technology, and consumption. Human destruction of habitats through direct harvesting, pollution, atmospheric changes, and other factors is threatening current global stability, and if not addressed, ecosystems will be irreversibly affected.	Overpopulation in an ecosystem can lead to depletion of resources and elimination of a species. a. identify the density-dependent limiting factors of a population and discuss consequences of overpopulation (1.6; 2.1; 2.3; 3.5; 4.1) b. discuss how changes in one population in an ecosystem affects the population of another species in that ecosystem (1.2; 1.4; 1.8; 2.1; 2.2; 2.3; 2.4; 2.7; 3.5; 4.1) c. identify the carrying capacity of an ecosystem and predict the limiting factors that will slow population growth (1.1; 1.4; 1.6; 1.8; 2.1; 3.5; 4.1)	Birth rate and death rate. Exponential Growth Rate or Geometric, J vs S Shaped curves, Logistic growth $dN/dt=rN$, where $r = (b-d)$, b= births/yr, d= deaths/yr density dependant, density independent negative feedback carrying capacity zero population growth ZPG k-selected pop., r-selected populations equilibrial pop., opportunistic pop., Intraspecific comp.	Species coexist in an ecological system because of their compatible needs and behaviors: they "get along." Populations exist in states of either constant growth or decline depending upon their position in a food chain. Some ecosystems are limitless resources and provide an opportunity for limitless growth of a population. The relative sizes of prey and predator populations have no bearing on the size of the other. Density-dependent factors are biotic, and density-independent factors are abiotic. Populations increase until limits are reached, then they crash and go extinct. There are more herbivores because people keep and breed them Varying the population of an organism will only affect the others that are directly connected through a food chain. Varying the population of an organism may not affect an ecosystem, because some organisms are not important. Varying the population of an organism will affect all other organisms to the same degree. Organisms higher in a food web eat everything that is lower in the food web. The top of the food chain has the most energy because it accumulates up the chain. Populations higher on a food web increase in number because they deplete those lower in the web.	Q16, 18, 68, 93, 94- expo (geo), log Q17- K Q18, 95, 96- lifehistory Q69, 70- formula use Q71- human demograph Q97 regulatory factors

reduce the fertility of the land.				Populations higher on a food web increase in number because they deplete those lower in the web.All factors are limiting except the most abundant one. The most limiting factor is the least abundant one	