THE TRANSFORMATION OF SCIENCE AND MATHEMATICS CONTENT KNOWLEDGE INTO TEACHING CONTENT BY UNIVERSITY FACULTY

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ABSTRACT

University science and mathematics education today is no longer solely focused on training the small fraction of students who will become tomorrow's science and mathematics researchers, but is required to engage and create scientifically/mathematically literate American citizens (Ball, 2000; Dean, 2009; Kind, 2009a; Mooney & Kirshenbaum, 2009; Olsen, 2009). University professors are typically content experts not trained in pedagogy. This creates unique teaching issues in transforming complex content material. Expert content mastery of a subject can blind faculty to potential student difficulties (Ben-Peretz, 2011; Nathan, Koedinger, & Alibali, 2001). This, combined with limited pedagogical training and curricular constraints, can create teaching difficulties, contributing to high levels of student attrition (Bhattacharya, 2012; Feldon, Timmerman, Stowe, & Showman, 2010).

Considerable research has been conducted on best teaching practices and the central role that content knowledge plays in teaching, yet little evidence is found to illuminate the processes by which subject matter content experts (faculty) unpack their expertise for use in teaching (Ball, 2000; Bouwma-Gearhart, 2012; French, 2005; Weiman, Perkins, & Gilbert, 2010). Much of the research literature defines deconstructing and unpacking content knowledge as the complex processes by which experts transform content knowledge into knowledge used for teaching (Abell, 2008; Ball & Bass, 2000; Hashweh, 2005; Shulman, 1986, 1987). According to the well accepted educational construct known as pedagogical content knowledge (PCK), teachers possess

unique and distinct sets of knowledge domains that enable them to transform their content into teachable knowledge (Shulman, 1986, 1987). Much of the literature agrees that strong foundational content knowledge is required in order to develop PCK (Hill, Rowen, & Ball, 2005; Lowenberg-Ball, Hoover-Thames, & Phelps, 2008; Padilla, Ponce-de-Leon, Rembado, & Garritz, 2008). If limited content is a major restriction in the development of PCK, how does this process proceed when content is strong, as in the case of university faculty? This study looked at the processes that occur as content experts (faculty) focus on the deconstruction process in order to develop lessons and teach. The study focused on the components or paths of the transformation process in an attempt to identify the development of the knowledge base that content experts use in order to teach.

This study developed a survey from the existing literature in an attempt to illuminate the processes, tools, insights, and events that allow university science and mathematics content experts (Ph.D.'s) unpack their expertise in order to teach develop and teach undergraduate students. A pilot study was conducted at an urban university in order to refine the survey. The study consisted of 72 science or mathematics Ph.D. faculty members that teach at a research-based urban university. Follow-up interviews were conducted with 21 volunteer faculty to further explore their methods and tools for developing and implementing teaching within their discipline. Statistical analysis of the data revealed: faculty that taught while obtaining their Ph.D. were less confident in their ability to teach successful and faculty that received training in teaching believed that students have difficult to change misconceptions and do not commit enough time to their

course. Student centered textbooks ranked the highest among tools used to gain teaching strategies followed by grading of exams and assignments for gaining insights into student knowledge and difficulties. Science and mathematics education literature and university provided education session ranked the lowest in rating scale for providing strategies for teaching. The open-ended survey questions were sub-divided and analyzed by the number of years of experience to identify the development of teaching knowledge over time and revealed that teaching became more interactive, less lecture based, and more engaging. As faculty matured and gained experience they became more aware of student misconceptions and difficulties often changing their teaching to eliminate such issues. As confidence levels increase their teaching included more technology-based tools, became more interactive, incorporated problem based activities, and became more flexible. This change occurred when and if faculty members altered their thinking about their knowledge from an expert centered perspective to a student centric view. Follow-up interviews of twenty faculty yielded a wide variety of insights into the complicated method of deconstructing expert science and mathematics content. The interviews revealed a major disconnect between education research and researchers and the science and mathematics content experts who teach. There is a pervasive disregard for science and mathematics education and training. Faculty members find little to no support for teaching. Though 81% obtained their Ph.D. with the intent to enter an academic setting, pedagogical training was non-existent or limited, both prior to and after obtaining faculty positions. Experience alone did not account for confidence or ability to successfully teach. Faculty that were able to 'think like a student' and view their material from a student's perspective' seemed to be the most confident and flexible in their teaching

methods. Grading and having an open and interactive teaching style, being on the ‘side of the students’ also seemed to allow faculty to connect more deeply with the students and learn about common misconceptions and difficulties. Though most faculty claimed to not teach as they were taught and not recall having specific content difficulties, this essential interaction with many students facilitated a shift in thinking about their content. This shift allowed for a reversal from teacher centered classrooms to student centered. Multiple issues arise when teaching at a traditional larger lecture style found in the majority of universities science and mathematics courses that constrain and provide unique teaching challenges. Many faculty have developed unique tools to incorporate successful teaching strategies, such as daily pre-quizzes and smart-phone questioning as well as small group work, computer posted guides, strategic class breaks, and limiting lecture style in favor of a more active engaged classroom.

DEDICATION

My family

You are my heartbeat.

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CHAPTER 1

STUDY SIGNIFICANCE: STATE OF SCIENTIFIC LITERACY

Science is a way of knowing the world, and is frequently written and communicated in a language that is not easily comprehended by students and the general public (Dean, 2009; Hazen & Trefil, 2009; Olson, 2009). A high quality science and mathematics curriculum is an essential component in maintaining United States competitiveness in a globally challenging market (Brockman, 2004; Hirsch, Kett, & Trefil, 2002; Mooney & Kirshenbaum, 2009; Randall, 2007; Trefil, 2008). Stewardship of planet Earth, the development of critical thinking skills, and the production of a scientifically literate citizenry is part of the responsibility of science and mathematics teaching from not only K-12, but through college (Pfund, Mathieu, Austin, Connolly, Manske, & Moore, 2012). According to the National Environmental Education Training Foundation (NEETF), many U.S. citizens lack basic knowledge about science and environmental issues facing the nation today (NEETF, 2005). The United States repeatedly ranks near the bottom in sciences and mathematics when compared to international peers (AAAS, 1989; Benbow, 2011), supporting the statement that most Americans are not scientifically literate (Mooney & Kirshenbaum, 2009; Seymour & Hewitt, 1997).

Educational research indicates that adults cannot adequately function in American society without sufficient math and reading skills, but seem to be quite capable of existing with missing and incorrect scientific knowledge (Byrnes, 2008; Olson, 2009;

Trefil, 2008). As journalism has moved from mainly print medium to electronic, shrinking budgets often lead to science segments being left out (Dean, 2009). American citizens are faced with reduced and limited news headlines concerning scientific issues such as stem cell research, nuclear power safety, the teaching of evolution in our schools, and technological competitiveness (Hirsch et al., 2002; Wieman, 2007). Many of these issues will be voted on by way of political elections, illuminating the need for American citizens to be scientifically literate as members of our country's political, economic and scientific discourse. However, citizens with missing and incorrect scientific knowledge are less qualified to make vital decisions related to healthcare and environmental issues, though they vote with equal status, potentially influencing key governmental and educational policies (Mooney & Kirshenbaum, 2009). In order to rectify this pervasive lack of scientific literacy academic scientists need to communicate their deep and detailed knowledge more effectively to students in ways that non-scientists can understand (Dean, 2009; Mooney & Kirshenbaum, 2009; Olson, 2009). University science courses are often the last opportunity for individuals to be exposed to scientific concepts, making effective communication by professors an essential link in education (Dean, 2009; Morgan & Whitener, 2006).

Role of Universities in Science/Mathematics Education

Unique Teaching Issues

Science and mathematics courses are among the most feared and avoided of college courses, yet in today's technology-based society they are one of the most essential. For many college students, the one or two science/mathematics requirements are the only and last courses they will encounter; therefore it is essential to make science/mathematics courses as engaging, comprehensive, practical, and true to the nature of science/mathematics as possible (Morgan & Whitener, 2006; Wieman, 2012). For some students it may spark a previously unknown or newfound interest in the subject matter or open the door to a possible major, increasing the much needed science/mathematics student population (Druger, 1998; Egger, 2005; Nauta & Kokaly, 2001; Thompson, 2003; Ware, Steckler, & Leserman, 1985). Therefore, the highest quality academic professionals, who possess not only expert content but pedagogical acumen, are needed in order to implement effective science/mathematics curricula that deliberately engages the population instead of acting as a barrier (Bain, 2004; Birnbaum, 2004; Gonzalez-Espada, 2009; Mooney & Kirshenbaum, 2009; Olson, 2009; Randall, 2007). Nationally, undergraduate majors in the sciences have high attrition rates (Benbow, 2011, Koenig, 2009; Seymour, 2007). Although a broad range of factors contribute to leaving a science major, poor instruction is almost universally cited (Feldon et al., 2010; Seymour & Hewitt, 1997). In a national study of college freshman who initially declared themselves as STEM (Science, Technology, Engineering, or Mathematics) majors, 90% who switch to a non-science major cited ineffective instruction as a primary reason (Daempfle; 2003; Feldon et al., 2010; O'Neal, Wright,Cook, Perorazio, & Purkiss, 2007).

Research indicates that college students enter science/mathematics classrooms with a variety of pervasive and strongly held misconceptions, as well as a disconnect from science content, that combined with fear of science/mathematics courses and limited background knowledge leads to an academically challenging teaching environment (Greiffenhagen & Sherman, 2008; Kuhn, Garcia-Milna, Zohar, & Anderson, 1995; Nelson, 2008). College faculty not only teach new and advanced material, but must engage, identify, and help students unlearn false beliefs before correct information can take hold. The dichotomy between high level content knowledge and pedagogical teaching methods combined with the vast array of student background knowledge leads to a unique combination of learning issues, often leading to a high drop-out rate among formerly interested and talented science students (Dubetz, Barreto, Dieros, Kakareka, Brown, & Ewald, 2008; Felder, 2012; Korthagen, 2004; MacLellan, 2008; Schell, 2009; Seymour, 2001).

The often large lecture-style introductory science/mathematics courses taught at most major universities also present unique teaching and learning challenges. Though college is non-compulsory, the greater variety of student backgrounds, passive engagement, and the limited contact hours can lead to difficult and ineffective teaching scenarios (Bain, 2004). Some aspects of instruction occur in response to external pressures rather than a teacher's own ideas about what is appropriate, as well as the 'teach as we have been taught' method (Henderson, Finkelstein & Beach, 2010; Porter, & Brophy, 1988). Professors often join an academic career as a result of content expertise; the lack of training in pedagogy does not prevent maturation into excellent teachers, but experience and time alone do not generate effective teaching (Ball, 2000; Fernandez-Balboa, & Steihl, 1995).

Science and Mathematics Teaching is Different

Teaching is an art form; it is fluid and dynamic and involves instantaneous decision making throughout each moment (Weingarten, 2010; Zeidler, 2002). Scientific thinking and learning are innately difficult due to the higher-level thinking and abstract skills needed, requiring unique pedagogical techniques not used with other content matter (Byrnes, 2008; Schroeder, Tolson, Huang, & Lee, 2007; Zeidler, 2002). Piaget's stage theory illustrates that most children do not develop the ability to think abstractly until at least the age of ten or eleven, corresponding to formal operations; therefore, many basic schemata are created prior to the full ability to create correct scientific concepts (Piaget & Garcia, 1974). If science courses are only taught in a limited way in the K-12 curriculum, how can university-level instruction counteract the years of pseudo-theories and misconceptions engrained in the minds of incoming 18-22 year olds? This level of teaching clearly requires a multitude of different teaching methods, including un-teaching a lifetime worth of incorrect schemata (Byrnes, 2008; McCarthy & Anderson, 2000).

Science content is particularly susceptible to the development of misconceptions, as students are exposed to a limited science curriculum and have developed incorrect or immature schemata based on personal observations or religious beliefs (Anderson, 1983; Chinn & Malhorta, 2002; Griffiths & Preston, 1992; Kendeou & Van Broek, 2005; Piaget & Inhelder, 1969). Research indicates that misconceptions are deeply rooted and difficult to supplant (Kuhn et al., 1995; Nelson, 2008), leaving University level science and mathematics teachers with the need to identify mis-information before any true learning can occur. This unique and difficult combination of complications, combined with science experts' deconstruction process has become part of this study's focus.

Knowledge for Teaching Differs from Expert Knowledge

In 1986, Lee Shulman published his seminal work recognizing seven distinct knowledge bases of teachers which he termed Pedagogical Content Knowledge (PCK). Three components are recognized as distinct and unique to the profession of teaching and remain the focus of the PCK framework: pedagogical knowledge (PK), curricular knowledge (CK), and subject matter knowledge (SMK). Shulman (1986) recognized an additional knowledge base, termed 'the missing paradigm,' which represented a special amalgam between subject matter, curricular, and pedagogical knowledge that is unique to teaching. Though originally presented in the discourse on the professionalization of teaching, the PCK construct invites an examination of a variety of broad issues pertaining to both pedagogy and content as they relate to teaching (Abell, 2008; Abell, 2007; Grossman, 1990; Segall, 2004). Teachers must have knowledge about learners, curriculum, instructional strategies, and assessment through which they transform their knowledge into effective teaching and learning (Shulman, 1987). Teachers need to understand not only what they teach but also be able to transform this knowledge to suit a variety of learner types, in multiple flexible methods, metaphors, and demonstrations (Abell, Park-Rogers, Hanuscin, Lee, & Gagnon, 2009; Bullough, 2001; Padilla et al., 2008). In essence, knowing science content is not sufficient for teaching science, or other subject matter (Ball, 2000; Berry, Loughran, & van Driel, 2008; Gess-Newsome, 1999). The transformation of subject content knowledge for teaching is at the pinnacle of

Shulman's (1986, 1987) PCK theory. PCK is, therefore, a specialized knowledge that distinguishes teachers from subject matter specialists, and focuses on how teachers transform subject, pedagogical and curricular knowledge into viable instruction.

Role of Content in Teaching and PCK Development

Considerable research has documented the essential and dominant role of subject matter content as the foundation for teaching, indicating that when content is lacking pedagogy often fails (Abell et al., 2009; Ball, Hoover-Thames, & Phelps, 2008; Henze, van Driel, & Verloop, 2008). Professional educators must understand why something is done as well as being capable of reflecting on the procedure to generate the end product (Park & Oliver, 2008). It is this meta-cognitive awareness that distinguishes the practitioner (scientist) from the science teacher. Teachers must understand content, a discipline's structure as well as pedagogical and curricular knowledge (Fernandez-Balboa & Stiehl, 1995). Halim and Meerah's (2002) study supported other research findings by Berg and Brouwer (1991) in which teacher trainees with limited content knowledge where unable to foresee students' difficulties and misconceptions. The recognition of this distinct and seminal knowledge base held by the best of the teaching profession may be the beginning of recognizing the unique skill set that teachers draw upon for excellence. The application of this model to college teaching is also critical, as little of their training addresses PCK (Bain, 2004; Chasteen, Perkins, Beale, Pollock, & Weiman, 2011; Coppola & Pearson, 1998; Druger, 1997; Fernandez-Balboa & Stiehl, 1995; Padilla et al., 2008)

While strong content knowledge is foundational to quality teaching, it is recognized as only one of several needed components (Abell et al., 2009; Ball & Bass, 2000; Fairbanks, Duffy, Faircloth, He, Vevin, Rohr, & Stein, 2010). Deep and sophisticated content knowledge helps teachers select the best metaphors, examples, and explanations suited for each classroom's unique teaching opportunities (Cox, 2004; Hill et al., 2005; McDiarmid, Ball, & Anderson, 1989). Davis, Petish, and Smithey (2006) showed that stronger science knowledge typically co-occurs with more sophisticated instructional practices; yet simple increases in a teacher's subject matter knowledge is not sufficient to improve student achievement (Jacobs, Martin, & Otieno, 2008; Borko, Eisenhart, Brown, Underhill, Jones, & Agard, 1992).

McEwan and Bull (1991) question the distinction between subject matter knowledge for teachers and that for scholars, indicating that all knowledge is inherently pedagogical since it involves representations and the intent to convey and communicate. Scholars must determine ways of representing their subject in order to make it comprehensible; although scholars are generally not concerned with the teachability of their ideas. Teachers are then assigned the task of representing and translating complex scientific concepts (Clermon, Borko, & Krakcik, 1994; Dennick, 2012; McEwan & Bull, 1991). This dichotomy between, and the successful merging of, complex scientific knowledge and the alteration into teaching knowledge is a component of this study.

Faculty are Content Experts

Much of the literature agrees that there is a domain of knowledge unique to teaching, a subject-matter specific professional knowledge (Ball, et al., 2008). This knowledge set acts as a bridge between content knowledge and the practice of teaching. The developmental paths and transformation of this knowledge remains unclear. What is clear is the content taught to scientific specialists (future faculty) is not the content that they will directly teach in college classrooms (Barnett & Hudson, 2001; Cox, 2004; Druger, 1997). While it is not being implied that future faculty or teachers should have less subject matter content, it is essential that teachers have the opportunity to learn how to transform the often practice-oriented subject matter into useable classroom-level knowledge (Davis, 2004; Kind, 2009a). In most Ph.D. granting institutions graduate students are directed to focus on their research skills and not communication or teaching skills, even when a future career in academia is planned or may occur (Dean, 2009; Jones, Moore, & Flannigan, 2004; Szymanski-Sunal, Sunal, Sundburg, Mason, Zollman, Lordy, & Morgan, 2009). What counts as subject matter knowledge for teaching and how this knowledge is created from scholarly content knowledge remains inadequately defined or studied? The process of transforming expert science content knowledge into usable teaching knowledge by university faculty represents a portion of the focus of this study.

Expert Blind Spot Theory

Expertise is often characterized and recognized by the ability to recognize direct routes to problem solving (Berliner, 1986). As a teacher this means recognizing instructional opportunities quickly and accurately (Berliner, 1986; Levin, Hammer, & Coffey, 2009). Content experts have well developed, extensive, and sophisticated schemas for their domain of knowledge, which serves them well in organizing and retrieving relevant information (Cooke, 1992; Ennis, 1994; Nathan & Petrosino, 2003). Streamlining the cognitive process reduces cognitive load and focuses attention on key factors, unlike novices who lack the ability to disregard irrelevant details (Nathan & Petrosino, 2003). This often comes at the expense of 'unpacking' and verbalizing the relationships and pathways, resulting in missed steps or inattention to background knowledge (Koedinger & Anderson, 1990; Wigboldus, Dijksterhuis, & van Knippenberg, 2003). The knowledge of students' understandings and misconceptions helps teachers to interpret their actions and ideas as well as plan effective instruction (Geddis, 1993; Magnusson, Borko, & Krajcik, 1988). A theory known as expert blind spot theory has emerged in the literature and points toward a unique communication restriction between experts and novices that may negatively impact teaching (Nathan, et al., 2002; Nathan & Petrosino, 2003). Content experts think about, retrieve, and communicate their knowledge utilizing flexible and well connected schema. As Wiley (1998), points out, expertise is highly schema-based which this tends to focus the expert toward only probable paths while eliminating extraneous information; a skill that eludes and confounds novices. This subject-matter expertise can overshadow knowledge of how novices (undergraduates students) develop that content knowledge, and can adversely affect teaching practices, especially when pedagogical training is lacking (Nathan et al., 2001).

Role of Experience

Quality teaching often develops with teaching experience. However, neither content expertise nor experience guarantee the development of the skills needed to become an expert teacher (Ball & Bass, 2000; Fairbanks et al., 2010). Much of the literature indicates that experienced teachers are able to identify key instructional opportunities and successfully interact and provide alternative teaching components (Sabers, Cushing, & Berliner, 1991; Shulman, 2000; Wilson & Mant, 2011). They are able to anticipate and make use of student difficulties to redirect and create teachable moments. DeJong and van Driel (2001) report that novice teachers were unable to predict student learning difficulties, were unable to identify misconceptions, and believed that few students would have difficulties learning subject matter. While all teachers have prior knowledge of teaching just from being students, that knowledge is from a students' perspective and therefore must be modified into a more sophisticated teachers' perspective. Novice and student teachers often teach as they were taught, oversimplifying the teaching process, and do not see the complex thinking, planning, unique choices and analysis, (behind the scene details), that goes into creating a lesson (Coppola & Pearson, 1998; Harlow, 2007; Livingston & Borko, 1989).

The many years future university faculty spend as students yield significant content. This strong content knowledge remains from a student's perspective; even doctoral programs that lead to a teaching profession often lack explicit attention to developing future instructors (Abell et al., 2009; Bates, Ramirez, Drits, 2009). Just as students lack the perspective of how a classroom functions from the teacher's perspective, new professors lack the experience of how a college classroom functions from an independent instructor's perspective (Abell et al., 2009; Addis, Quardokus, Bassham, Becraft, Boury, & Coffman, 2013). A portion of this study seeks to look at the dynamic role that experience plays in the development and deconstruction of specialized content knowledge used for teaching, as well as how does it develop from content expertise?

Research Questions

This study intends to focus on university science content experts' path while they transform their unique subject matter into usable knowledge for teaching, how this process develops, what role experience, knowledge of students as learners, and meta-cognitive actions play in it development. Most of the literature relating to PCK development confirms that strong content knowledge is the foundation to PCK development. Without this base PCK development is likely to be restricted (Ball et al., 2008; Davis, 2004). This study intends to remove the question of strong content knowledge by using as a population university faculty who are agreed to be experts in their content fields. With the vital content component removed as a restriction to PCK development, I intend to look at the processes of transforming the content into teachable material. The primary research question asks: How do science and mathematics experts (i.e. instructors with a Ph.D.) develop, expand, and modify PCK for teaching in a University setting. The secondary research questions asks, do instructor characteristics affect the development, expansion, and modification of PCK. The characteristics investigated are: Gender, the number of years teaching (to reflect levels of experience), self-reported status as a researcher, teacher or both (to reflect the personal view of their jobs purpose), academic department, having received prior training in teaching and teaching status at the university such as Tenured/tenure-track, non-tenure track or adjunct.

According to van Driel, Verloop, and de Vos (2002) PCK develops from acknowledging and resolving students' questions while teaching lessons, correcting tests, understanding students' responses to specific assignments and observing student behavior during lessons taught by a mentor, peer or themselves. Reflection and grading of papers, quizzes, assignments, and homework provides teachers with insight into student difficulties, hopefully leading to the development of PCK (Stein, 2007; Van der Valk & Broekman, 1999). The recognition, identification, and codification of this unique knowledge base for teaching could directly inform teaching practice (Shulman, 1987). Effectiveness in teaching resides not simply in the knowledge a teacher has accrued, but how this knowledge is used in the classroom (Hill, et al., 2005; Goldey, 2014). By looking at teacher knowledge growth from novice to expert, researchers hope to identify the complex body of knowledge and skills needed to function effectively as a teacher (Shulman, 1987; van Driel, Verloop, & Vos, 1998).

The focus of this study is to identify the methods and techniques used by university-level science content specialists to deconstruct and transform their sophisticated content knowledge for teaching to non-content specialists – undergraduate students. I hope to identify which components of content knowledge are identified and modified for use in teaching and the process by which this occurs. I hope to identify the development of PCK as faculty begin to modify and expand their content knowledge for teaching purposes. I will look for evidence of teacher awareness of student difficulties, and ability to adjust lessons to resolve learning issues (Bain, 2004; Burrows & Nazario, 2008; Slater, 2008). Experts have well developed knowledge of their content area; as this may influence their teaching practices I hope to identify evidence of the teaching tools utilized to develop the PCK skills needed to become effective teachers.

CHAPTER 2

LITERATURE REVIEW

Pedagogical Content Knowledge - History of the Theory

The transformation of subject content knowledge for teaching is at the pinnacle of Lee Shulman's Pedagogical Content Knowledge framework (PCK) and serves as a theoretical lens through which we can view the distinct components of science teacher knowledge (Shulman, 1986; 1987). In 1986, Lee Shulman published his seminal work recognizing three separate professional teacher knowledge bases: pedagogical knowledge, curricular knowledge, and subject matter content knowledge, as a framework for understanding the unique knowledge base needed for quality teaching. Shulman (1986) recognized that there is an additional knowledge base, termed 'the missing paradigm,' which represented a special amalgam between subject matter content, curricular knowledge and pedagogical knowledge that is exclusive to teaching. Teachers must have knowledge about learners, curriculum, instructional strategies and assessment through which they transform their knowledge into effective teaching (Shulman, 1987). Teachers need to understand not only what they teach (subject matter content) but also be able to transform this knowledge to suit a variety of learner types, in multiple flexible methods, metaphors, and demonstrations (Abell et al., 2009; Bullough, 2001; Padilla et al., 2008). Though strong content knowledge stands as a pillar for quality teaching, knowing content is not sufficient for quality teaching of science, or other subject matter (Lee & Luft, 2008; Loughran, Mulhall, & Berry, 2004). PCK, therefore, represents a specialized knowledge base that distinguishes teachers from subject matter specialists, and focuses on how teachers transform content, pedagogical and curricular knowledge into viable instructional knowledge (Ball & Bass, 2000; Gess-Newsome, 1999; Kapyla, Heikkien, & Asunta, 2009).

Shulman (1986, 1987) was following in the theoretical footsteps of educational scholars such as Dewey (1904), Fenstermacher (1978), and Schwab (1983), when he proposed to understand what qualities, skills, and traits, represent a skilled teacher. Among the multiple knowledge bases that teachers draw from (content, general pedagogy, curricular knowledge, knowledge of learner characteristics' educational contexts), Shulman (1987) focused on a special blending of content and pedagogy. This special knowledge utilized by teachers focuses on an understanding of how particular topics and problems are organized, represented and presented for instruction. Science teachers must have knowledge about science learners, curriculum, instructional strategies, and assessment, as well as the ability to transform strong content knowledge into usable effective teaching knowledge (Abell et al., 2009). It is these characteristics that distinguish a content specialist from a pedagogue. This special amalgam of pedagogy and content makes teachers different than other scholars in the field (Shulman, 1987).

PCK: Defined and Redefined

It has been two and a half decades since Shulman's presidential address (1986) and the related *Harvard Education Review* article (1987). According to Ball, Hoover-Thames and Phelps (2008) these two works have been cited no less than 50 times each year since 1990, appearing in 125 different journals ranging from law to nursing to business. Many researchers have redefined, added to and interpreted the academic construct of PCK. Grossman (1990) re-categorized the three main original components into four sets of knowledge: curriculum, students, instructional strategies, and the learning context. He indicated that it is not the separate components that lead to effective teaching but the integration of them all. Grossman's (1990) work also expands on the three initial knowledge bases of PCK to include teachers' beliefs into each component. An example of this expansion is Grossman's (1990) subdivision of subject matter knowledge redefined to include substantive knowledge and beliefs about that knowledge. Wilson and Wineberg (1988) looked at teachers' specific disciplinary background and how this influenced their representations of historical knowledge when teaching social studies. Ball (2000) focused on determining the knowledge needed about mathematics for teaching rather than the knowledge of mathematics. Ball et al. (2008) focused their attention on the role of prior knowledge in learning and misconception formation. Their research generated a line of research illuminating the knowledge teachers need to know about students' background and the special ways in which teaching demands a simultaneous integration of key ideas in the content with ways in which students apprehend them. Ball et al. (2008) sought to delineate the components of PCK into greater detail. They demarcated subject matter content into common content (used in settings other than teaching), horizon content (awareness of how topics are related to other curriculum) and specialized content (unique to teaching). Ball et al. (2008) used mathematical teaching as their content area and subdivided Schulman's content knowledge into specialized content knowledge (unique to teaching), and common content knowledge (used in settings other than teaching). The distinction illuminates the necessary unpacking of math content for teaching that is not needed and may be undesirable in settings other than the classroom. Ball et al. (2008) define two empirically detectable sub-domains of PCK as well as a less recognized domain of content knowledge for teaching that they postulate is essential for effective teaching – specialized content knowledge. This distinction is a valued addition to the understanding of the complex content construct, and may serve to illuminate the necessary components of subject matter content needed for teaching. I intend to use the Ball et al. (2008) definition of subject matter knowledge when considering content experts' deconstruction of subject material.

Magnusson, Krajcik, and Borko (1999) incorporated a teacher's unique perspective into the development of PCK, by relating that teacher knowledge is filtered through individual orientations toward science knowledge and teaching. Their individualistic orientation toward PCK development made it contextual and individualistic. While the incorporation of an overly contextualized view of PCK development may make generalizability difficult across content areas, Magnusson et al.'s (1999) research focuses on determining an individual's science perspective when determining teaching strategies. Magnusson et al.'s, (1999) and Grossman's (1990) views are also in alignment with Ennis (1994) who suggests that teachers' beliefs about their subject matter influence how they represent the material, which components to focus on and how to engage the students. When the transmission of knowledge is the main purpose of teaching, explanations, enriching details and student centered construction of knowledge diminish; therefore, an individual's beliefs about the nature of science and how science is to be learned greatly influences the development of PCK (Ennis, 1994).

In the educational discourse community, PCK is recognized as an academic construct and is used as a way to understand the complex relationship between teaching and content (Ball, 2000; Bullough, 2001; Loughran et al., 2008; Nilsson, 2008). Van Driel et al. (1998) have contributed to the current discourse and redefinition of PCK by distinguishing professional content or craft knowledge from that of knowledge needed for teaching. They state that craft knowledge is used to guide teachers' classroom actions, making it knowledge in action rather than static content. The recognition of PCK as an individual, fluid and dynamic habit of mind rather than a fixed body of knowledge that can be developed through reflection, application and training may enable researchers to identify key components (Fernandez-Balboa & Stiehl, 1995). Magnusson et al. (1999) posit the position that all components of PCK function as a whole and must be fully developed together. This creates questions about the traditional teacher training programs that demarcate subject learning from pedagogical course work. This division also appears to strongly influence faculty as they are rarely schooled in any pedagogical techniques prior to teaching.

PCK represents the skill and knowledge base that enable teachers to translate complex ideas into concepts that students can grasp. While reciting factual details may lead to high test scores, the teaching of abstract concepts and deeper analytical skills requires more flexible content knowledge to be merged with knowledge of students as learners. Wilson, Shulman and Richert (1987) indicate that having explicit content knowledge enables teachers to better explain, choose important details and content order, as well as generating meaningful metaphors and representations. Most beginning teachers and content experts have recitational knowledge, but need to have an epistemological knowledge about how the nature of work in that discipline is carried out. This specific content knowledge is unique to teaching and represents a kind of subject specific professional knowledge that bridges content and the practice of teaching (Loewenberg-Ball et al., 2008). Hill, Schilling, and Ball (2004), attempted to develop a measure to determine the content knowledge needed for teaching mathematics and how the components of this knowledge developed. They concluded that several domains of knowledge exist and that knowledge for teaching mathematics exceeds basic content knowledge of mathematics. In science, disciplinary courses have the tendency to be oriented toward knowledge and methods for doing science, and not toward the teaching of science, leaving those who teach with the task of merging content with teaching practices (Loewenberg-Ball et al., 2008). Teachers have the sophisticated task of unpacking the complexity of difficult content and incorporating it into usable classroom teaching, this represents a unique body of knowledge specialized for teaching (Borko et al., 1992; James & McCormick, 2009). Teachers need to be cognizant of the unique subject matter knowledge that is needed to facilitate classroom learning, known as PCK, and understand the development of this knowledge base.

PCK is defined in many different ways, often to conform to the research context, including the emphasizing of one or more components. Much of the literature agrees that content knowledge is the strongest component needed for the proper development of

PCK (Grossman, 1990; Grossman & Richert, 1988; Magnusson, Krajcik, & Borko, 1999; van Driel et al., 1998). In my attempts to illuminate the development of PCK, I have chosen a population (University faculty) with whom strong content knowledge is granted. I am, therefore, removing one of the most commonly cited restrictions to PCK development in the hopes of understanding the content transformation process.

Measurements of PCK

Since the articulation and identification of the professional knowledge base held by teachers, many have conducted research with the intent of measuring the amount of PCK present in an individual. Recently, Loughran, Mulhall and Berry (2004, 2008) developed an approach to capturing and portraying the nature of PCK, as well as a method to explicate expert teachers' PCK through reflection of teaching practice. They developed an aid to identification of science teachers' PCK that they termed content representation CoRes (particular science content) and pedagogical and professional-experience repertoires - PaP-eRs (teaching practice). Loughran et al.'s (2008) measure represents an attempt to provide a framework for the translation of content into a developed lesson. Their framework was meant to act as a tool for preparing lessons and in doing so illuminates some of the possible pathways by which content is transformed. An outcome of the development of their CoRes and PaP-eRs tool was greater PCK development and insight into the value of the practice of reflection on PCK development. The practice of reflection upon teaching will be incorporated in this study, though not through the use of Loughran et al.'s (2008) CoRes and PaP-eRs tool. Rohaan, Taconis and Jochems (2011) also attempt to measure PCK as it relates to a crucial and distinct domain of teacher knowledge. They identified several underlying components related to technology education: knowledge of pupils' concepts of technology, knowledge of their pre and misconceptions relating to the subject, knowledge of the nature and purpose of this type of content in education, and knowledge of pedagogical approaches and teaching strategies. Rohaan et al. (2011) used multiple choice, structured and semi-structured interviews or stimulated recall for interviews, observations and a reflective journal in order to test for latent factors underlying PCK's presence. Their results indicate that PCK is intrinsic and obscured by multiple factors. Therefore, attempts to illuminate its presence must be preceded by a clearer understanding of its development. It is this thread of research to which this research project hopes to contribute.

Measurement of PCK has proved problematic, as the processes behind preparatory and active teaching choices are often tacit and not expressly verbalized. Faculty are often not cognizant of the specific educational pedagogy involved in lesson development, especially those untrained in the discourse of pedagogy. The specific paths are not always entirely expressed through behavior either, as many teaching decisions and the options that are discarded are not observed (Baxter & Lederman, 1999). Therefore, measuring the myriad of discarded, unconscious and chosen options for any particular lesson has proven difficult. Individuals' beliefs about the position and purpose of their subject matter greatly influence pedagogical teaching choices (Baxter & Lederman, 1999). The attempts to measure PCK in the classroom are time consuming and labor intensive with limited comparable components; no one measurement or test stands as a standard at this time. I agree with Abell (2008), Hill, Schilling and Ball

(2004), Kapyla et al., (2009), Loughran, Mulhall and Berry (2008), and Nilsson (2008), Rohaan, Taconis and Joechem (2009) that the outward measurement is not truly clear until we can determine the paths through which it develops.

Components of PCK

The mastery of content represented by the acquisition of a Ph. D. in a particular subject matter acts as the standard for university faculty. However, faculty agree that their knowledge changes and is temporal, especially when working with students who are still trying to create their own knowledge (Weingarten, 2010). As teaching scientists faculty are faced with the necessary modification of expert content to incorporate the changing knowledge about students, numerous instructional strategies, teaching content, and eventual identification of one's teaching purpose **(**Fernandez-Balboa & Stiehl, 1995). Though PCK as an academic construct has many components, of the agreed upon components knowledge of students is central and contains many subdivisions. Effective teachers use this knowledge to alter their instruction in an effort to create a more efficient and effective learning environment. The recognition that students learn differently than oneself and therefore our own individual path of learning may not be the best teaching path is often cited as the beginning of the development of PCK.

Knowledge of instructional strategies is another component of PCK which involves:

- having concrete instructional strategies;
- a deep understanding of the implications of these strategies;
- creating a positive and effective learning environment;

- using diverse delivery systems;
- teaching important terminology first;
- questioning students;
- modeling;
- role playing;
- implementing alternative strategies to enhance understanding and motivation;
- assigning specific tasks in class;
- organizing students into groups;
- allowing students to have input into class activities;
- assigning tasks outside of class;
- creating an environment in the classroom that is fun and exciting;
- making students comfortable and safe;
- being reflective and thought provoking;
- implementing alternative instructional strategies in response to students' knowledge;
- carefully monitoring students understanding and motivation;
- continuously performing summative assessments;
- altering teaching plans as lessons change, ranging from repeating, paraphrasing, summarizing, starting all over, and re-examining assumptions about the student's knowledge (Abell, et al., 2009; Bain, 2004; Burrows & Nazario, 2008; Druger, 1997; Gonzalez-Espada, 2009; Kind & Traber, 2005; Magnusson et al., 1999; Nelson, 2008).

Ball (1988), Borko et al. (1992), and Morris, Heibert, and Spitzer, (2009) conducted lines of research focusing on the foundational component of subject matter content for effective teaching. This is in part where this study begins with the acceptance that content knowledge is foundational. As faculty are assumed experts in their content area there can be no greater knowledge base. With this component serving as the base I seek to remove it from the components of PCK development and focus on how this content is transformed. It is widely recognized that expert content knowledge is necessary but not sufficient for excellent teaching. Part of the value of identifying science based university level PCK development is in the bridging of academic disciplinary knowledge and the practical world of teaching, as well as shining a light on teaching in a research focused environment.

The academic construct of PCK is comprised of several powerful components (Abell et al., 2009), yet each individual component must be attended to for novice teachers to ultimately integrate them. PCK is not knowledge of content, knowledge of pedagogy, and knowledge of curriculum separately, but the unique amalgam among them. Many researchers specialize in a single subject or component of PCK resulting in parallel and/or independent strands. For the purpose of this study I will use the much agreed upon definition of PCK which includes the knowledge of students' learning difficulties, conceptions and misconceptions and the knowledge for representing specific topics both of which were conceptualized by Shulman (1986) and van Driel et al., (1998). I seek to understand where in the journey from content expert to university professor does this skill set develop. Research on PCK development is valuable for it can provide insight into effective teaching processes that can span from pre-service teacher training to university faculty.

CHAPTER 3

METHODOLOGY

Pilot Study – Sample

A pilot study was conducted at a small (approximately 5,000 students) urban University, in the fall semester of 2011, to further focus the questionnaire measures and to gain insight into the transformation of science content knowledge used for teaching. All measures and questions were chosen directly from the literature with permission form the authors. The pilot study consisted of science faculty from four departments: Biology, Chemistry, Earth and Environmental Studies and Physics. Faculty members were asked to complete a four-part questionnaire consisting of 30 questions. Ten questions collected data on the respondents' background: gender, the number of years teaching, current and previous teaching experience and support. The remaining questions included several five-point Likert-type questions related to knowledge of students' background, misconceptions, grading and assessment practices; one ranking scale question related the relative importance of various influences on and the tools used to develop teaching; and four open-ended questions related to their lesson development strategies, choice of content and alteration of content material (Appendix B). Sixteen surveys were distributed and fourteen returned (87.5% response rate). The piloted University's science faculty consists of 10 males and four females; all are tenured. The sample faculty have a mean of 23.13 years teaching experience (SD 14.3 years), and an average of 29 years since obtaining their Ph.D.'s (SD 9.5 years). Table 3.1 includes a chart with additional descriptive information relating to the pilot sample.

Table 3.1

Demographics of Pilot Sample Faculty

Question	Percent answered Yes
Obtained Ph.D. with the intention of entering academia	46%
Taught in some capacity during doctorate years	46%
Received specific training related to teaching	23%
Consider self as a Teacher not Researcher	69%

Analysis of Pilot Sample

Demographic Information to Questions Relating Teacher Knowledge of Students and Teaching Practices

Correlation analysis relating demographic information to knowledge of students and teaching practices, using the 15 five-point Likert scale questions, revealed the following statistically significant results. Of the 15 questions, 10 statistically significant correlations emerged. The results can be seen in Table 3.2. As a result of the data obtained in the pilot study changes were made to the questionnaire that reflect a more streamlined and organized set of questions along with subtle rephrasing. The open-ended questions were modified in order to attempt to obtain greater detail and specific teaching insights. Follow-up interviews were also conducted in the study with this experience informing the interview question section of the main study.

Table 3.2

Demographics of Faculty and Teaching Correlation

Demographics of Faculty and Teaching	**Pearson Correlation**	**Sig (2-tailed) p=0.05**
Greater number of years teaching and looking at content material from a students' view	-0.559	0.047
Greater number of years teaching and confidence in ability to teach successfully	-0.557	0.048
Greater number of years since obtaining Ph.D. and looking at content from a students' view	-0.759	0.003
Greater number of years since obtaining Ph.D. and belief that students have great difficulty learning basic concepts	0.629	0.021
Greater number of years since obtaining Ph.D. and belief that students are disconnected from content material	0.565	0.044
Entered academia with the intent to teach and reducing the depth of material over the years of teaching	0.676	0.011
Faculty who have taught at other institutions and belief that students have great difficulty learning basic concepts	-0.507	0.077
Faculty who have taught at other institutions and a belief that students have misconceptions that are difficult to change	-0.621	0.025
Faculty who have taught at other institutions and a belief that students do not commit enough time to their course	-0.537	0.059
Faculty who have received training in teaching and grading of all assignments and tests themselves	-0.704	0.007

Overall Percentages of Faculty Related to Knowledge of Students and Teaching Practices

The fifteen, 5-point Likert scale questions yielded several conflicting results when compared to correlations with demographic information. For example, nearly 77% of the faculty agreed or strongly agreed that they looked at content material from a student's view; the demographic analysis revealed a negative correlation between faculty with a greater number of years teaching and looking at content from a student's view. While it is possible that the nearly 8% that disagreed to strongly disagreed had the greatest number of years teaching, further distinctions with the number of years teaching, is warranted.

Table 3.3

Teacher Knowledge of Students and Teaching Practices

Question	**Percent disagree/strongly disagree**	**Percent agree/strongly agree**
I look at my content material from a student's view	7.7%	76.9%
Limited time constraints influence my choice of content material	7.7%	76.9%
I am confident in my ability to teach successfully	0%	84.7%
I have reduced the depth of content material over the years	23.1%	69.3%
I have received instruction in student learning styles or how people learn	30.8%	61.6%
At the end of a subject unit, I reflect with intension to modify future sections	0%	76.9%
Students have great difficulty learning the basic concepts of my course	15.4%	38.5%
Students are disconnected from my content material	38.5%	30.8%
Students have misconceptions that are difficult to change	15.4%	53.9%
Students do not commit enough time to my course	0%	100%
I grade all assignments/tests myself	7.7%	92.3%
I often modify a class after grading an assignment/test	7.7%	38.5%
I use the textbook as a guide to content order	15.4%	84.6%
I learn a lot about how to teach from listening to my student's questions	0%	77%
I teach this course the way it was taught to me	46.2%	15.4%

Ranking Scale of Strategies used to transform Subject Knowledge

A ranking scale question (1 most important – 10 least important) relating to the strategies and tools used by faculty to develop and transform their subject knowledge into teaching lessons yielded the following results. The resources used by university faculty, as well as the resources dismissed unimportant indicate a source of tools employed in the transformation process of scientific content. As faculty members rarely have formal pedagogical training, the acquisition of teaching methods for the development of PCK is unique. Teaching insights are gained primarily from textbooks, the internet, and from colleagues while education literature and personal student notes are dismissed. I believe this to be a starting point in exploring the beginning stages of PCK development.

Table 3.4

Ranking Scale of Strategies used to transform Subject Knowledge

Strategy Used in Transforming Content Material into Teaching Material	**Ranking 1(highest) - 10 (lowest)**	**Percentage With Top Or Bottom Rank**	**Mean**
Making notes from the textbook	1st	6 out of 13 ranked this strategy as 1^{st} or 2nd	3.38
Asking colleagues	3rd		4.46
Searching the internet	2nd		4.08
Reading science/math education research	8th		6.77
Reading misconception literature	10th	8 of 13 ranked this strategy 9^{th} or 10^{th}	7.92
Reading textbooks	4th	6 of 13 ranked this strategy 1^{st} or 2^{nd}	4.62
Grading exam papers	5th		4.92
Grading homework	6th		5.85
Using information from university sessions	7th		6.62
Using notes from your own schooling of the same subject	9th	7of 13 ranked this strategy 9^{th} or 10^{th}	7.69

Open-ended Question Relating to Teaching Challenges and Lesson Planning

Four open-ended questions relating to teaching challenges and lesson planning yielded insights into the development and transformation of content. Most respondents provided very brief answers. The results were categorized into generalized statements by myself and two committee members independently and can be seen below in Table 3.5.

Table 3.5

Open-ended Question Results

Question	**Most common response**	**Neutral**	**Least common response**
When thinking about your expert content area, how do you decide what content material to include in your courses?	What material is needed in higher level courses – attempts to be interesting to students – The textbook chosen guides the content and sequence	Basic and useful information	Time available
What difficulties or challenges do you face when deciding what content to include/exclude?	Limited time available – attempts to be interesting and make the material interesting	Will new ideas - teaching methods work in the classroom – limited student background	Lack of student work outside of class – testing material choices
What is the most important factor you consider when planning a lesson or unit?	The need to make the material understandable and interesting	What material is needed in other courses	How much time can be devoted to any section – limited student background knowledge -
What factors distinguish science knowledge of teachers from that of scientists?	Researchers do science with a narrow focus – Teachers focus on communicating and engaging students in the learning process in order to make them want to learn	Teachers are concerned with broader concepts and application	In teaching there is no room for opinions – teaching is visual

Discussion of Statistical Analysis Results

Faculty Demographic and Teaching Correlations and changes made to the Questionnaire

Research indicates that experience is commonly related, but not sufficient for the development of PCK (Berliner, 1986; Borko et al., 1992; Daempfle, 2003; Feldon et al., 2010). It is postulated that as teachers gain experience their focus shifts from a content expert's perspective to a student's perspective (Ball et al., 2008; Fantilli & McDougall, 2009; Wilson, Shulman, & Richert, 1987). The pilot sample faculty with more teaching experience indicated that they looked at content material from a student's perspective, less often. And also indicated a lack of confidence in their ability to teach successfully. This component disagrees with the general literature and indicates that a disconnect develops between faculty and students as a result of a significant number of years teaching. Though my pilot sample was small (n = 14) and faculty had an average of 23 years of teaching experience, I was unable to determine when more experience leads to a lack of student connection and a lack of confidence. Expert blind spot theory suggests that content experts have difficulty viewing knowledge from a novice's perspective (Feldon et al., 2010; Livingston & Borko, 2010; Nathan & Petrosino, 2003, Parikh, 2011). This theory would indicate that it is not a loss of connection associated with a greater number of years teaching, but the vast gap between experts (faculty) and students (novices). I will attempt to explore the connection between experience and confidence in teaching as contributing factors to PCK development in this study, as I believe this speaks directly to my research questions.

The results also indicated that faculty with a greater number of years since obtaining a Ph.D. were less likely to look at their content from a student's perspective. This component correlates to a greater number of years teaching and indicates a level of disconnect between faculty and students. These faculty were also more likely to believe that students have great difficulty learning basic concepts and are disconnected from their content material, further supporting the disconnected view. The small sample size and average 29 years since receiving a Ph.D. may contribute to limited insight into when during a teaching career these beliefs manifest. In the study, I attempted to determine if a change in belief is correlated to a specific number of years of experience teaching, and if any particular activities or events trigger this change.

Faculty members that taught at other institutions were less likely to believe that students had difficulty learning basic concepts or had misconceptions that were difficult to change. They also believed that students committed enough time to their course. Experience teaching at other universities, with different student population characteristics may help facilitate the shift in focus to a student centered perspective. Working with a varied student population may provide faculty with the necessary insight that content material may remain stable, but students learn differently. Faculty who had taught at other universities seem to be more insightful about students as individuals and more aware that they may have misconceptions and difficulties with content material.

Much of the PCK literature indicates that faculty learn about students understanding from analyzing answers and determining the source of errors (Abell et al., 2009; Bain, 2004; Ball, 2000; Rubin, 1989). Faculty with no pedagogical training may be unaware of the importance of this source of student knowledge. The pilot sample indicated that faculty members who reported receiving training in teaching were less likely to grade all tests and assignments themselves. This result seems counter to the literature research relating to successful teaching practices. In the study I attempted to determine if and when a faculty member begins or ceases grading assignments and the relative importance they place on this critical factor. On average the grading of exams and assignments ranked 5th and 6th in relative importance for faculty when designing lessons as reported in the ranking question.   Though the educational literature indicates grading as an important source of student understanding, the faculty of the piloted study does not seem to avail themselves of this insight, nor consider its value.

The faculty who reported obtaining their degrees with the intent to teach reported that they have reduced their content material over their years of teaching. I hope to further explore this correlation to determine the reasons for the reduction.

Percentages of Faculty Related to Knowledge of Students and Teaching Practices and the Resulting changes made to the Questionnaire

The data presented in Table 3.3 seem to indicate that faculty agree or strongly agree that they (a) look at their content material from a student's perspective; (b) are concerned with limited time constraints; (c) are confident in their ability to teach; (d) grade their own assignments; (e) reflect on teaching; (f) learn about their students from listening to their questions; (g) use the textbook as a guide; and (h) feel that students do not commit enough time to their course. However, much of the demographic correlations conflict with these findings. Faculty disagreed or strongly disagreed with the statement that they teach courses as they were taught, and that students are disconnected from their content material. In the main study I attempted to further refine the links between the number of years of teaching and the factors that contribute to the content transformation process, as the small sample size and limited range of experiences may have contributed to the apparent conflict in results.

As a result of the insights from the pilot study the number of 5-point Likert scale teacher knowledge of students and teaching practices questions was reduced from fifteen to ten. The remaining questions focused on faculty members' views of students as they relate to content material. The paradigm shift from content expert to teacher and when and which factors contribute to an understanding of students and how they learn remained the focus of this study. The data indicate that the chosen textbook, confidence in teaching abilities, a lack of awareness of misconceptions, and reflection on teaching with the intent to modify future sections drive many teaching goals. Further exploration of book adoption choices and how teachers are reflecting were added to the additional interview portion. No official individual interviews occurred with the piloted sample, and I believe that this portion of the study will yield more detailed insights, thus shedding light on the content transformation process.

Results also indicated the faculty are concerned that students do not commit enough time to a course and are disconnected. The awareness of this lack of time indicates that teachers are aware of potential student problems. To further explore what teachers do with this type of information as it relates to content modification, I inquired during the interview portion of the main study.

The Ranking Scale of Strategies used to transform Subject Knowledge

From the single ranking of teaching strategies question, it seems that the textbook and internet use, as well as colleagues, are the most valued sources of knowledge concerning developing lessons. While reading educational literature on misconceptions, one's own schooling notes and science education research literature ranked the lowest in strategies used by science faculty when developing and transforming content knowledge into teaching knowledge. Science education researcher's results appear to be limited in reaching and connecting with science educators at the University level.   Grading of student exams and assignments appears to influence teaching material but in a non-dominant or dismissive manner, as they ranked 5^{th} and 6^{th} in importance.

The results of the relative importance of textbooks, the internet and colleagues on developing teaching strategies influenced my decision to include questions relating to how and what manner these tools are used in transforming content material. The reasons for the lack of value in science education literature by faculty were explored in the main study. What barriers prevent specialists in science education research from reaching science teachers? Are faculty members unaware of the research or do they dismiss its importance or connection to their teaching? While much of the current PCK literature indicates that looking at content from a student's perspective and the insights gained from grading are necessary components that aids in the development of teaching skills, these factors appears to fall in the middle ground of importance when developing teaching strategies. As a result of their importance in the literature, I continued to explore in greater detail how faculty identify student knowledge and lack of understanding and the role that student difficulties have in teaching.

Open-ended Questions Relating to Teaching Challenges and Lesson Planning

As a direct result of the brief open ended responses received during the pilot study, I modified the open-ended section to a single broad question requesting the volunteer faculty members to think back on their teaching and describe how and why it has changed over the years. I also requested an interview with willing participants in which I further probed into the strategies and factors that have been used to transform their content knowledge into teaching knowledge. It appears from the piloted survey data that faculty rely heavily on the chosen textbook for teaching scope and depth, as well as colleagues and the internet. I explored how they choose a text and when and why they would deviate from its order or depth. Also the lack of use of scientific education research was further explored to determine why it is regarded as relatively unimportant for developing teaching strategies.

Data Collection Procedures for the Main Study

This was a non-experimental design using a questionnaire to determine the techniques, skills, insights and methods science and mathematics expert faculty use when modifying content with the intention to teach. A four-part questionnaire was developed from the existing body of literature relating PCK measurement and development (Appendices B, D). The questionnaire was modified due to the results of the pilot study. The initial eight questions relate to gender, content area taught, when Ph.D. was received, was training in teaching prior to an academic career obtained, and the type and amount of teaching during graduate school. The subsequent 10, five-point Likert-type questions were used to distinguish the level of importance placed on the components of PCK development, such as knowledge of students as learners and reflection on teaching. A ten-part highest to lowest ranking scale sought to determine the relative importance and use of certain aspects of PCK development, such as reading science education literature and grading assignments. Lastly, a single open-ended question concerning influences and modifications to science teaching over their teaching career is included. A request for a brief interview occurs as the last statement. The semi-structured interview questions (Appendix E) seek to examine the transformation process that occurs as a science expert intends to teach. Components from validated surveys were chosen to address the specific research questions of this study. Permission from each author was obtained regarding use of the specific measures.

All questionnaires were confidential and anonymous where subsequent interviews did not occur. Permission to distribute was obtained from each science and mathematics department chair. I was permitted to send a request to complete the survey to each faculty member, as a method of introducing myself and to encourage voluntary participation in the attempt to increase originally low participation numbers.

Most of the literature relating to PCK confirms that strong content knowledge is the foundation to PCK development, without which growth is likely to be restricted (Atay, Kasliosky, & Kurt, 2010; Ball et al., 2008; Borko, Eisenhart, Brown, Underhill, Jones & Agard, 1992; Davis, 2004). This study intended to remove the question of strong content knowledge by using university faculty members who are agreed to be experts in their content fields. All members of the sample have obtained the highest level of content knowledge in their field - a Ph.D. With the vital content component removed as a restriction to PCK development, the goal was to look at the processes of transforming content into teachable material. Though experience is considered necessary for the development of PCK (Park, Jang, Chen, & Jung, 2011), it also appears to be insufficient by itself to develop effective teaching practices (Brownwell & Tanner, 2012). With this variant in mind I analyzed the sample by three levels of experience: one to four years (early stage), five to eighteen years (mature stage) and over eighteen years (advanced stage). These three stages represent demarcations within an academic career relating to experience in teaching. I also analyzed the sample on the basis of gender, status at the university, particular department and the self-reported view as a researcher or teacher, and whether the participant faculty received prior training in teaching. This study focused on university science and mathematics content experts' path while they transform their unique subject matter into usable knowledge for teaching, how this process develops, what role experience, knowledge of students as learners, status at the university, and meta-cognitive actions play in its development.

Sample - Participant Access

Due to differences in departmental hierarchy and access to faculty, each department chose to distribute and request voluntary participation by different methods. Two departments requested to distribute hard copies to each member via the department assistants after full consent and support was given by the department chair. A brief opening letter and a statement of purpose for the study was included with the survey request. Several follow-up electronic requests were made to encourage participation. All participation was voluntary and anonymous. A folder for returned questionnaires remained in the possession of the department assistant. One department elected to distribute hard copies to each of its faculty members at a staff meeting with returns to the department assistant. An interested faculty member in one department elected to distribute questionnaires to as many faculty members as possible as well as collect returns. The final department chose to distribute electronic copies via a previous chair and current senior faculty member. He collected and returned to me all submitted surveys. Several reminder requests were sent electronically. In three departments specific faculty were sent personal requests both hard copy and electronic as their names came to my attention as faculty who either had many years of teaching experience, were new to teaching, or were of a specific gender. This is a sample of purpose and may not fully represent the gender or experience level distribution of each Science or Mathematics department.

Demographic Data of the Sample

A study was conducted at a medium sized, approximately 35,000 student, urban University, from the summer of 2012 through the summer of 2013 after a pilot study was conducted at a different smaller, 5000 student, urban University in the Fall of 2011 and Spring of 2012. Science and Mathematics faculty from five departments, Biology, Chemistry, Earth and Environmental Sciences, Mathematics and Physics were asked to complete a four-part questionnaire consisting of twenty-four questions. Seven questions related to gender, years teaching, current and previous teaching experience and support;

twelve 5-point Likert-type questions related to knowledge of students' background, misconceptions, grading and assessment practices; one ranking scale question related the relative importance of various influences and tools used to develop teaching strategies; and three open-ended questions related to influential factors and events that have remained stable and changed over their years of teaching (Appendix D.). All participants were asked if they would allow a follow-up interview. Seventy-two content experts, defined as having obtained a Ph.D. in their science or mathematics field, completed and returned the survey and served as the sample for the study. Of the seventy-two completed surveys, twenty-two faculty members agreed to a follow-up interview. Twenty interviews were conducted. One faculty member left the university and the other rescinded their consent for an interview.

As the existence of strong content knowledge is agreed to be one of the major limitations in PCK development, this population was chosen in order to remove the limited content knowledge component. The questionnaire focused on the development of the transformation process of content with the intent to teach. Specifically, how and when does the meta-cognitive process of transforming content from an instructor's perspective to a student's perspective occur? What factors contribute to this transformation?

CHAPTER 4

MAJOR STUDY - RESULTS OF THE QUESTIONNAIRE

Chapter 4 is divided into three sections. Section 1 presents the demographic data on the sample of science and mathematics instructors who completed the survey. Section 2 presents quantitative data from the questionnaire which is included in Appendix G Section 3 presents an analysis of the instructors' responses to the three open-ended questions contained at the end of the questionnaire. Data from the interviews can be found in chapter 5.

Section 1. Demographic Data of the Sample

Descriptive data on the 72 instructors who participated in the study are presented in Tables 4.1 to 4.5.

Table 4.1

Academic Department and Gender Characteristics of the Sample

Department	Total number	Percent of sample
Biology	18	25
Chemistry	16	22
Earth & Environmental Science & Physics	17	24
Mathematics	21	29
Male	48	67
Female	24	33
Total	72	

Table 4.2

Demographics Relating to Career Intent and Training

Career and Teaching intent	**Yes**	**No**
Intent to enter an academic career	81%	19%
Received training in teaching	54%	46%
Agreed/Strongly agreed Training impacted their teaching	49%	51%
Taught while obtaining degree	83%	17%

As shown in Table 4.2, instructors overwhelmingly viewed academic positions as their intended career path; however, only half received training in teaching methodology prior to their academic job placement. A question concerning the faculty members' self-reported view of their primary responsibility at the university was asked, as well as their teaching status as a faculty member. The distribution of their responsibilities and status is seen in Table 4.3.

Table 4.3

Distribution of Sample based on Primary Responsibility and Teaching Status

Self-reported consideration of primary academic responsibility		
Researcher	Teacher	Both equally
12.5%	41.7%	45.8%
Teaching Status at the University		
Adjunct	NTT	T/TT
20.8%	33.3%	45.9%

As shown in Table 4.3, approximately the same percentage of the sample considered themselves teachers or both teacher and researcher. The relationship between self-reported responsibility and teaching status is presented in Table 4.4.

Table 4.4

Perceived Responsibility and Teaching Status

Status	Researcher	Teacher	Both
Adjunct	3	7	5
NTT	1	18	5
Tenure Track/Tenured	5	5	33

The distribution of the total sample by years of teaching experience and by department is presented below in Table 4.5.

Table 4.5

Years Teaching and Years since Received PhD of Sample Faculty

Years teaching at University	N	Range	Mean
Total	72	1-53	14.36
Biology	17	3-38	10.56
Chemistry	16	1-47	15.34
EES-Physics	18	1-35	15.38
Mathematics	21	1-53	16.05
Years since received PhD	**N**	**Range**	**Mean**
Total	72	1-52	26.46
Biology	17	1-43	17.44
Chemistry	16	2-50	19.81
EES-Physics	18	1-41	22.29
Mathematics	21	3-52	20.71

Section 2 - Quantitative Data from the Questionnaire

As a reminder, the first research question for the study was: How do science and mathematics content experts (i.e. instructors with a Ph.D.) develop, expand and modify PCK for teaching in a university setting. To answer this question, the responses of the entire sample of 72 science and mathematics instructors were analyzed. The ten, 5-point

Likert-type scale questions were regrouped into three subcategories: “Strongly Agreed” and “Agreed” were combined into one group; “Neutral” remained separate; and “Disagree” and “Strongly Disagree” were combined into one group. The ten questions were subdivided into two subgroups - the first reflecting specific knowledge of students and confidence levels in teaching and the second representing teaching behaviors exhibited by the faculty. The frequency data for the instructors’ responses are presented below in Tables 4.6 and 4.7.

Table 4.6

Knowledge of Students and Teaching Confidence

Total Sample	**Strongly Agree/Agree**	**Neutral**	**Strongly Disagree/Disagree**	**Mean**
I am confident in my ability to teach successfully	91.7%	8.3%	0.0%	4.40
Students do not commit enough time to my course	63.9%	25.0%	11.1%	3.76
Students have misconceptions that are difficult to change	45.1%	26.8%	28.2%	3.28

Table 4.7

Teaching Behaviors

Question	Strongly Agree/Agree	Neutral	Strongly Disagree/Disagree	Mean
At the end of a subject, I reflect with intent to modify future sessions	81.4%	12.9%	5.7%	4.00
I look at my content material from a student's view	80.6%	8.3%	11.1%	3.97
I use the textbook as a guide to content order	75.0%	14.1%	9.9%	3.85
Limited time constraints influence my choice of content material	73.6%	9.7%	16.7%	3.78
I often modify a class after grading an assignment or test	55.6%	19.4%	25.0%	3.42
I have reduced the depth of content material over the years.	29.1%	26.4%	44.4%	2.83
I teach this course the way it was taught to me	14.1%	25.4%	60.6%	2.37

As shown in Table 4.6, faculty are very confident in their ability to teach successfully (highest mean of 4.40) but have a somewhat negative view of the students they teach (the students do not spend enough time preparing for the course and they have misconceptions that are difficult to change). The data in Table 4.7 show that science and mathematics instructors generally engage in reflective teaching practices with the intent to modify future lessons, believe that they look at their content material from the students' point of view, have time constraints when determining course material, use the textbook to guide content organization, and modify class presentations after grading exams or assignments. On the other hand, the instructors indicate that they have not reduced the depth of the material they teach over the course of their career, nor do they teach the way they themselves were taught (which has the lowest mean 2.37). This last figure is especially interesting as one of the common beliefs about why teachers choose teaching techniques is that they follow the model by which they were instructed and that experience as a student provided sufficient knowledge for teaching. At least for this group of instructors, the perception is that this common belief is not true. Overall, the data in Tables 4.6 and 4.7 present a picture of science and mathematics instructors who state that they are confident of their teaching ability and who use a variety of exemplary teaching techniques. These instructors, however, have a somewhat negative view of their students' motivation and ability.

The second measure was employed to ask about strategies and tools that are utilized by content experts when transforming their expertise into teaching lessons. This measure involved asking the experts to rank order a series of items on a 1 (most important) to 10 (least important) scale. The rankings were analyzed by computing which strategies were given the highest and lowest ranks and these data were then summarized into a 1 – 10 list. The rankings were subdivided into percentages that represented the first, second and third place ranking (most valued), and then a group representing the eighth, ninth and tenth place (lowest) ranking. These ranking are presented in Table 4.8.

Table 4.8

Ranking Scale Tools used to Transform subject Knowledge – Total Sample

Strategy used in transforming content material into teaching material	**Ranking from 1 (highest) to 10 (lowest)**	**Percentage with top (1-3) rank**	**Percentage with bottom (8-10) rank**
Making notes from the textbook	1st	65.7	12.0
Reading textbooks	2nd	57.4	11.8
Grading Homework	3rd	50.9	12.1
Grading Exams	4th	45.6	16.2
Asking colleagues	5th	26.4	20.7
Searching the Internet	6th	22.4	28.4
Using information from university sessions	7th	21.9	40.6
Reading science/math education literature	8th	26.2	47.6
Using notes from your schooling of the same subject	9th	18.5	40.0
Reading misconception literature	10th	12.9	59.8

As shown in Table 4.8 faculty content experts most commonly utilized textbooks and notes from textbooks as the main influence guiding teaching material transformation. This is potentially insightful information as textbooks and textbook companies are so strongly influencing university teaching. Additionally, instructors report that the grading of exams and student work greatly influences their knowledge of students and lesson planning. On the other hand, the instructors report that they do not use information from university sessions (this might refer to the University's Teaching and Learning Center), they do not read science or mathematics education literature, they do not use notes from their own education (which is consistent with the statement above that they do not teach as they were taught), and they do not read misconception literature.

Overall, the data from the questionnaire present the following picture - in general, science and mathematics instructors:

- Are confident in their teaching ability
- Mostly use textbooks to construct their lectures
- Do not believe that the students they teach work hard enough
- Utilize the results from exams and homework to modify the content they deliver
- Do not believe that they teach as they have been taught, and
- Do not read science and mathematics education journals to obtain information on how to teach.

Investigating Patterns in the Results Related to Instructor Characteristics

This section of the chapter will present the answer to the second research question: Do instructor characteristics affect the development, expansion and modification of PCK? The characteristics investigated are: the number of years of teaching; teaching status (tenured/tenure/track/ non-tenure track, or adjunct); self-reported status (researcher, teacher, or both equally); gender; academic department; and, having received prior training in teaching. Each of these instructor characteristics will be reviewed. To decrease the amount of material presented, only statistically significant results will be reported.

Number of Years Teaching

Faculty were divided into three divisions based on their place in a career: new teachers with less than four years' experience (28% of the sample); mature teachers with between five and eighteen years of experience (40% of the sample); and advanced teachers with over eighteen years of experience (32% of the sample). This categorization of teaching level is based on literature that indicates distinct changes and maturation in the first four years of teaching, as well as a decline in attention to new teaching methods when an academic career has progressed passed eighteen years (Good, McCaslin, Tsang, Zhang, Wiley, Rabideu & Bozack, 2006).

A one-way ANOVA was conducted with the three groups as the independent variable and the responses to the Likert questions presented in Tables 4.6 and 4.7 above. None of these analyses was statistically significant. The ranking data were then analyzed by the three group division. These data are presented in Table 4.9.

Table 4.9

Ranking Scale of Strategies used in Transforming Subject Knowledge by Experience

Strategy used in transforming content material into teaching material	**Early**	**Middle**	**Advanced**
Making notes from textbooks	1	1	2
Asking colleagues	6	5	6
Searching the internet	5	6	8
Reading science/math education research	9	7	9
Reading misconception literature	10	10	10
Reading textbooks	2	3	1
Grading exam papers	4	4	4
Grading homework	3	2	3
Using information from university sessions	8	8	5
Using notes from own schooling	7	9	7

Similar to the total sample, textbooks provided the primary tool for faculty members to develop teaching strategies at all three career levels. From Table 4.9 it is evident that this reliance drops slightly as faculty gain significant experience teaching. Grading homework and exams remains the next most important tool for early and late stage faculty, but becomes a primary source of knowledge about students for experienced faculty. Reading science/mathematics literature remains a dismissed tool for faculty as a whole based on level of experience.

Teaching Status

The instructors were divided into three categories based on teaching status at the university: full time, tenured or tenure track faculty with teaching and research obligations (46% of the sample); full time faculty whose primary responsibility is teaching, non-tenure track (33 % of the sample); and part-time faculty with adjunct status (21% of sample). As before, one-way ANOVAs were computed with teaching status as the independent variable and the Likert questions as the dependent variables; none of these analyses was significant. The ranking data for the three types of instructors are presented in Table 4.10.

Table 4.10

Ranking Scale of Strategies used in Transforming Subject Knowledge by Teaching Status

Strategy used in transforming content material into teaching material	**Adjunct**	**NTT**	**Tenure Track**
Making notes from textbooks	3	1	1
Asking colleagues	9	5	5
Searching the internet	5	8	6
Reading science education research	8	7	9
Reading misconception literature	10	10	10
Reading textbooks	2	2	2
Grading exam papers	4	3	4
Grading homework	1	4	3
Using information from university sessions	6	6	8
Using notes from own schooling	7	9	7

The data in Table 4.10 indicate that there are both similarities and differences between the three groups based on their status. All three groups rank reading misconception literature as the least used tool and all rate using notes from their own schooling as low. Adjuncts, however, make more use of homework and less use of textbooks than either of the two groups of full-time faculty. As might be expected adjuncts less typically ask colleagues since they are at the University on a part-time basis.

Self-reported Status

As described above, the sample was divided by their self-reported status as to their beliefs about their primary job responsibility. As before, one-way ANOVAs were computed on the Likert data. There were two significant findings: researchers are less confident in their ability to teach successfully than teachers or those instructors who consider themselves equally researchers and teachers. Second, those who considered themselves either teachers or researchers and teachers equally were more likely to look at their content from a student's point of view. The means by group for these two items are contained in Table 4.11.

Table 4.11

Means for Status on two Significant Questions

Confidence in ability to teach	**Mean**
Researcher	3.67
Teacher	4.50
Both researcher and teacher equally	4.52
Look at content from a students' perspective	
Researcher	3.44
Teacher	3.83
Both researcher and teacher equally	4.24

Because of these two significant results, a multivariate discriminate function analysis was computed on the ten Likert-type questions. There was one significant function (Wilks' Lambda = 0.584; p= 0.033) which differentiated those who consider themselves researchers from the other two groups. The difference between the three groups represents a medium effect size.

The ranking data for self-reported instructor type are presented in Table 4.12.

Table 4.12

Ranking Scale of Strategies used in Transforming Subject Knowledge by Self-Reported Status

Strategy used in transforming content material into teaching material	**Researcher**	**Teacher**	**Both**
Making notes from textbooks	2	4	1
Asking colleagues	3	6	5
Searching the internet	4	7	7
Reading science/math education research	7	8	9
Reading misconception literature	10	10	10
Reading textbooks	1	2	2
Grading exam papers	8	3	4
Grading homework	6	1	3
Using information from university sessions	9	5	6
Using notes from own schooling	5	9	8

The data in Table 4.12 again indicate both similarities and differences between the three groups of instructors based on their status. All three groups rank reading misconception literature as the least used technique and all rate reading science and mathematics education literature as relatively low. Perhaps the most interesting difference is that teachers and researchers/teachers use homework to adjust their teaching to a far greater extent than instructions who consider themselves researchers.

Gender

Though gender differences were not a focus of this study, it was decided to compare males and females in the sample, especially in view of the low percentages of females in science and mathematics disciplines and the recent interest in increasing female representation in all STEM disciplines. Separate samples t-tests comparing males and females on the Likert items found no statistically significant differences. There were also no differences in the ranking data of tools and strategies used when transforming subject knowledge.

Department

Though specific science and mathematics departmental differences were not the focus of this study the data were collected and analyzed to see if any differences existed. The sample was divided into four departmental groups and the Likert data were used to determine if there were any significant differences in the faculty members' knowledge of students or teaching practices (see Tables 4.6 and 4.7). There was one significant difference: Instructors from the Biology department are less confident in their ability to teach successfully as compared to instructors from the other four departments ($F = 6.95$, $p = 0.001$). The effect size, however, was small. Therefore, considering all of the items, there were few differences among the five departments. The ranking data by department are contained in Table 4.13.

Table 4.13

Ranking Scale of Strategies used in Transforming Subject Knowledge by Department

Strategy used in transforming content material into teaching material	**Earth/Envir. Science/Physics**	**Chemistry**	**Biology**	**Math**
Making notes from textbooks	1	1	2	4
Asking colleagues	5	5	5	7
Searching the internet	9	6	6	6
Reading science/math education research	8	8	8	9
Reading misconception literature	10	10	10	10
Reading textbooks	3	2	1	3
Grading exam papers	2	4	4	2
Grading homework	4	3	3	1
Using information from university sessions	7	9	7	5
Using notes from own schooling	6	7	9	8

Although there are more similarities than differences among the departments, it is evident that instructors in the mathematics use textbooks less than instructors from the other three departments and mathematics more commonly use homework as a way of modifying instruction.

Prior Training in Teaching and Other Background Questions

There were several questions on the survey asking the instructors about their background and experience. All seven of the questions were analyzed against the Likert questions. There were three significant correlations which are presented in Table 4.14.

Table 4.14

Correlation Analysis of Total Sample Faculty

Items	Pearson Correlation	Sig (2-tailed)
Teach during the years that instructor acquired doctorate With Confidence in teaching	-0.243	0.039
Receiving training in teaching With students have difficult to change misconceptions	0.289	0.014
Receiving training in teaching With students did not commit enough time to their course	0.234	0.048

As shown in Table 4.14 instructors with teaching experience during graduate school seem to be more aware of student difficulties in the area of misconceptions and levels of work load needed for success in their courses. Interestingly, instructors who taught while obtaining their degree (Ph.D.) were less confident in their ability to teach successfully.

Section 3 - Open-ended questions relating to changes in teaching over time

The survey concluded with three open-ended questions regarding changes made over the years regarding their teaching and what factors or events facilitated these changes. I also asked what factors may have remained stable over their years of teaching. The faculty responses are divided into the three main categories of early years in teaching career (1- 4 years), mature years of teaching (5-18), and advanced teaching years (18+). The responses from this section, in part helped guide many of the interview questions as I was searching for the pathways of their thought processes as they transformed content and the development of knowledge of students and teaching.

The First Open-ended Question. How has your Teaching Changed or Transformed over the Years?

Early

I have included below the many reported statements made by faculty in the early years of teaching regarding their perceptions of how their teaching has changed in the early years. Each of the phrases represents an actual statement made by faculty members. Early teaching career faculty frequently reported that their teaching became more engaging as they endeavored to be more interactive. As experience increased they reported greater levels of confidence, which led them to try new methods of teaching and to incorporate more technology into the classroom. The increased confidence in teaching stemmed from greater awareness and knowledge of their students. This significant knowledge of student issues, difficulties and strengths provided the faculty with the confidence to resolve existing teaching problems. They recognized that students easily lose interest in a lecture style format environment, and began employing interactive teaching techniques to counter this issue.

Faculty comments

- More interactive with students.
- Less lecture more problem solving.
- Try to engage students in active learning rather than traditional lectures.
- Go over examples together with students in class instead of watching me work out problems. More comfortable in front of a class with my own authority.
- More comfortable to make class less formal. Less afraid to modify and retry.
- More willing to hear about incorrect answers.

- I explain every little thing and detail, even basic concepts from middle school.
- Less lecture, more examples in class with emphasis on concepts.
- Can now anticipate student confusion.
- Better able to manage the class, and identify better teaching strategies that fit a particular class or group of students.
- Class is less focused on pure content and more skills needed to function in field.
- More patient and have slowed down lectures.
- More assessments such as pop quizzes in order to gauge the students understanding.
- More powerpoints and less chalkboard talk.
- I try to avoid inconsistency and teach more precisely.
- Use more examples from own field research experience.
- More technology incorporated.

Mature

As faculty moved into more experienced years of teaching their focus shifted from gaining confidence in teaching that stemmed from increased knowledge of students understanding to their ability to focus on improving their teaching techniques to broadening the variety of methods used in the class. At this stage faculty report that they begin expanding the variety of pedagogical techniques employed in the classroom. Their confidence levels continue to be reported as improving as does the incorporation of new technologies into the classroom. More mature faculty report a desire to remain current and incorporate current trends and information from their field into the classroom. Newer faculty did not report this view. Several mature faculty also reported viewing learning as identifying and determining which part of learning is the students' responsibility and making it clear to the students that they are responsible for much of the learning that takes place.

Faculty Comments

- Increased level of confidence in teaching has occurred with experience.
- Experience has allowed me to be much quicker on my feet in terms of fluidity and working on the spot.
- Less reliant on the textbook as a guide.
- I use much more technology and visuals.
- Infuse more current thinking topics.
- Much less ‘talk and chalk’.
- Go at a slower pace, use more graphs, not graphics.
- Show don’t tell guides class structure.
- Reduced the depth of material drastically.
- Add ‘youtube’ demos.
- More technology. Greater use of technology in and out of the classroom.
- More small group work and discussion oriented knowledge leading to critical thinking.
- Involve the class in the learning process more.
- Incorporate guided discovery.
- Spend more time trying to get students to do their job.
- Students need to develop processing skills.
- How information is presented.
- Constantly updating to keep content current.
- Deeper understanding of the subject.
- Exams have gotten easier.
- Use a more conversational Socratic method in class.
- Build a greater rapport with students.
- Put more emphasis on formative assessment.
- Become less attached to my students in order to be more impartial.
- No significant changes because students are satisfied.

Advanced

Faculty in the advanced years of their teaching career frequently reported that they increase the use of technology into their teaching and are still striving to learn about how students understand their content material in order to better teach. The desire to stay current while engaging in less research has shifted their focus to better teaching. They are generally more relaxed and able to focus on students.

Faculty Comments

- Infuse more technology into the classroom.
- Introduce more technology.
- As I gained confidence through experience that I had fully mastered the content material myself I interacted more with the students.
- Pay much more attention to student understanding, not just memorizing.
- More patient. I review more and back-up to make sure that true understanding is occurring. More interactive.
- I am more relaxed.
- More group work, less lecture, more interaction in class.
- Focus more on higher level thinking skills less on writing facts on the board.
- I used to teach as I was taught which contained a lot of factual memorization.
- More inquiry based dialogue.
- Try to adapt content material to student acuity.
- Increase the amount and focus of student-peer teaching.
- Students present some of the information; have them teach, because if they can teach it they know it.
- Comfort level with the fast pace at which material is covered.
- Incorporate more active learning and group activities.
- The introduction of recitation in some courses has greatly improved material coverage. Experience has taught me better organization, better examples, and homework problems.
- Provide more extra help sessions, and use a variety of examples.
- Use extra projects that allow students to focus deeply in a few areas.
- Teach has shifted from just lecturing to more interactive.
- Incorporate more real life application.
- More applied, more computational work.
- I now view topics from many different vantage points.
- I also give more take-home problems.
- Require less content memorization and more understanding of graphs and scientific communication.
- Require more outside reading of scientific literature on the students' part.
- Lowered my expectations.
- More attuned and empathetic toward students.
- Assessment techniques have changed.
- More time spend on teaching and less on research over the later years.
- Research is for the younger set.
- Found better textbooks.

The Second Open-ended Question. What Factors/Events were most influential in changing your Teaching?

Early

Awareness of one's own teaching and the purposeful understanding of teaching methods and pedagogy is the beginning of PCK development. Faculty who are aware of how students learn are looking for the myriad of cues in order to modify lessons and assessments. Faculty may recognize that they have changed their teaching but connecting the change to specific events shows PCK development in the field of student awareness about leaning. Faculty in the early years of their teaching career primarily discovered knowledge of students from direct student interaction and feedback. This led to the greatest awareness of teaching changes. Student feedback both through formal university forms and direct interaction, grading of homework and exams greatly informed my teaching. New teachers also stated that a strong need to teach better motivated change as well as increased confidence brought on by experience. Several newer faculty also expressed support for teaching as a factor that helped bring about change.

Faculty Comments

- Student feedback forms provided information about teaching that helped me change.
- Gauging students understanding or misunderstandings allows me to change lectures, and problem sets.
- Student and peer feedback.
- Figuring out what the students needed.
- Actively working on problems in class together instead of watching me or just grading homework helps the learning process.
- Discover students' level of knowledge and then adapt my teaching accordingly, I discover this level from grading homework and the types of questions asked in class.

- Discovered that the very basic skills are often lacking, therefore I explain all details.
- Desire to deconstruct even the most complex concepts in order for all students to be able to understand.
- Experience let me be more confident and have less stress about teaching.
- Attend teaching workshops.
- Know more teaching strategies.
- Observations from class as to which teaching betters helps them learn and retain.
- Attending the lectures of experienced and excellent professors, I have been able to develop my own methodologies to help students understand the material better.

Mature

Faculty in their mature years of a teaching career continued to express that many of the changes made to their teaching were due to an increased knowledge of students and their understanding as a result of feedback. As with newer teachers they strove to improve their teaching. Many said that the incorporation of new technology lead to teaching changes and as with newer teachers, teacher training sessions was the support that facilitated change.

Faculty Comments

- Learning from the students as to what they find difficult, and common mistakes allows for them to be foreseen and either diverted or addressed more specifically.
- Student feedback and insight from grading and interaction in class has shaped teaching.
- More communication with students outside of class informs my teaching.
- Becoming aware of the variety of skill deficits that students bring to the classroom.
- Better understanding of the students.
- The way students ask questions.
- Dealing with real students teaches you to understand how to explain material in an interesting way.
- The individual interaction with students allows me to see common misconception.
- I use this information to change my lectures.

- Learn and make changes from reading student evaluations.
- Observe students having disinterest in subject, so modified teaching method to incorporate more practical applications.
- If the students have to explain their work they catch many of their own mistakes, this is more powerful than my grading them.
- Recognized just how un and under prepared students are for college level work.
- They have many difficulties with basic skills that hinder more advanced learning.
- Discovering the serious deficiencies that many students come to college with lead me to try to rectify the background limits.
- I am constantly providing remediation.
- When students did not do well in subsequent courses I had to take a look at my grading style and work level.
- The explosion of the known knowledge base and easy access via the internet have led to difficult decisions about content choices.
- Students are very savvy about the internet and its uses, so I need to stay on top of this.
- Graduate courses taught me new methods to teach.
- Teacher training sessions at another university provided alternative teaching methods.

Advanced

As faculty move into a more advanced stage in their teaching career the responses to factors that contribute to teaching change narrowed. Most recognize that knowledge of students from grading assignments and class activities is the main factor contributing to change. A few faculty attribute educational support as an influence.

Faculty Comments

- I recognize now that students do not carry knowledge from previous classes.
- This has caused me to change my teaching, and repeat and review more.
- Getting to know individual students allowed me to realize that they have very diverse backgrounds and aptitudes, this informs my teaching and reminds me to think more broadly.
- Teaching and grading student work as well as communication with colleagues influenced changes to my teaching.
- Grading exams and discussions with colleagues.

- Going over and grading homework and assignments allowed me to see what they and how they erred.
- Working individually with students has made me more attuned to them and their needs.
- Assessments of students allows me to understand their issues and problems more clearly.
- Student complaints would drive some changes.
- Pressure from the college to make class easier and give higher grades for less learning.
- Former students saying thanks.
- Discovering that a one-on- teaching and learning method is the most effective.
- Real life applications seem more meaningful and interesting to the students.
- Joined an education group and learned a tremendous amount from excellent high school teachers on how to teach.
- During a sabbatical learned about science education journals.

Third Open-ended Question. What Factors remained Stable?

Early

Faculty in the early years of their teaching career responded with a wide variety of stable teaching habits. The most common response indicated a passion and commitment to teaching and content as well as a strong desire to make their class interesting for students. This desire was also seen at all levels and places in faculty careers. The desire to provide open and easy access and communication between students and faculty as well as very mixed and strong feelings toward the use of blackboard and powerpoints, instead of whiteboard writing.

Faculty Comments

- Passion for teaching and topic.
- Commitment to teaching and student learning and understanding.
- Desire to make the class as attractive and interesting to students as possible.

- Enthusiasm for subject.
- Desire for every student to be able to understand even the most complex concept, this guides the way I teach.
- Try to give students as much access to me as possible.
- Demand critical thinking from every student.
- Still emphasis hands on work.
- The need for lots of homework for practice.
- To be as approachable as possible, quickly respond to emails.
- Being an advocate for the students, and wanting them to be successful.
- Get to know students by name, and want them to enjoy class.
- Balance powerpoint and blackboard time.
- Still continue with a standard lecture format with content designed to help students accomplish challenging homework.
- I stick to the content in the textbook and try not to digress too much.
- I write at my lectures using a document camera/whiteboard.
- Use whiteboard to teach.
- Will not use powerpoint as I don't believe that they learn science this way.
- Incorporate as much current research as possible.
- Do not use powerpoint, or hand out notes.
- Use whiteboard not powerpoint.
- Learned that reducing expectations does not improve student mastery or retention.
- Lecture is still very didactic with little discussion.
- Basic course content.
- Belief that lecture is how this field is meant to be taught, then followed up with individual practice.
- Kept grading policies stable.
- Use up to date literature in own subject area.
- Link concepts to real life and to represent complicated concepts in simple ways.

Mature

Faculty with five to eighteen years of teaching experience still report their love and passion for teaching and their subject matter as well as a strong desire for strong teaching and learning, as well as a goal to remain interesting. They report a wider variety and a deeper, more complex view of the teaching process and student learning. Desire to stay current and to make students responsible for their education presents itself at this stage as faculty become more aware of students' needs abilities, and deficiencies. Teaching is not simply the transference of expertise to novices but in part the responsibility of the learner. Many faculty become aware of greater curricular constraints such as class size and assessment limitations in the form of large group multiple choice exams, and attempt to modify their teaching in order to accommodate these curricular constraints.

Faculty Comments

- Love of subject leads to enthusiasm for topics.
- Passion for topic.
- Total commitment that learning concepts deeply, not just memorizing facts.
- Enthusiasm for teaching and learning.
- Desire to improve and understand how students learn.
- Try to make subject as real and relevant to real world issues.
- Enjoy teaching.
- My expert knowledge is used to guide and focus the content so that students do not spend time on insignificant topics or details.
- Keep lectures as stimulating and interactive as possible.
- Try to identify interesting topics to the students and focus on them, and show how they apply to their lives.
- Engage students during lecture by having them solve examples during class.
- Maintain high standards of excellence, use a variety of teaching methods, and maintain an orderly classroom.
- As much one on one communication as possible really helps students.
- Incorporate current questions about field to maintain student interest and relevance to their lives. Don't present material as a set of rules or instructions.
- Constantly updating material to stay current.
- Making students responsible for their education.
- Keep content level high.
- Need and attempt to maintain small class sizes.
- Still teach the basics.
- Try to constantly connect previous courses and lay the groundwork for next level course.
- Stress concepts over memorization, use Socratic approach in lectures.
- Avoid multiple choice exams.
- Provide the correct information to guide the students to learn on their own.

- Include my research activities into lectures.
- Assessments are still traditional and individualized.
- A relaxing classroom decor.
- Use many examples, repeat important facts.
- Cumulative testing.

Advanced

Faculty with more than eighteen years of teaching experience still express a passion and enthusiasm for teaching and learning. They are committed to treating students with respect and to make their class interesting and relevant. They understand the role of student work in the learning process, and express a desire to stay current and make connections with individual students.

Faculty Comments

- Being as interactive as possible in a large classroom.
- Enthusiasm for the subject matter.
- Desire to present material in an orderly manner, and create clear presentation.
- Trying to encourage strong study habits.
- Treat students with respect, and recognize that they are individuals with personal lives and issues.
- Commitment to preparing students to move onto next level of life and to become better citizens, to motivate students, and maintain high standards.
- Commitment to content and making content connections to the real world for students.
- Making subject as understandable as possible, in order to do this you must understand the students' perspective.
- Focus and concern for students learning and retaining material content.
- Using effective examples to explain concepts.
- Explain concepts in clear plain language.
- Try to reach each student individually to make sure that they absorb the concepts.
- The students are responsible for the course content, which is immutable.
- High standards and expectations.
- Treating each student the same.
- Being fair in grading.
- I also treat each student as an individual.

- Energize students to try a variety of ways to practice.
- Answer every question in class.
- Remain open to any suggestion in order to improve teaching.
- Lecture is still the most basic mode of teaching, but one must be aware at all times of how well the class is absorbing the concepts.
- Students need to do a lot of homework that is graded and required.
- This homework must also be covered and reviewed in class.
- I expect a lot of homework.
- Staying as up to date as possible with the currents of my field so as to infuse them into my courses.
- Reflect on recent and current development in field.
- Large class sizes with enormously diverse students in terms of prep skills, abilities, motivation. Focus on analytical skills and problem solving.
- Content standards are pretty stable.
- Careful preparation of material for lesson is the most important factor.
- I write out every set to focus on the details, connections, thought and order.
- I am pretty much the same.

Summary Comments

Overall, passion for subject matter and the desire to teach and to teach well remains a primary motivator for faculty of all stages. As faculty mature and gain greater confidence and awareness of students' abilities and deficiencies their teaching pedagogy expands and they are able to incorporate a greater variety of pedagogical skills. They become more in tune to curricular constraints and ways to work within and around them. Their focus shifts to a student centered teaching model, allowing them to transform their content expertise into teachable content.

In summary, the early years of teaching at the faculty level are fraught with insecurities, limited knowledge of students, and a traditional lecture- passive teaching style. As confidence and renewed insights into the broader scope of the discipline as well as a significantly expanded knowledge base of students and learning, teachers are able to develop a student centered classroom environment and attempt to incorporate technology and active learning activities. They are aware of student misconceptions and can teach preemptively to avoid and dispel potential misconceptions from developing. This paradigm shift from a teacher centered view to a student centered view did not always simply occur with time. Grading of assignments and exams, as well as the essential reflective searching allowed for honest shifts in teaching style. Revisiting content with the specific audience in mind and actively searching for tools to teach as the necessary level facilitated a teaching change. Overall, faculty are passionate about their subject matter and wish to transfer and develop that same passion in their students, they care deeply that they learn.

CHAPTER 5

FOLLOW-UP INTERVIEWS

Faculty participating in the survey were asked to voluntarily agree to a follow-up interview. Of the seventy-two surveys completed twenty-three agreed to a follow-up interview (30%). Twenty-one interviews were conducted. One faculty member left the University and one changed their mind. Demographic distinctions can be seen in Table 5.1 below.

Table 5.1

Demographic Distribution of the Interviewed Sample

Demographic	**Number**	**Number**	**Number**
Gender	5 Female	16 Male	
Years Experience	5 early stage	8 mature stage	8 advanced stage
Status	1 Adjunct	9 NTT	11 TT/T
Position	3 Researchers	11 Teachers	7 Both equally

Interviews were scheduled and lasted between thirty-five minutes and 2 hours and thirty minutes. All interviews were recorded with prior permission then transcribed. The interviews were reviewed and decoded yielding 3 major themes relating to the components of teaching: learning to teach, knowledge of students, and research and teaching balance. The three main themes were determined to represent major components in the development of PCK along with the added knowledge base of research, which seems unique to university level teaching. The 3 themes also reflect the main research questions of the study. Several standard interview questions were asked of all faculty (Appendix F). The questions were chosen from the literature with written permission from the authors, and reflect the research questions posed in Chapter 3. Many faculty contributed personal and detailed views of their years of experience, background, joys and frustrations in addition to specifically directed conversations. All names have been changed to pseudonyms to protect confidentiality. The transcribed interviews were reviewed by two additional education experts. An inter-rater reliability of 87% occurred. All discrepancies were discussed and agreed upon. The following represents the data obtained with direct quotes and generalities expressed by the interviewed faculty.

Chapter 5 is subdivided into 3 sections. The first section, learning to teach, reflects the myriad of methods and activities that contribute to the development of pedagogical training for science and mathematics faculty. An outline of the subdivisions within the first theme is presented below to aid the reader.

- **Learning to Teaching**
  - **Training**
    - **Formal**
    - **Informal**
    - **Value of Training**
    - **Teach as Taught**
    - **Positive Role Models**
    - **Teaching as Instinct**
    - **Textbooks Guide Teaching**
  - **Personal Influences on Teaching**
    - **Family Influences**
    - **Confidence in Teaching**
    - **Experience – Initial**
    - **Transitioning Moments**
    - **Reflective**
  - **Tools Used to Modify Content**
    - **Specific Ideas**
    - **Education Literature**
    - **Write-out Lectures**

Section 1. Learning to Teaching

Training

The primary research question that this study sought to look at focused on how content experts developed, expanded and modified PCK. Reflecting on the three components of PCK we looked at how pedagogical skills were developed in a university setting. The topic of prior and current training in teaching as well as the role of modelling current teaching on prior experiences as students was captured in both the survey and followed up interviews. Overall 81 % intended to enter an academic career while obtaining their doctorate; 83% taught during graduate school, with 54% received specific training in teaching. Of this small set 61% strongly disagreed or disagreed that they currently taught their courses as they were taught to them (see chapter 4 for additional details). As can be inferred from the sample, most faculty career goals included the likelihood of teaching, experiences as students seems to be the primary source of teaching knowledge; though frequently as an anti-model (for more detail on teacher training please refer to Chapter 2). Pedagogical training in teaching for science and mathematics experts is rarely incorporated in doctoral level courses (Clayton-Pedersen & Rogers, 2012; Felder, 2012), although most teach as graduate assistants and are aware that teaching is part of most academic positions. Research lines remain the focus of job interviews while teaching skills are minimally considered during the interview process and occur, if at all during the final stages (Hazen and Trefil, 2009; Jones et al., 2004; Samuelowicz & Bain, 2001).

Formal

Faculty members were asked to comment on their experiences as graduate students and the skills learned about teaching as well as to expand upon how they learned to teach and upon what they modelled their current or past teaching. They were asked to expand upon any training that they received prior to or are currently utilizing. The commentary represents direct quotes from faculty members who addressed and responded to questions relating to training in teaching. Although six faculty members addressed this point specifically the four quotes chosen illuminated the main views that formal training prior to obtaining a teaching position did not occur. Nancy reported that she received “nothing, because nothing was offered. You graduate and then go out and teach.” This is a typical response with Susan stating “You want to do research in an academic setting, and teaching is just a part of the job. It is on-the-job training. But nothing formal pedagogically. I trained myself in teaching.” She also states that her training consisted of “We are thrown in with very little mentoring.” Duke states “They simply said go and teach.” Vince adds “No one taught you how to teach, we did not discuss teaching. To me it was and is purely instinct. I have no acquired knowledge. Sometimes you just try something.”

Informal

Formal training in teaching may have been extremely limited, but informal training took many forms. Once an academic post is obtained availability, support for and access to training varied. Four interviewers commented specifically on their unofficial mentor-training experiences learning to teach as graduate assistants and two faculty commented on current collegial support for teaching. Other graduate students would often mentor the younger students as Arnold states,

> There were several older graduate students who had taught and they would help. The senior grad students would watch you and grade you and tell you what you did well. Then the head TA and professor would come to your classroom and sit in on your recitation once a semester to see how things were going and give you some feedback. They prided themselves in a fairly rigorous science education program. I wish some of my colleagues here could be taught how to teach. It was just assumed that when you reach the faculty position you already have been taught how to teach. There are some professors who start as assistant professors who have never really taught before. The first few years are very rough for them, they don't know how to relate to students. They don't know how to gauge the level of explanation for a freshman or sophomore.

Brad states that

> I had to try out to see if you would be a good TA. You actually had to do a thirty minute presentation on a subject matter that they assigned before you started there. You give like a teaching demo.

When I asked from where did he obtain or generate these skills Brad replied,

> From being very observant from my classes in undergraduate, I had a lot of different styles. I TA'd and tutored. Tutoring was the best, because you had good students who could explain what they were stuck on…they had to think about a different way to solve it. I have never been taught (to teach) but I always try to think of the most efficient way to do things ... and boil things down to the simplest point and use analogies. There was a lot of sharing information to your peers and to the younger graduate students. By way of lots of seminars, lots and lots of public speaking, weekly seminars, talking about your work or reviewing a paper or getting up in front of a classroom and trying to teach then. I wouldn't say that it was pedagogy, but it is something that we did. … So there is this bootcamp and it was really very student run, and we did guest lectures.

This experience as a graduate assistant was the most common avenue for teaching experience and first time exposure to the professorial side of learning. Only two faculty members expressed a positive mentoring experience. Pat adds,

> Sometimes I sit in on other lectures. Some people always get really positive ratings. It is not because they are easy and give good grades, they make it fun and interesting. When you look at the class you see people are paying attention, they are engaged. It is not enough for me to be competent, which I prided myself in being competent and teaching accurate information. But that does not make people learn. People have to want to learn. And the only way they want to learn is if it is meaningful to them.

Victor adds, “I would get lots and lots of advice from my colleagues who have taught then I would get the format and the timing. There is an aspect of showmanship. There is a performance. It is a skill that would come.”

Value of Training

Science and mathematics education literature illuminates a severe disconnect between science and math experts who are teaching and the education experts (Davis, Petish, & Smithey, 2006, Dennick, 2012). Of the interviewed faculty that sought educational support, much of the guidance was unrelated to the intended specific course content or course level and therefore unvalued. Pat’s comment illustrated a common view concerning the value obtained from any training received, “The educators who are available for support don’t know what they are doing... horrible. We are not given any tools. They don’t give them any skills, they just go through the motions.” Barry comments on the lack of usefulness of current training sessions at the University. His comments mirror many of the faculty that have voluntarily explored educational training sessions. “It’s all bologna. This ed. stuff is nonsense... maybe it works in grad courses, but not in early lower level.” Morris points out that their department and many of his colleagues do not value the educational side of their discipline.

> When you have a Ph.D. in (your field), you are deficient in education and the language of education. It is then not valued. A few people advocate (subject) instruction and pedagogy, but it is looked at as second rate. There is zero support for education (teaching).

Arnold conquers with this basic view of science education journals and training.

> I have never really been interested in (science) education. I used to subscribe to the journal of (science) education but nothing there really interested me… not that it doesn’t apply, I just don’t feel that it is useful to me. … Science educators are really social scientists and don’t really understand the science anyway.

This comment illuminates much of the divide and disconnect between scientists who teach and science educators, the scientists do not see the educators as having sufficient content to speak their language. Soren offers one of two positive views of educational training. ”I learned the vocabulary of education and now only go to science education conferences, while other faculty are not aware of science education.” Rachel also found training beneficial. ”They were very useful...I became interested in teaching…I appreciate it... I have incorporated cooperative learning when I first heard of it at a university session. So I read about it and learned the method, and tried it and it works. It was and is a lot of work.”

Teach as Taught

Though many faculty have had little to no formal training, and there is a pervasive view that if you have been a student especially one who has advanced into and through the doctoral level you have sufficient experience to be a teacher. Frank comments that being a student for many years was the only teaching preparation received. “By the time I taught my first seminar I had been the recipient of schooling for twenty years. You learn from this. This was my model… Some people learn from negative examples.” This may indicate that we use our teachers as models. One specific line of questioning (see appendix E for the full list) related to the view that we teach as we were taught was introduced during the interviews. Our teachers seem to be our trainers in many ways, both positive and negative. Such as Henry states “I looked at what they did not do (and) I should then do.” Darren comments, “That the first time I gave a lecture …I got my old notes out and copied what someone else had done... I watched someone else do it and gave it my own spin.” Though six faculty members made similar statements Nancy sums up a pervasive view of previous professors as models for current teaching.

> I had terrible professors. I began looking at my professors and began thinking that I could do a way better job… They were self-absorbed, they were researchers, many were downright lazy. They would complain that that was not what they were hired for. This (teaching) was not interesting to them. I remember a lot of negative images. Careless nonchalant presentation of lecture material. Multiple choice exams. No study focus, and all that time I said I would do a better job.

Pat uses her recollections of previous professors to teach better stating,

> They never explained why, they just told us to memorize… it didn't make sense… I didn't know why I was doing most of the stuff. So like my students they are easily lost at the first change because they don't understand why. That is not a way to teach. It would be better to have something engaging, to make science interesting. To find out why people go into science.

Vince states, "My professors, I think they did not care if I learned or understood. It was just blah blah blah… they have to teach and whatever the students make out of it is their problem. I am much more interactive." Though this is the prevalent experience of most faculty members. This path disregards the complex processes of behind-the-scene decisions. Students only see what is presented, not what is considered and dismissed or any of the myriad paths that could have been taken to present information in a timely, organized and cogent manner.

Positive role models

Though not all teachers inadvertently were taught by negative role model. Pat recalls a valuable lesson shown to her by a non-science teacher that she carries into her classroom today.

> She respected us, and she said something that stuck with me my whole career which is that you have to treat your C grade level students with the same respect as you're A level students. Because they are good at different things and need your help more. The idea that you only pay attention to the A students and the other people you consider riff raff just turns them off and they don't get anything out of it. What you should be doing is getting everybody to reach their potential and not be judgmental and convey that you care about them just as much. … Somehow caring about teaching was synonymous with bad research.

Two faculty members recall positive role models. Brad states,

> A lot of it I think is from being very observant from my classes in undergraduate, I had a lot of different and great styles to work from. One of my professors won a best teacher in the country award from the White House… He was very interactive inside and outside the class, he was very organized. And I then had all ends of the spectrum in between and I pick on what I liked and what I learned best from.

Derrick had wonderful teaching role models as he illustrates,

> I think I was blessed with excellent teachers. They were all good. They were enthusiastic about their subject, orderly and precise in their presentations. My freshman prof at (SCHOOL) was the classic college prof, he had a bow tie with tweed patches on his jacket. And he had curious mannerisms. He started at one end and filled the board. I still remember him. He didn't have any notes. I later learned that he got his Ph.D. at Temple. Orderly, and exams where fair, he was interesting. They were into their subjects.

Teaching as Instinct

Many faculty felt that teaching is not a skill that you can learn because it is instinctual and can only occur from experience. They are not incorporating the science of learning and how people learn science. Though Susan comments "You cannot be taught the discipline of teaching… you have to do it, but you have to know what it means."

Dareen adds,

> I learned all the academic stuff, constructivism etc… all that crap. It was very interesting academically but I didn't use it all that much, because I was busy with the nuts and bolts of class. I am interested in the psychology of how people learn, and there is no answer of how people learn. … You cannot be taught the discipline of teaching, just like you cannot be taught the discipline of bench research. I can teach someone how to (subject specific). But you have to do it.

Duke states that teaching, “was obvious to me. The way to communicate to infuse them with the same amount of enthusiasm for the subject that I have. Teachers are called. You can’t just make them.” Sam adds, “So you want to know where I picked up teaching. … It just came. I am naturally interested in talking about things that interest me and what I do. It’s my natural ability to try to make is sensible to others. It’s related a little bit.”

Textbooks Guide Teaching

Faculty obtain teaching insights and therefore informal training techniques from a myriad of places. Textbooks were cited as a common (five interviewees) source. As many departments assign a particular text for larger courses this can have mixed results in providing teaching support and insights. Pat discusses the role of finding a good textbook to guide the class.

> One of the best textbooks that I read by (Author), first edition. .... He started each chapter with a question, how is the (system) organized? And each chapter showed all the sides, and you didn’t know the answer until the end of the chapter. We need to ask the big questions and then how would you experimentally answer them. This is what makes science worth knowing. Not a bunch of known facts. … This is the opposite of what science is.

Susan had similar comments about textbook publishers generating books that don’t fit.

> When I looked at other (subject) schools, and what other comparable schools use. All (subject) books are huge. Can we streamline just the

> important stuff. Well publishers are making these decisions, and it didn’t match what I would choose. It had the illusion of looking user friendly but it really wasn’t.

Arnold is also committed to dedicating time to finding and using a strong book and following it “I follow the textbook to the T… Because the students can and will use it to go back to get the information. Some colleagues go off on a tangent. I discourage that because where would the students get additional information. I write my notes from the textbook.”

Personal Influences on Teaching

Family Influences

Many faculty have family members, parents, siblings, and spouses in various levels of academia. They often discuss teaching and teaching issues with them and ask for advice. It seems teaching support is sought though not frequently from science or mathematics education specialists. Susan states “I come from an academic family, my (parent) teaches (subject) at (University). And my (parent) teaches at (University). So I knew what that looked like. Sometimes I talk to my husband about a problem and he makes suggestions.” Frank also has family members in academia “My father was a professor... He got fairly elaborate training in how to teach, he read books by Pestalozzi. My (family member) was a (subject) professor, now he is retired and he never had a single course in how to teach.”   Brad one utilizes the skills of several family members for educational tools and techniques and his comment is similar to Victor.

> My (parent) is a high school teacher. My (family member) is a high school teacher also. It played a role in wanting to teach but I don't think I learned how to teach or teaching styles, since he taught (subject). Then I met my (spouse) and he/she got more education. Doing blackboard stuff, and he/she would tell me about pedagogy and it was really interesting, I picked up a lot of things that I wouldn't have gotten otherwise. So he/she taught me a lot about learning styles, about using different types of techniques, like how to organize and use different types of blackboard assessments. We argue a lot about bell curves and straight grading, lecturing vs Socratic, which is like clickers on their cell phones, and he/she introduced me to that.

Confidence in Teaching

One of the many components that distinguishes novices from experts in any field is their confidence in their knowledge and skill bases (Good et al., 2006, Kardos & Johnson, 2011). Confidence levels seem to naturally arise from years of experience (Atay et al., 2009). Some research has focused on the development of pedagogically sound teaching skills and shows that experience alone does not produce a high quality effective teacher (Cohen, 2009). The question remains, what skills are produced through experience that lead to effective and confident teaching. Many faculty members expressly stated their confidence and passion for their content area and for teaching. The six quotes show the variety of sources that generate confidence in teaching skills. When discussing how they decide what to teach and where they obtained their confidence in teaching, Duke who had considerable years of experience states, "it was obvious to me. The way to communicate, to infuse them with the same amount of enthusiasm for the subject that I have. I did that for a semester, and it gave me logic." Karl indicates "just knowing it is fairly clear in my mind why they need to know a particular bit of (subject)." Other faculty garner confidence and support from fellow colleagues. For example Arnold states "Many of my colleagues look to me for help." Which bolsters his individual confidence level. External accolades influence confidence levels Nancy responds.

> I have great CATES - I think, for me, knowing the material cold and hard not only the material but the background, and the above and beyond I am not afraid of any part of it. I know from all of my years of teaching that I am comfortable with it. I think if you know your content then you don't have any sticking points.

The same commitment of solid content and passion for their discipline was echoed by many faculty as an influence on their confidence levels.

Experience - Initial

Though many new faculty have experience as graduate students and or teaching with faculty in labs; this guided knowledge does not show them the necessary components of creating, organizing and delivering an entire course. Many faculty comment on the very difficult first few years teaching, and the little to no guidance and support. Susan shares a common sentiment about the first few years of teaching, which is typical of the five comments made relating to this topic.

> It was really rough (Laugh). I was half a step ahead of the students. It was exhausting. Creating lectures is time consuming. I had to figure out what I wanted to cover and what was really sort of important. I didn't like the book, but I was sort of stuck with it. I had to make a book I didn't like work for me. So I had to use other sources to flush certain things out. It was literally week to week.

Pat shares a similar experience.

> Those first two years, I was probably horrible. I was very ineffective. It was a disaster. And a steep curve. Two things happened. One I wasn't terrified of getting in from of giant audiences. Up to like year three or four. You look up and there are a zillion people, it is intimidating. You have to get them to pay attention to you and not be fidgeting, or walking around. You have to be relaxed and look like you are enjoying it, and to connect to people. You have to learn to look at them.

When I asked about when and how this changed Pat responds,

> At a certain point I realized that it wasn't about me and weather I was failing or they were going to judge me or how they would find some flaw or I made a mistake. It was more about me looking at them, and seeing if I am reaching them, am I backing up enough, making it clear, interesting. It is all about them and not about me. If it is about them, that will affect how they view me. But if I worry about me I am going to be terrible.

Elenor makes a similar comment.

> The first semester was a total disaster, not prepared I had the book and teaching, but by the second semester, 200 students, nobody ever explained the Gen Ed. What might be interesting to their lives, and I started to work more on instruction. Without teaching gen ed. you don't know this. People think that everybody knows the background. But they don't. We would be happy if they knew 2+2. I now expect that they know nothing. I now teach how things work. After the first disastrous semester, I started to explore more from a students' side, and that the students did not know anything, any math.

A seemingly natural occurrence of knowledge from experience is a common thought process from many faculty as Soren also states "Much of the amount of content and order is trial and error, if the first time it was too much you cut back or shift. I look at student performance comprehension and modify next semester. Look at grades for future modification." Arnold feels that only active teaching experiences can lead to the development of teaching skills. "You never really understand science until you teach it. You can learn all the (subject), all the science as an undergraduate or graduate, you might do well on the exams. But you really don't fully understand it until you teach it to somebody else. You learn how to teach effectively as you progress through your professional career."

Transitioning Moments

The interviewees were asked to recall any specific events or interactions that marked a transitionary moment in their teaching. Five faculty members commented specifically on their experiences. Morris describes a transitioning moment in teaching.

> Initially I thought of them as they are no good they do not study, but you start to reassess your position maybe I was doing something wrong. (I ask how and when this happened.) Initially I thought it was them, then after correcting papers I saw the same mistake is repeated over the years I could foresee their mistakes so I modified my teaching. That is the difference between new and now but the number of years does not matter. (I ask: Is it time or an event, what caused you to shift your perspective.) Some people refuse to see this. They are predetermine that this is how it is. So I started to change. Initially I did not appreciate education in (subject), I thought it was a waste of time, and then when I used it, it made more sense. Others with no training do not appreciate it. They teach as taught.

Jonah articulates well the events that led to his changes in teaching.

> It is a matter of experience, you gradually get to a point where you understand what the students can understand and what they can't. Just by quizzes and give and take in the class room. I talk to the students. The interaction. You know what they are capable of. So you try to communicate at a level that they can handle. It becomes natural after a while. I think my teaching has evolved over the years, based on my experience and relationship with students. The way I was taught was get out your note pad and will write everything on the board and you copy it. I

> would go home and rewrite it, because it was coming faster than you could understand anything. So the way I learned (subject) was to recopy my notes. That is not the best way to learn, I have a much more give and take relationship with students.

Reflective

Many faculty are meta-cognitively reflective of their past teaching with the intent to modify future lessons. When asked what they think about as they planned to teach or after teaching especially if they noticed the students struggling with the content. Pat recalled noticing that “The student struggled with this. So my husband said write down every step that you use – create a paradigm, don’t leave anything out. So I would give them the skill set, how do you learn, - back up and think.” Nancy recalls that her role as a mother was often used as a guide in how she would explain material. She thought “how would I explain this to my kids.” Susan discusses how to utilize each year’s experiences in teaching to improve next year. This reflection with intent to modify marks an awareness of one’s teaching and is illustrative of 5 faculty comments.

> Sometimes you can see where the problem is. Do they have no idea where to start the assignment or in the middle. I keep a running set of notes through the semester, a folder with notes to myself with what did and didn’t work and what I want to change for the next time. Each class can be different. … In the beginning (of teaching) you don’t know all of this big picture. The first two years. Now I can say this is important and set them up better for later. I can stress stuff knowing where this was going.

I recall from previous teaching weather material is really needed for later courses or (standard tests). What are the most important topics? Here are the chapters, and what don’t I need to cover, and how can I have the most time for the necessary future courses and big exams.” Barry adds,

> We are experts and it takes a while to get the level down. Sometimes I reflect and think boy I really sucked at that, so I change things. You feel more confident…. When I teach (a bit out of specialty) I have to refresh that content and relearn it in order to teach it. You have to think about different ways to teach, metaphors work. You teach things that you haven’t thought about in a long time.

Derrick adds “I ask how would I like to have this presented to me? We have presentations, experts come in and they jump into the middle of a complex topic. So you sit there and have no ideas of this topics relevance. So I often think about how I would like (subject) presented to me. I think about this often.” Arnold adds to this line of thought.

> There are some professors who start as assistant professors who have never really taught before. The first few years are very rough for them, they don’t know how to relate to students. They don’t know how to gauge the level of explanation for a freshman or sophomore. It is not really transforming your knowledge, it is backing off your difficulty level. Coming down the ladder. You are using the knowledge that you were given.

Many faculty are self-reflective and actively intend to modify courses during and/or for next semester. An essential component of this improvement as a major source of growth with experience. Pat discusses her philosophy for good teaching,

> Part of it was trying to remember what was important to me. What teacher I liked, what course I liked and what it was about them that made me find them worthwhile or interesting. Obviously being clear is important but that isn’t going to make somebody fall in love with something. Just being

> clear isn't enough. Again there are certain things like having your own personality come through, being funny, having people relate to you. Like being boring and clear is not good. So you have to have a certain amount of confidence. You don't need to stand there and tell jokes you can be funny in your own even Socratic way of talking or presenting things. They know what to expect. That is why I don't think this online learning is going to replace the connection.

Teaching and learning is all about change. Duke "When Gutenberg started printing people were outraged that people would not remember anything anymore. It is just change. I grew up in a house filled with books, we memorized poetry and music that is what we did. Children today don't memorize anything." Duke tells a story of the "taxi cab drivers who had to memorize and take tests on the streets of London. Now they us GPS and are lost all the time. So the point is our heads are changing. As they did with Gutenberg. Is it good or bad?? We don't know. Each generation I am sure thought the following one was doomed."

Tools Used to Modify Content

Most faculty have little to no formal education in science or mathematics teaching. Most teaching tools stem from instinct or trial and error. Connecting expert science/math with specialists in teaching science and math is crucial. Research based best practices are the hallmark of most scientists yet most science and math teachers are unaware or dismissive of the science and math education literature. During the many interviews the faculty were asked to elaborate on specific techniques used in the classroom to facilitate student learning and how they learned of the efficacy of these tools. Nancy explains a special learning technique,

> So I have to explain why we care about this. Remembering important points is critical, it builds your foundation. What I tell my students is memorization is necessary, but not sufficient. And many have never had that before. And they have to write it out, not type. This allows them to not be so preoccupied on facts and memorizing information. They actually have the information in their heads because they did their study guides and class notes. If they hand write it, it is theirs, not photocopied. Well they come into lecture, they see it and hear it, that is one level of learning, then they go back and do their study guide, they are reading it and writing, it, that is a second level of learning. Those two levels combined, I think I can get most of the salient points across, so that they can synthesize.

This point of writing over typing is supported by recent research, indicating that note taking by hand is more effective than typing notes (Mueller & Oppenheimer, 2014). Darren also uses a similar technique "First of all you tell them what you are going to tell them, then you tell them, then you tell them in context what you told them. It is great to have little vignette, and stories to illustrate. It is still a matter of when I am talking you are listening and taking notes. It is necessary to engage the students, because they are not mature enough to engage themselves."

Brad adds,

> I address lots of different learning styles in my classroom. I have art majors in my class, I have premed, dental. I have Spanish majors. For a lot of the pre-whatever they like organization, so I have a lot of lists, a lot of check lists, a lot of compare and contrast, But then for the art – more abstract people I do a lot of outside analogies – so I use a lot of cooking in my class. How chemistry relates to cooking. I use a lot of visual aids, I have them voluntarily make me a video as a different way of learning the material. I put up a lot of academy links. And things like that, suggest that they use different options outside of class. The non-science people really like that and can pick up on it. I like that they are using cell phones for the right reason in class, and not the wrong. I can make all my questions on line. I have a TA put all the questions online. It saves everything. It is very user friendly. The app works on i-phone and androids. My students liked it a lot, I think it worked out really well.

Victor talks about a useful teaching tool,

> I'll do pop quizzes, every week. The first thing I write on the board is one question. You can look in your notes. Open book. If you were paying attention you can answer this questions. Then I can also look at all of the pop quizzes. To see who is doing especially bad at retrieving this information.

Based on student difficulties many faculty have reflectively looked at their learning experiences and developed content specific tools to facilitate learning. Though science and mathematics education experts have published myriads of research-based tools they are largely ignored in favor of self-developed ideas (Bucat, 2005, Mastascusa, Snyder, & Hoyt, 2001, Schroeder, Scott, Tolson, Huang, & Lee, 2007). Elenor adds how she actively works to create improved visual aids, "I go looking for things, and bought with little department grants, to create more demonstrations. I use it especially for Gen Ed." Arnold recommends real world connections as a key to learning.

> I try to use real world life analogies because it helps them understand the concepts. The concept of (subject), what is it to be free, how do you measure it. It's like a potential energy, when you have a very high value of delta g you are unstable. So I climb on top of the lecture bench, and have my toes at the very end, and say I am about to fall off. Then I jump down. So, now I am lying on the floor and say my potential energy is very small. So what has happened have gone from a very high delta g to a very low potential energy, my change in delta g is negative. It was spontaneous, when I leaped off the bench I spontaneously fell to the floor. So those analogies those demos they remember. … I think back to when I was a student as to what concepts were difficult to me; and I said, well what is a better way of explaining this in layman's terms, say an analogy. And so I just built up a bunch of neat analogies that I give my student when I know that that is needed for a difficult concept.

Specific Ideas

When asked where they generate new ideas for teaching. Five faculty members specifically commented. Darren states "go to the computer, a lot and the publishers give a lot of ideas. Pictures. Most of that stuff you can get this help from the web, publisher. Some content, or examples, research examples." Jonah also uses additional sources for examples and support "the internet is a great source, not so much other colleagues. You just google application on commutative groups, and you get stuff. I work this into my routine." Brad also consults a variety of sources for teaching support. "I use the internet a lot. I have a lot of friends who are professors now so I ask them how they teach. I find web sites that have helpful questions and problems, and types of strategies, on how to teach a topic. Harvard has a data base of questions." Morris also recommends staying current and seeking new methods each time you teach.

> I always go back. Constantly reviewing. You can teach the same topic for years but you should always stay up to date. Seek out educational research. Use online MIT lectures to see what they are doing. Keeping up to date, gets you good and new ideas. I found out that their approach to teaching is similar to mine. Try to use examples in books and how they explain it. I try to use as many books for examples and alternative explanations' as possible. The key to successful teaching is constant modification. I can teach 20 years and never teach the same, must modify when they do not change teaching it is their negative attitude toward pedagogy and lack of background prevents them.

Education Literature

Though this is a rarely used tool two faculty mentioned that they consult science education literature in search of teaching tools. Victor mentions where he generated tools for teaching "I get them from Journal of (subject), you search a topic. If you do enough searching you find things. You find models that are pretty good models. This is standard fair for examples. There is a lot of really great labs in the Journal of (subject)." Brad uses a similar personal connection to students to engage and modify teaching.

Write-out Lectures

Many faculty write their lectures either in their mind prior to teaching or tangibly with notes as a way of organizing, solidifying and clarifying a lecture with an attempt to think like the students. Frank, who has been teaching for many years explains this method.

> I write notes, it is fresh each semester, but not that fresh. I use homework questions from last year that I will use again this year. This is todays prep. I wrote these notes yesterday for class. (He shows me a few pages with hand written notes.) Outline form. They are not uploaded to blackboard. I start backwards. I think about what do I want to tell them about this. I know the (subject) cold, I know it better than the people who wrote the books. What will I say, what will I not say, where do I think they need a little help. The students don't have the background to understand. You explain things with your arms and your elbows at the time, Demonstrations experiments. (I ask him where he gets those from, is there a pile of supplies), He just finds simple things with the intension of showing. Instead of using a technical defraction grid, he uses an umbrella, which is better for non-science majors. These everyday items are better than something that needs science equipment. (He states that he does not know if he made this up, or not. But it was not from any literature or supplies by the department or physicists.) You want to teach them that science is everywhere. Not just in underground labs in Geneva.

Sam uses a similar technique, "I'll say this when I first started teaching at (university). I actually wrote out my lectures word for word, like a script. I would spend a couple of hours writing out each lecture."

When Shulman (1986) first presented the academic construct of PCK as representing a unique knowledge base that teacher's process, the three major components held equal value. As research has shown over the years, limited content knowledge seems to greatly inhibit the development of effective PCK to teach (Marks, 1990; Mohr, 2006; Morris, Hiebert, & Spitzer, 2009; Nilsson, 2009). As a reminder to the reader content experts (i.e. faculty with a Ph.D.), were chosen for this study with the purpose of removing this limit in order to focus on the developmental path. As can be gleaned from this rather extensive data set; learning to teach with little to no formal pedagogical training takes many forms and contributions from a myriad of sources.

Returning to the research questions exploring the development of faculty PCK, the interview data revealed a few conflicts with the quantitative analysis (see Chapter 4). Though faculty disagreed that they currently teach as they were taught, the interviews revealed that much of their information about teaching emerged as a result of being a student, mostly as an anti-model. The second measure explored the tools utilized and dismissed. In this case both the quantitative and interview data concurs with the use of textbooks and the value of grading as well as the dismissal of education literature.

Section 2. - Knowledge of Students

This second section of the interview data reports on the development of how content experts develop knowledge of students. One of the cornerstone of effective teaching and the development of PCK is a teachers developing knowledge of their students as learners (Akerson, Medina, & Wang 2002, McDonald & Dominguez, 2009;

Postareff, Lindblom-Ylanne, & Nevgi, 2008). This knowledge includes an awareness of student understanding, difficulties and misconceptions (Banks, Leach, & Moon, 2005; Szymanski-Sunal et al., 2009). Most content experts (Ph.D.'s) have a complex and flexible knowledge set which can lead to an inability to see the difficulties and errors that novices make (students). The development of an awareness of how students learn and the difficulties often comes with experience, though not always. How faculty obtain this crucial component to effective teaching varies. The faculty population sample was asked how they gain information about their students' prior knowledge and difficulties as well as the flexibility in their teaching methods when misconceptions are identified. An outline of the layout of section is listed below to aid the reader in following the large amount of data obtained by this study.

Knowledge of Students
- **What they know about Students and how they know it**
  - **How they learned about Students' Knowledge**
  - **Grading**
- **Techniques used in the classroom**
  - **How to treat Students to Facilitate Learning**
  - **Cognizant of Students while Teaching**
  - **Student's Perspective**
  - **Group Activities to Facilitate Learning between Students**

What they know about Students and how they know it

Knowledge of students is a foundational principle in developing PCK. The initial measure employed was to look at faculty member's knowledge of students and teaching behaviors that reflect on this knowledge. This section explores the ways in which faculty learn about students and the students' knowledge as well as the specific development of skills and tools used to support and guide student learning.

When inquiring about how they became aware of what students know Pat comments,

> You should assume that they know nothing, (Prereqs don't transfer up). Looking at the exams, if you start to assume they know the basics you find from looking at the exams that they did not. The students are very compartmentalized. The way we teach here, we require them to know the most 'Jeopardy-like' superficial knowledge and aspects of everything. But to a lot of our students they don't have that internal sensor if that does or doesn't make sense. They will put in an hour of reading and if it makes sense or not, I am done in an hour. One person may need three hours to have it make sense. A lot of our students don't have an idea of what it means to understand something. They take all of these multiple choice tests they are not required to actually understand.

Though most (46 %) faculty members had not obtained official training in the pedagogy of how students learn, they had valuable knowledge into students learning and techniques needed to help students learn; though the insights did not originate from research-based educational practices. Darren comments on the changes in his students as they mature from a freshman to a sophomore.

> I also teach sophomores for interest many are non-science. … The differences between them as mature disciplined determined and a freshman is unbelievable. It is not that they (sophomores) are Einstein and the freshman are Forest Gump, it is just that they have such a different view point of what it takes to be successful. One semester can really mature them up and work harder in the next semester. Some of them have a different mindset. They have accepted their fate and know what they have to do. If they fail they don't blame us for it. Some are not smarter but harder working. This is what I want to do to become successful, if I want to compete with that guy from Villanova for that (advanced) school position. We have (subject) classes for non-majors – they are here

> because they want to be, they are forced to take some number of sciences. There is a big difference between someone who enlists in the military and someone who is drafted.

How they learned about Student Knowledge

A major research questions attempted by this study was to see if any particular paths emerged during the years that content experts transformed their content into usable knowledge for teaching. Though experience seems to lead to the discovery of certain techniques; we also know that effective teaching does not always simply develop with time. Are there particular experiences that lead to improved teaching and what tools are these experts relying on? Since research seems to indicate that few utilize educational sources for inspiration. I frequently inquired as to why and how they choose a specific teaching techniques and how they know if it worked to facilitate better teaching. As scientists something as important as teaching and developing the next generation should not be left to instinct and chance. Faculty are very busy and new teachers should not have to 'reinvent the wheel' so to speak in order to teach a course. The responses are quite varied in the source of ideas that lead to modification of create a certain teaching tool, and to the evaluation of the success of any particular technique. Teaching is too important to be left to such random chances.

Grading

From Chapter 4 Table 4.8 we can see that grading ranks third and fourth as a tool used to transform content knowledge, preceded only by textbooks. The comments that follow reflect a strong positive correlation in support of the quantitative data. Vince comments that he learns about the quality of teaching from grading.

> I see that from exams that I didn't do enough problems. So when I lectured it was just blah blah blah. So now I do problems and explain ideas within the problems. They are more attentive now. They are more hands on. I give an example with problems. My teaching evolves all the time. I teach much less and many more problems. If you try to teach people you lose them. Nobody and follow anybody when we just talk. So I do hands on. I give them a problem in class and tell them to work with classmates, and then we discuss it. The exams are better now, not a lot, just better.

Morris also relies on tests to guide current teaching.

> From their content knowledge it is obvious when they take tests/quizzes. The type of testing plays a very important role in helping me determine where the deficiencies are. The final and major exams are departments. The quizzes, I make my own. The type of testing is not like multiple choice. We focus on showing the logical sequence of events/steps. By following through I can detect deficiencies.

Jonah adds to the importance of grading your own work to take the pulse of the students' knowledge.

> I use the quizzes as formative assessment, for what went over and what didn't, what needs to have more emphasis, or less. So by the time the test comes around I have a pretty good idea of what is working. It tells me and them what they know. The class as a whole. Quizzes are absolutely essential. It is a matter of experience, you gradually get to a point where you understand what the students can understand and what they can't. Just by quizzes and give and take in the class room. I talk to the students. The interaction. You know what they are capable of. So you try to communicate at a level that they can handle. It becomes natural after a while.

Arnold adds, “I really can’t read students that effectively, it comes when I give an exam. That is how I gage, how I know. I know now when I write an exam if it is going to be a tough one – how well they are going to do. I know the average before I give it. This comes from twenty-two years of experience. I experimented with different types.”

The majority of faculty obtain a significant portion of their insight into student knowledge learning and misconceptions from grading assignments and exams. This vital source of knowledge is too often turned over to multiple choice exams or graduate assistants to grade. This insight allows the faculty that do their own grading to get a clearer picture of their effectiveness. Frank responds to the questions concerning grading his own students work “when I grade exams it tells me a lot. I often go back and repeat a class. Or do it differently the next time when I realize that what I said did not penetrate.” The grading of exams and assignments is a valuable and essential tool for faculty to asses where students are. This sentiment is recognized by most faculty. Frank states it well “When I grade exams it tells me a lot. I often go back and repeat a class. Or do it differently the next time when I realize that what I said did not penetrate.” Teachers learning from their students was a common sentiment among faculty. Victor uses smaller formative assessments to constantly modify teaching.

> This is influenced from other people in the department and from my wife (chuckle) is I’ll do pop quizzes, every week. The first thing I write on the board is one question. You can look in your notes. Open book. If you were paying attention you can answer this questions. Then I can also look at all of the pop quizzes. To see who is doing especially bad at retrieving this information. I just handed them back as a study guide, it is a nice little portrait – now that you have all of them, make sure to go back. If I don’t think they are getting things, I will spend ten minutes/5 minutes. That

> happens a lot after the midterms, one question I thought was really really easy, and they just were not getting it. So I'll go over it.

Brad uses a reflective teaching method that is strongly connected to quizzes and exams currently in use, not just changing something next term.

> If I mis-assess something, then I will go back are re-teach. The pop quizzes, I basically went back and re-taught an entire chapter. More teaching on the fly than I thought it would be. Me being very flexible. I thought the students would be resistant to me not following the syllabus, but they aren't. It helps they appreciate it. I am very open with my students about expectations, what is on the exams. I return grades within twelve hours after. So I have all their grades to them that evening or next morning.

Darren states that he learns how to teach.

> From talking to them. I actually ask them questions during class and they come and see me after class. Some questions have a lot of depth and they are looking for some subtle thing, and some questions make no sense what so ever. The question makes no sense, there is so little understanding that the question makes no sense. One of the frustrating things for me is that I wish that I had the resources or training to reach those people. Even when I have people come to office hours and try to explain it.

Several nights before my lectures I print out my slides, then I will talk it out and write stuff down. I know areas where there are difficulties in the past. I look at the audience; they ask a lot of questions. I can see on tests that they had difficulty sometimes. It depends on how many. I don't say you didn't get this so we will go over. I reinsert this into a new segment. We will reintroduce it in another topic. I can tell on my final. I can tell when I really pushed them, yah they all get it right. I am always thinking about things. The clearest way to me. Sometime I ask them to come up with ways to clarify."

Students are often a teacher's best teacher. Pat states how she gets information from her students as she is teaching "I am watching their expressions, and their participation. They ask questions. You can tell if they are out to lunch or bored to death. If they are fidgeting, they are inattentive. You want them to be engaged." We learn what works and does not from them if we keep our eyes open and are willing to change. Henry illustrates the necessity of personal connections when teaching

> Non-human contact, machine contact are very acceptable these days. Students are not machines, I am not a machine. I can handle as many students as are in the class 200 not a problem. But when I look at them I can understand were this answer came from. When I look at them I can understand when they are puzzled. They may look puzzled even after giving the right answer. It is this kind of feedback that I am looking for. One human being to another. Someone should have my full attention instead of another piece of equipment. They need my full understanding of the person. Teaching is a performance. You see their faces. If they are blooming then you say you have done something successful. See their faces down or nodding. You have lost them and they are waiting for the time to finish. I look at their faces, I don't look at the blackboard, I use powerpoints. The lights should be so that the slide is illuminated, but also their faces should be illuminated. I need to see their faces. I don't like lower lights.

Brad also uses the student teacher interaction to learn about the students.

> I look for faces. I can tell when people are lost or not. If they are lost, I backtrack. I can explain most anything in many ways. In (subject) three different ways. So I will switch it around, I'll reiterate what I said, I'll talk about key points, I'll try to simplify it down to the essentials. A lot of times I will follow up on strategic concepts. I'll explain a concept a different way, I show a worked example on the board then assign them three more to work on in small groups. One person will go to the board and explain their answer. Even if they have it wrong, they can see that they have the same confusion as to why it is wrong. To bring this back to what the main concepts are. I have never been taught that but I always try to think of things the most efficient way to do things. And teach things and

> boil things down to the simplest point and use analogies that are not (subject) based.

Morris clearly points this out “I was (subject) arrogant like the others. Education people mellowed me. I started to see content from the students view, my best teachers are my students. That is the conclusion I reached as a teacher. I learn so much from them.” When I inquired as to was he always teaching this way and when did these revelations became apparent he comments,

> I faced the sad fact that I was trying to teach and I could see that my message was not going across. Initially I thought of them as they are no good they do not study, but you start to reassess your position maybe I was doing something wrong. Initially it was after correcting papers I saw the same mistake repeated over the years I could forsee their mistakes so I modify. That is the difference between new and experienced. The number of years does not matter. How could someone, who has taught for ten years, not grasped this point? Some people refuse to see this. They are predetermine that this is how it is. So I started to change. Initially I did not appreciate education in (subject) I thought it was a waste of time, and them when I used it, it made more sense. Others with no training do not appreciate it. They teach as taught. I always go back. Constantly reviewing.

Susan also uses feedback and student interactions to constantly modify and develop new teaching tools.

> I have alternate analogies, and activities, and explanations. Sometime I just come up with them. The best is when the students try to help me. It is not just on the fly. I am thinking about this all the time. I know areas where there are difficulties in the past. I look at the audience; they ask a lot of questions. I can see on tests that they had difficulty. I don’t say you didn’t get this so we will go over. I reinsert this into a new segment. We will reintroduce it in another topic. I can tell on my final. I can tell when I really pushed them, yah they all get it right. I am always thinking about things. The clearest way to me. Sometime I ask them to come up with ways to clarify.

Techniques used in the Classroom

How to Treat Students to Facilitate Learning

Creating a classroom environment that facilitates learning is a key pedagogical skill, (Gallucci, 2009, Horvath, 1995; LaPointe, 2005; Senechal, 2010) though most faculty are not aware of this educational factor from a research setting. During the interviews I inquired about what skills and tools were used to facilitate learning in the classroom. Pat has found treatment of students is key to learning.

> So I can't do things that make people feel like you are condescending to them that is the biggest way people stop learning. You'd think that they don't care by that age, but they do so if they have a personal connection to you they try harder. If they think that you don't give a crap about them they won't. So something as trivial is learning their name, and talking to them by name – even though I have eighty-five people. To show that they are not some anonymous nobody. To ask about their lives, address them personally, to show that I remember that you are the guy that plays football. This will make them work harder. That trivial effort on your part makes a difference in whether they learned the material. Those are things that I learn from doing. In terms of whether people learn it is all the other things that they don't teach you as a Ph.D. that make it work. There is a study by the president of William and Mary, about what were the ingredients that make people learn at a deep level. And the only thing in all this research was contact hours with a living person. Nothing else, no tech computers, or online this, helped people learn deeply. It wasn't that someone told them how to do it, but having a connection that made them want to do it, that made them put the extra effort it, wanting to please people or show them they are interested. Those sorts of things matter. At any level even at my age, having somebody pat you on the back and show that they know you exist. Those are not trivial things. If you are a teacher.

Barry concurs with the pedagogical requirement of engagement being necessary for student learning. "I use a standard lecture format, but for my (subject non-majors) class, I stop and ask all the time. I don't care if they are right just to have thought about it before they come to class." Brad states" I am on their team" meaning that students know he is with them. "I think that if they have the respect of coming to class and studying for tests than I can be respectful of getting their grades back and telling them where they stand."

Cognizant of Students While Teaching

When I inquired about techniques and tools used to facilitate engagement one very strong response emerged among the 4 that directly related. Teachers respond to the subtle cues of the class, they are aware of every point being made and how it is received. No longer is there a 'sage on the stage' endlessly droning on. Henry states this awareness and method perfectly.

> I break this class into two parts. Because it is about 90 minutes. 40/40 plus ten minutes. For 90 minutes not even a noble laureate can pay attention. That break is very important. Sometimes I make it very flexible, when they seem bored. I can see on their faces. I don't talk to the board, I talk to them. I ask them to participate in the class. I say we have to learn together. I have to know what you do not know. In the third person – you – I say to them that their absorption I read by their faces. I am going to questions them I am not going to let you sleep. These are the facts of a large class of 200 with students who have never taken (subject) some of them have never taken science. Some of them hate science they believe that it is beyond them. My job is to take the fear out of them. I tell them that I will not let them sleep. I will give them breaks and be very flexible. When I see them look away, I call for a break sometimes it is 30 minutes into class others time 40 or 50. Second thing I say to them if you participate in the class I will reward you.

Brad has a similar technique.

> I have never had a teacher that taught exactly. So for instance in my class of 75, I have people go to the board, I walk around, I call people by name,

> I have them work in groups during class. I pole the class a lot. So I have taken the best of everything that I learned to kind of amalgamate together. I look for faces. I can tell when people are lost or not. If they are lost, I backtrack. I can explain most anything in many ways. In (subject) three different ways. So I will switch it around, I'll reiterate what I said, I'll talk about key points, I'll try to simplify it down to the essentials. A lot of times I will follow up on strategic concepts. I'll explain a concept a different way, I show a worked example on the board then assign them three more to work on in small groups. One person will go to the board and explain their answer. Even if they have it wrong, they can see that they have the same confusion as to why it is wrong. To bring this back to what the main concepts are.

The essential component of individual interaction over passive learning in a large lecture is a struggle. Many faculty have developed techniques that they feel are effective in overcoming this limitation to learning. Duke states,

> How do you get a large group of people to pay attention to you. I put on a microphone, and walked up and down always facing the audience, I could look right into their eyes and say look at the left hand of that curve, because I knew exactly what was on the slide, and discuss it with them. They hadn't done that type of teaching before. So I called the college of education, and the college of nursing, I talked to all of them about teaching, and I listened to them. I make models out of gum drops marshmallows. I try to find ways to help make sense. I keep trying news ways. Some things work for some people not others.

Vince discusses the interactive component necessary to teach well.

> I enjoy my students I try to see if they understand. They look at me and if they give me a look. I say let's stop, you don't look happy, what's the problem, I try to make a joke and work with them. You have to have a general desire to want to help them and have them learn something. I am much more interactive. Seeing that I can talk for one hour then I give them a quiz and they know nothing. So I realized that that doesn't work. Then I try something else. My teaching evolves all the time. I am now over (age) and I change all the time. I think my teaching really changed four or five

> years ago. I teach much faster now. I realized that doing problems is much more important than teaching.

Student's Perspective

When attempting to develop lecture material many faculty share the same sentiment as Soren "think about the learning from a student perspective. How can students learn this, how can I help the students learn this?" Susan also uses reflection to modify future teaching, but she goes a step further and asked for student's reflections.

> So when I first started teaching it. I have taught it 10 -11 times. I think about what assignments worked, what exercises in class worked, I ask for student feedback on things. I ask for them to reflect on the process. I ask them to critique themselves and the assignment. Most of the times it matches up with what I am seeing. But every semester I revise that class. Some of my information is from outside sources. I sit on different committees and I hear about what other people are doing in their classes and I think oh that might be cool. Let me modify that and include it in my class.

Sam credits his ability to

> Think like a student. There is a certain amount that comes from empathy, and a certain part comes from how far down do I drill. And the trick is of course to get the content coming at the rate that students can absorb it. Open their head up and shove the info in. To a certain extent we have to do this because the background content in so necessary. But what I do in my teaching is I actually do it in terms of where/how did we find this stuff out. Where did it come from? I understand and pick stuff up better if I learned the context.

Many of the techniques used by faculty come from experiences of being a student. Faculty that are able to or attempt to look at their content from a student's perspective, or through their individual experiences as a student often develop specific teaching strategies. Nancy discusses a useful study tool created from her own personal experience as a student.

> I found that by making up my own study guides I really really did well in courses where I did this myself and so what I discovered early on that my students were not doing that. So in order to help them I will make up these very detailed study guides and help them learn how to get through this vast amount of material and know the material. I developed this on my own from what worked for me.

Group Activities to Facilitate Learning between Students

Rachel uses small group work to encourage the students to learn from and teach each other as well as listening to their communications she is able to gauge their difficulties.

> So in this case the group method and work somehow helps. It is not so boring. They come alive. They are doing something. And secondly which is useful to me is it is interrupting, and active. They are talking and I go around and hear what they are saying. Teaching each other, and they teach me. I hear what they say. I sometimes cannot even imagine that it is that that they don't understand.

Brad also recognizes the power of groups to facilitate learning.

> They (the students) were doing (subject) and no one was really mentoring them so I started what I call a (club), where every week students took the initiative and made up problem sets and I supervised it and they lead it an hour and a half during lunch, and I think the students got a lot out of it. … I get to meet with them one on one. You have to work with other people. A lot of people are resistant to working in groups. Most study groups are about 5 or 6 and they are the most successful. I have some students who ask what other students need help.

Jonah "I encourage them strongly to work in groups. At home, not necessarily in the classroom." Keeping students engaged and receptive to learning Rachel mentions some techniques "the group method and work somehow helps. It is not so boring. They come alive. They are doing something. And secondly which is useful to me is it is interrupting, and active. They are talking and I go around and hear what they are saying. Teaching each other, and they teach me. I hear what they say. I sometimes cannot even imagine that it is that that they don't understand. Often the lack of basic skills. Even after all this time, I can now address the issues, right then and there. That is a benefit. Oh yes, (subject) anxiety is. They are so afraid, I am always kidding, and tell them that I am not biting today. Your opinion matters, so don't be afraid to say anything silly."

In summary, this section relating to knowledge of students points out that faculty members overwhelmingly learn about student difficulties, misconceptions and strengths from interacting during active teaching and grading. As a result of increased knowledge of students they are able to develop techniques and employ tools to facilitate learning in the classroom, they became more in tuned with, interactive and cognizant of students. This allowed them to transition their knowledge from a content and discipline focus to a student perspective. This vital paradigm shift represents the hallmark of teaching skills and PCK.

Section 3 Research and Teaching Balance

Section three presents the role of a unique component to PCK developed in university level faculty. As university level faculty are uniquely researchers by training and the personal identify of many is in part a researcher (58%) the influence of this identity effects their teaching knowledge, perspective and choices. This section also presents the many unique issues facing faculty in the classroom. An outline of this subsection is presented below.

Research and Teaching Balance
- **Research helps teaching**
- **Differences between researcher and teacher skills**
    - **Knowledge set**
    - **Purpose of Job**
- **The Role of strong content knowledge**
    - **Expert blind Spot**
    - **Transformation**
- **Teaching Issues**
    - **Large class size**
    - **Reading skills is an issue**
    - **Lack of Background**
    - **Bias not all teaching issues reside with a student**

University faculty members are hired as content experts in their discipline. Though many have taught and/or conducted research as graduate students, independent teaching is rare and holds a myriad of challenges. Most of the essential decisions concerning teaching remain hidden within the minds of the teacher (Kimmich, 2013, Sternberg & Horvath, 1995; Talanquer & Morgan, 2005). What content to include is readily visible, but the decisions of order and elimination or the reduction or expansion of certain topics remain behind the scenes (Weiman, 2012). Though all current faculty have been students for extended periods of time; the meta-cognitive processes of developing and presenting a course are not apparent to students, even teaching assistants. Much of the research literature of faculty hiring practices (Clement, 2000, Flannigan, Jones & Moore, 2004, Kimmich, 2013) indicate that faculty are hired primarily for their research acumen. Teaching skills, if considered at all, are taken into account at the very end of the hiring process (Brownwell & Tanner, 2012; Hazen & Trefil, 2009; Serow, 2000). Several of the questions I posed to my interviewees focused on their internal views of what they saw as the purpose of their job, how they balance their time as a researcher and teacher, how does being a researcher influence and affect their teaching, as well as does being a teacher impact your research. Thirteen faculty members commented on the dichotomy between research and teaching goals. Overall there was a pervasive sentiment that "being a good teacher took away from being a good researcher … and that universities would literally sic on their students the researchers that they had and it was good luck to you," says Nancy. Morris also points to this same issue of lack of support.

> There is zero support for (subject) education. If you are hired as a research faculty pedagogy has no sense to you. How about a faculty member hired to teach (subject). They don't have education background, no training in pedagogy, many end up teaching but have no training. Pedagogy is not valued. This is true up the line from elementary to PhD. There is a negative perception of education literature and lower level courses that comes across. A negative perception against NTT vs adjunct etc. Faculty have deficiency in pedagogy it is not valued. Education people are not valued. They have a negative perception across the board always looking down to next level. This is wrong. The university is too attached to content but not how to transmit knowledge. This is something that they cannot do. He then credits his work in education for his ability to learn how to teach.

Karl adds that in his department, “there is not much interest in the teaching side. It is just a way to pay for the students for a lot of people. Mainly research is more important than schooling.”

The dichotomy between good researcher and teacher can be sharp, as Pat states, “I hear, if you win a teaching award at (other university) you won’t get tenure. They think your focus is wrong.” Jonah states, “we don’t hire anyone (who is) teaching only for a tenure track position. Not even consider someone. We are replacing our NTT’s with combo teaching and research. Research is number one, getting grants.” Brad relates the lack of value for education papers and teaching to research,

> I have some interest and need to write education papers, but tenure decisions prevent. I doubt five education papers is going to affect tenure much at all. My teaching is not going to get me tenure, it may get me a pat on the back; but, if I don’t get tenure, maybe I can get a job teaching school, but not here. … I spend sixty percent of my time on teaching. I don’t receive any merit on my teaching… but I don’t get any support for that. My tenure is linked to research… and not suck at teaching (chuckles). If I am border line on papers my teaching won’t do it. If you are excellent at teaching and OK at research and OK at service, then you can’t get tenure. It doesn’t really matter (teaching). There is little merit for teaching.

Arnold questions whether, “tenure-track professors really care about their teaching performance. I don’t think that they really do. Because they are there to get the big grants. Money gets results. Their teaching does not count for very much in terms of getting tenure.” Darren adds much the same sentiment,

> The thing is do you care. You put the effort in to improve. I think it is sad that there is no reward for doing a good job. Everybody knows that the only thing that counts toward tenure is how much grant money you bring

> in. You don't waste your time on teaching. Before my time there were people with grant money who were denied tenure because their teaching was bad. That would not be today.

Henry points to the power and position that being a lucrative researcher gets and the status that the money provides. "My research money was more than any other five departments put together. That's why you see all this space and office. (He gestures to the very large double office space plus a separate double lab room) Research money gets you space." Duke adds,

> My goal is to write proposals and bring in money. Actually, it is not my goal, but the goal of the department and deans. Faculty are now expected to bring in money. Teaching is not important. The deans are interested in money. They bring in people who can bring in money. Your teaching doesn't get rewarded. Research and money do. … Current teachers are too busy doing there research.

Victor points to the limits that he must impose on the time spent on teaching as it would consume his entire week. "If I don't limit myself to a few days to write lecture notes I would just be doing it all the time and all of my other activities would suffer. I always feel that I am unprepared."

Research helps Teaching

Many faculty believe strongly that their "research helps to really really develop my teaching." says Susan. Rachel concurs that,

> Being a researcher helps me a lot now. I try to build my class very logically. It is like small research. When I teach class I tell them that we will do this and start here and go here and here. Then in the next class we review and then I tell them why we did that and how we learned that and

> where we will use it. I think this comes from my research experience. Everything is connected.

Difference between Researcher and Teacher Skills

Knowledge Set

Though the majority of science and mathematics faculty enter the academic realm as skilled researchers with narrowly focused Ph.D. fields, teachers face the challenge, especially in lower level and introductory courses, of needing significant breadth. This reversal of broadness of scope appears to be a major challenge for young teachers. "As a teacher you need to be a better communicator." Susan further explains that,

> The top guys (in research) may have a broader view, but you as a small researcher are trying to ask a very specific question. In teaching this narrow view will derail you, as it would as a small researcher. As a teacher you always need to be able to look at the broad, where does this all fit together. Researcher start narrow than can go broad as you move up the line. As a teacher you need to stay broad." As a teacher I know where I want to be at the end of the semester ... The big picture.

Pat also comments that as a researcher you get very narrow.

> One of the things that I like about being a teacher is I get to keep up with all of the new work and literature. Each semester I change my syllabus to keep up. This keeps me broad. I have been very far removed from my original research. I get exposed from so much from my teaching. Teachers are better at explaining. Researchers are better at intensity ... they may be disorganized in a lecture.

Morris also points out that,

> If you are hired as a research faculty, pedagogy has no sense to you. Any faculty member hired to teach (subject) has no education background, no

> training in pedagogy. It is not valued. You often just teach as you were taught because you have no idea how to teach at first. That is a main difference between a (subject) researcher and a (subject) teacher.

In 1986 Lee Shulman postulated that teachers possess a unique knowledge base used contextually while teaching. The base of this knowledge is strong content in addition to this knowledge teachers develop a unique ability to see their content differently with students as the focus. Seven faculty members commented on their understanding of how they have transformed their content expertise in order to teach and the skills necessary to be effective. To see content differently Jonah states that,

> An effective researcher has a different skill set than an effective teacher. Teachers have to have patience, and to really care about your students. You don't have to care about students or people to be a researcher. In research you are at the cutting edge, where the concepts are not that well understood. Teaching concepts are more packaged. You need to focus on effective delivery. You are not fighting to understand the concepts yourself.

Henry comments that the difference in knowledge between a teacher and a researcher is "more than knowledge. Knowledge is common. Teachers have a different attitude than researchers. An attitude of a teacher is to satisfy a student, a researcher is to satisfy himself, a very different customer." Vince states that as a researcher you use (knowledge) as a tool, when you teach you are a storyteller." Brad comments on the qualities necessary to be a good teacher verses a researcher,

> They can't distill things down to the simplest, and then they get frustrated when you can't understand something exactly the way they are telling you, I think that is the biggest problem. I think if somebody can't explain something to you in three different ways and they get frustrated when you

> don't get it they are never going to be a good teacher. They are too stubborn to be a good teacher.

Arnold says much the same thing about the researcher teacher skills dichotomy.

> I don't think people who start out as poor teachers will ever be good or become excellent teachers. They find it hard to deliver or find it difficult to relate to students. Hard to get their point across. Maybe they are too high up, they don't explain things well, don't know how to explain things. They don't know how to go about explaining things in a way that students can understand. They don't know how to use analogies effectively. They can't relate it (content). Some people can't do that effectively.

Purpose of Job

During the interview process each faculty was asked to consider their skills as a researcher and teacher. Ten faculty members responded in part with insights into the purpose of their jobs as university faculty and the changes that occurred as they modified their research skills into teaching skills. Five quotes illuminated the main points. Henry comments on the necessity of scientists valuing their role as teachers. "A teacher's job is to teach. So therefore he has to know what the student's level is. So if he cannot come to the student's level then he is not a good teacher. The connection has to be made. If the level is not there, teaching cannot be done. If you call yourself a teacher you should be loyal to teaching." Vince includes that teachers "have to have a general desire to want to help them (the students) and have them learn something." Pat comments,

> My husband, who went to (University), said Nobel laureates taught all the intro course, and the labs. And they took pride in teaching. In those days teaching wasn't considered demeaning. People would take those courses

> and decide to major. Now the NTT's teach these courses. And they may not be able to bring the research interest to the course.

Brad comments on the pride and satisfaction of influencing the lives of future scientists, his quote represents three similar views. "Because I like making an impact on people's lives. It is a lot more satisfying than research. Getting better and improving having eighty people to listen instead of five." Susan sees part of her job as "passing on certain facts to the next generation." Darren plainly states the importance of the highest quality teaching. "We cannot afford to produce underperforming students. Our students need to be competent because it reflects on us. They are learning the structure of our discipline. We compete with other students trying to get into (advanced) school." Barry adds "Science is about precision. These are people being our (job) etc. They cannot be sloppy."

The Role of Strong Content Knowledge in Teaching

A myriad of research points to the vital and foundational role of strong content knowledge for the basis of quality teaching (Ball, 2000; French, 2005; Weiman et al., 2010). Though research also shows that strong content alone does not make for effective teaching (Abell, 2008; Park & Oliver, 2008; Shulman, 1986, 1987). Shulman indicates that teachers have a unique type of knowledge base known as pedagogical content knowledge which is deeply rooted in flexible content and experience gained from plying ones craft with knowledge of the classroom and pedagogy. The focus of this study was based on removing the necessary role of strong content from the PCK equation by using a sample population that has obtained the highest content level possible in their science and mathematics fields – Ph.D.'s. By removing this often debilitating restriction (not enough basic content) (Grossman, Wilson, Shulman, 1989, Johnston & Ahtee, 2006) to good teaching I hope to discover what other tools and paths where lacking and are necessary to developing effective teaching skills. By using content experts (Ph.D's) as my sample population a possible hindrance emerged known in the literature as Expert blind spot theory, where the vast difference between the knowledge level of the teacher and the student (novices) hinders effective communication (Nathan & Petrosino, 2003). Research shows that experts do not just have more knowledge than novices but they retrieve, and think about their knowledge differently; cataloging and flexibly making connections in ways that novices are unable (Nathan et. al., 2001). These sought after thinking and problem solving patterns have been shown to create a barrier to expert-novice interactions (Carter, Cushing, Saber, Stein, & Berliner, 1988; Nathan & Petrosino, 2003).

Expert Blind Spot

Many of the faculty were asked if their strong or narrowly focused research path influenced their course planning, assignment choices, or student interactions. They were asked to comment on teaching outside of their original discipline and to non-majors and lower division courses as this broadens the expert-novice gap. Many of the comments relate their content knowledge combined with several years of experience which lead to confidence in course planning and execution. "I think, for me, knowing the material cold not only the material but the background, and the above and beyond I am not afraid of any part of it. I know from all of my years of teaching that I am comfortable with it. I think if you know your content then you don't have any sticking points." states Nancy. Morris quantifies much the same sentiment "Content is number one. If content is weak pedagogy is non-existent. It is the starting point then pedagogy, 20 % pedagogy presenting 80 % is content."

Four faculty comment that teaching in their areas of expertise at lower course levels was much more difficult than teaching outside of their individual experience. Frank points to an example of this "My (family member) is a Nobel prize winning (subject). When your levels are very far apart it is very difficult to learn from each other. Things that I thought were easy they cannot do. This is hard to tell you." Pat explains,

> It is hard when you are a research scientist to think about the little steps – and what their (the students) knowledge or lack is. But you have to do that. I discovered that the topics that are my expertise I was the least effective at teaching because I was way over their head. When I was near or at their level, so that I had to learn it with them I was able to start back far enough. It is really hard when it is so familiar to you to know where they are beginning.

Transformation

> When I inquired about how they transformed this high level content knowledge into usable classroom material Frank38 explained, "I sit at my desk and I work out every last step of the illustration, I have done it a million time, I know I can walk into class and get it right, but I want to concentrate on their reaction when I am in class not on what I am doing." Barry8 adds, "Make sure you know what you are talking about. You can't look like a screwball, or you will have lost them. We are experts and it takes a while to get the level down. Sometimes I reflect and think boy I really sucked at that, so I change things. … When I teach (out of immediate discipline) I have to refresh that content and relearn it in order to teach it. You have to think about different ways to teach, metaphors work. You teach things that you haven't thought about in a long time. Upper level courses are not nearly as bad.

Arnold adds to the necessity of knowing your content in a flexible way "It requires lots of different skill sets, you have to have a good memory, and be good at problem solving, to think quickly and look at a passage of information and quickly get from that passage the relevant pieces of information."

Strong content knowledge allows faculty to see the big content picture and if they can think like a student they can develop guided learning techniques (Hanuscin, Lee, & Akerson, 2011). As Brad points out,

> I try to teach them my style of thinking from day one. And teach them (subject) my way so I can kind of steer off those initial mistakes that a lot of other classes probably have. And then I know what the mistakes are. … By being able to walk around class while they work on problems I can see the people who are struggling. I can give them one on one time in class. I can also see where the struggling is. … I use a lot of models – physically, have them make some themselves. That is beneficial. Drawing it by hand. Getting through to them that you have to put in a lot of work.

Teaching Issues

University faculty face unique teaching issues due in part to the traditional large lecture style classrooms, time limits, modern technology distractions, and the wide range of student background and diversity. Science and Mathematics faculty are content experts and rarely acquainted with science or mathematics educational research on best teaching practices, and methods to overcome unique teaching challenges. Four faculty members commented on current teaching issues. Frank comments on one current issue facing teachers. "My colleagues and I had a conversation recently about students being too distracted; I think it is true in the last five years. Ever since the invention of cell phones." Elenor adds that the distractibility of students has become a major issue in teaching. Four years ago, she explains a 10% drop in grades. She mentions a piece of research on a class with a control group and research with students who are texting in class and there was a 17% drop. She corresponds her 10% drop to this same phenomenon.

> Texting is horrible. The phone is in control, it is a drug; they cannot exist without it. Even if they are not texting it is their focus, concentration is distracted. If they could not text for 50 minutes they would die. Ten years, same class. It is changing in ten years. A significant decrease. There is a decline. She relates this to active texting in the class. It's not laptops but texting on phones.

Jonah sums up a pervasive thought. "I wish they would stop texting." Jonah points to the division between full time and part time faculty as an issue. "Small private schools have a lot of adjunct faculty who teach all over the place in order to make a living. So how much time can they devote to teaching one course? It is really a disgrace, we are supposed to be an enlightened group as college professors and we have this itinerant group teaching. They are like fruit pickers. They have to work like crazy to make a living."

Large Class Size

Nancy "Large class size restricts exam style." Well documented in the literature (Bland, Sunder, & Kreps-Frisch, 2007) is the traditional large lecture promoting passive disconnected students, Darren states it well. "A five hundred freshman lecture is not conducive to anyone. Let alone a freshman, they don't know how to deal with that." Victor adds "What are the best ways to engage students, these large lectures – people just fall asleep for an hour. When I am in the front of my class of 16 students. I will engage them and interact them all the times." Pat comments on the limitations of multiple choice exams and how to work around this.

> A lot of our students don't have an idea of what it means to understand something. They take all of these multiple choice tests they are not required to actually understand it. So about 15 year ago I switched to requiring only short essays. So they not only had to tell me the correct answer, but they had to provide the reasoning why it was correct, and if they could not tell me why it was the correct answer they got zero credit. If they had memorized what the right answer was, unless they memorized some understanding that went with it they didn't get it.

Reading Skills are an Issue

Darren points to the lack of strong reading skills negatively influencing science learning "I think it is particularly difficult for people who do not have high level reading skills. I am not talking about 3rd grade level. College grade level of very conceptual material. There is no easy way around it." Rachel expresses a connection between reading skills and independent learning.

> Another problem is they don't know how to read books. They just want powerpoints. They don't know how to read books. They don't want to go on their own and do work. The books are good. Everything is in there, they don't need teachers. They are not taught to learn. I hear that in schools they don't use books, they just give handouts. They come to college and are not familiar with how to do this. Slides are good. I make slides, but after that they need to go to the book.

Nancy comments on necessary knowledge contributing to student learning.

> This I think happens as a natural process when you read for pleasure. If you read good novels, even good short stories. This I think makes a big difference in how the brain develops. What I found, and also talking to some of my better student who say they have always read for pleasure. When they take my courses, enjoy the course they enjoy doing the reading, doing the study guides, they do well on the tests. A lot of my students who really struggle, when they come to me I ask them did you ever read for pleasure as you were growing up. They say Oh no, I only read for school (strongly stated). I only just read for school. Those are the students that I see are having a real problem trying to read and comprehend and develop from that point on. Reading and comprehension is the entire goal. Synthesis and creative thinking, they are just not there yet.

Pat adds,

> I think three things. Not reading effectively, not studying effectively, not knowing what you are looking for, second is having no curiosity, and third is not knowing when you understand something. Not being satisfied until you understand. We have to read for long term understanding, I take notes, or underline, I look for further info to look up. I don't just skim like a People magazine article. They read just to skim. One of the biggest barriers is they don't know how to do this. They think it is too difficult. They have phobias. Nobody wants to do something extra if they associate it with unpleasant things. There is such a diverse sense of knowledge out there in the books that it is an overwhelming vast amount of information. Not the exploration.

Lack of Background

Rachel illuminates a very commonly perceived issue in university level instruction. "Background, there is such a gap that it does not allow them to follow concepts. Their lack of skill keeps them back. Those skills should be like that. Snap. Then they concentrate on that part, and they get tired and cannot follow you. Often the lack of basic skills." The lack of value placed on teaching is evident in Karl's comments, as a possible explanation for the lack of student motivation.

> More often teaching a required class for other majors they are not necessarily that happy about being there, so that can cause some issues. The fact that you are required to take some classes outside of your major/discipline and what you are concentrated in. You (the students) are less motivated, less happy to be there. You are busy, lots of things you have to prioritize them, some other class in some other discipline you may not understand why it is required. This causes you to put it lower on your list.

Morris comments on the lack of prior knowledge and background that hinders learning and how he identifies and remedies this issue.

> Always go back to remediation, bring back the basics. All the time. What determines that approach, the spiraling nature of (subject) forces us to continually go back to build the basics. Or the foundation is weak. Specialization is so bad. It is the curse of math and science. We need the whole student not parts. We need to be all a teacher, parent, psychologist in the classroom. In class don't always talk about (subject). Talk about jokes, take it out of the classroom into humans. Teaching is messy.

Bias not all Teaching Issues Reside with the Student

Nancy comments on the difficulties of being a female faculty member in the male dominated (science and mathematics) field. This bias is well documented in the literature (Seymour & Hewitt, 1997; Thompson, 2003; Ware, Steckler, & Leserman, 1985) and persists from interviews (Jones et al., 2004; Wigboldus et al., 2003) to promotion and tenure (Kimmich, 2013) but in her cases it is cultural and is generated by the students. "Bias against women often by the students, who address her as Mrs. instead of Dr. or Professor. The students' experiences with most women are as elementary or high school teachers. … (subject) is not kind to anyone. It is particularly not kind to people who have children and families." Pat also refers to the female bias issue.

> Many of the Ivy leagues are looking for power players. This is one of the reasons women don't get the top jobs. They may not be looking to be the power player. If affects women in these fields. I find that sad. The women don't get tenure or are stuck in an associate level. I don't want what a man wants. It is a major impediment to women in STEM.

Summary Comments

Twenty-one interviews, yielded three broad scoping insights into the transformation of expert content into knowledge used for teaching. The considerable data set was divided into three main themes: Learning to teach, Knowledge of Students, and Research and Teaching balance. Learning to teach took many forms mostly informal, involving family members, and a self-reflective process. There is very limited support from professional educators and little from universities or colleagues. Past teachers are often anti-models, while the textbook serves as the main source of depth and teaching ideas. Faculty are primarily forced to invent and test teaching tools and methods themselves. The science and mathematics education literature exists but is not utilized by science and mathematics experts. These two connected disciplines need to engage together to develop effective research-based teaching practices.

Faculty members' knowledge of students and their misconceptions is a cornerstone of PCK development. With little to no formal training faculty members glean knowledge of students and level via grading and interactive teaching. This single component allows the teacher to shift content views and develop material that is student focused. This is certainly a significant and necessary development towards effective teaching

The main restriction in the development of PCK in teachers has been shown to be limited content knowledge set. University faculty are therefore content experts, removing this limitation. As university level faculty began as research experts, I was interested in the unique role that research plays in teaching. Many faculty were able to ponder the distinction between skill sets of a primary researcher and a primary teacher. The depth, range, and context of their specialty needed to be revisited by most new faculty. As researchers they became increasingly narrow focused in their field. The main purpose of their focus also changed from pursuing answers and generating questions to passing along information and passion to the next generation. Their new knowledge set needed to include understanding their material from an uncomplicated novice view. This was quite a shift for many faculty members. Universities also face unique teaching issues that result from an historical perspective. Large lecture halls and passive learning has been inherited from generations before. This is slowly changing as science and mathematics education, and the need to educate more effectively takes center stage. Scientific and mathematic literacy rates in the United States have become a mainstream issues with STEM courses focusing on bringing the general population into the fold of knowledge.

CHAPTER 6

CONCLUSIONS

The intent of this study was to illuminate some of the insights, tools, barriers, and paths that science and mathematics experts used to unpack and transform their content as they attempt to develop courses and teach. The purposeful choice of university level faculty (content experts – Ph.D.'s) intended to remove the overwhelming issue of lack of content knowledge that appears to act as a major restriction for the development of PCK in teachers (Johnston & Ahtee, 2006; Segall, 2004). This study did not attempt to define or redefine the elements of PCK (Ball et al., 2008; Grossman, 1990; Magnusson et al., 1999), or measure it (Loughran et al., 2008; Rohaan et al., 2011), but to attempt to illuminate any significant events that lead to content experts' ability to teach. Experience seems to lead to the development of confidence in teaching and the beginnings of an awareness of student learning, yet many faculty with considerable years of experience have not mastered the skills needed to be a flexible and effective teacher. Therefore, experience alone nor combined with sufficient content knowledge can account for the development or lack thereof of PCK skills. This study attempted to probe into which specific events or knowledge lead to and facilitated the development of PCK.

This study's sample was confined to university level science and mathematics experts. Though 81 % responded positively about their intents to enter an academic career only 54 % received any prior training in teaching. This lack of perceived need for training speaks to the undervalued skill sets of those who teach. Doctoral programs and institutions of higher learning seem to be disconnected from STEM community educators. There is significant research-based best teaching practices literature available, yet it is dismissed, as not relating to their level, discipline, or class type. New faculty seem to rely on instinct, past experiences as being a student, and graduate assistant experiences for their knowledge of pedagogy. As the literature on STEM attrition rates indicates that poor teaching contributes significantly to student drop-out (Burton, 2007; Watkins & Mazur, 2013; Wilson & Mant, 2013), these tools are insufficient. Though nearly half of the sample considered themselves equally researchers and teachers, university and departmental views and support for allotted resources (time) for teaching also facilitates a culture that devalues pedagogical strength.

Ranking Scale of Transformation Tools and Strategies

A ten-part ranking scale question was answered to determine which tools and strategies are most utilized and which are dismissed. Textbooks and grading homework and exams ranked in the top positions as providing faculty with insights into teaching knowledge about content and students. Seventy-five percent of faculty agreed or strongly agreed that they use the textbook as a guide to teaching. Many faculty inherit a book from a previous teacher or are required to adopt the specific text for a large lecture course. This places significant power in the hands of publishers, though current literature seems to point toward a growing reluctance of students to read and utilize their assigned textbooks. Due to the high costs of books certain courses are eliminating the requirement of published textbooks in favor of smaller documents and web activities. The role of science and mathematics education specialists is uncertain in the development of textbook writing. Science and mathematics education, and misconception literature ranked in the lowest value for obtaining insights into teaching. This supports the previous statements that education experts and science and mathematics content experts are disconnected from one another.

The research questions stated below are followed by conclusions and insights gleaned from the major study. **Research question 1:** How do Science and Mathematics content experts (i.e. instructors with a Ph.D.) develop, expand and modify PCK for teaching in a university setting. **Research question 2:** Do instructor characteristics affect the development, expansion and modification of PCK?

Content Shift

The data from this study revealed several interesting lines of insights about how science and mathematics content experts develop, expand and modify PCK for teaching. Approximately 81 % agreed or strongly agreed that they look at their content from a students' point of view and reflect at the end of a unit with the intent to modify future sessions. Both of these insights are evidence of PCK development. Faculty members who are able to unpack their expertise with a student's learning in mind are indicative of the type of transformation that sometimes occurs and may eventually lead to improved teaching. During the interview process faculty members were asked to reflect on the changes that occurred over their years of teaching and which events lead them to change their teaching; viewing their content expertise from a student's perspective appeared to be the single most significant event. Once faculty were comfortable with the many unique teaching issues associated with university level environments such as, time restrictions, large class size and mixed student backgrounds, many were able to rethink their content and engage students with increased use of technology and attempt pedagogical techniques such as small group work, problem solving, and demonstrations, while remaining current in their fields. Being able to view your expertise from a students' perspective reflects a milestone in the development of PCK.

Overall, the transformation process was characterized by a shifting from expert content centered view to a student centered view. Once the faculty members were able to stop thinking about themselves they began to look at each unit, the course as a whole and what the students were seeing and needed to see. Most typically, faculty members who developed this, engaged in a daily reflective pattern, whereas shortly after a lecture, and or the grading of exams and assignments, and personal interactions with students either through classroom discussions, questions or office hours they were awakened to the difficulties and misconceptions that were held by the students. This transformation, if it occurred, typically developed within the early stage years of teaching (3 to 5 years). Faculty frequently reported that grading and one-on-one interactions with students facilitated a shift in perspective. Grading assignments and exams provided an essential role in helping many faculty to rethink their content. It is essential that the grading of your own students work occurs. The students are a teacher's best teacher regardless of the number of years teaching. Therefore, creating an environment that encourages interaction between students and teachers with limited barriers is needed.   The significant and essential knowledge of students gained from grading homework and exams is consistent between the statistical and interview data. Next after textbook use this remains the most common tool used in developing teaching strategies.

Weak content knowledge has been shown in the literature to be a major restriction in developing PCK for teachers. A major reason for choosing Ph.D. experts was to remove the limits from content expertise. This in turn presented a different potential obstacle. A theory referred to as expert blind spot theory portents that the greater the difference in content levels of two groups attempting to communicate the greater the difficulty in that communication. Experts, as the research indicate, retrieve and utilize their knowledge differently than novices (students). They have complexly interconnected schema and are able to focus directly on the most relevant issue of a problem. On the other hand, novices have disconnected and fragmented knowledge and are easily distracted by superfluous and surficial issues when faced with a problem. Experts often skip multiple steps and find it difficult to break down steps and details when explaining their paths. Experts often fail to see difficulties and misconceptions. They themselves may not have experienced the barriers that many of their students are encountering. Many faculty commented on how difficult it was to teach at lower levels especially when the content was very close to their expertise. It was much easier to teach farther from their expertise, as they were forced to refresh and or relearn the material from textbooks which are designed to teach that level of material. One faculty member commented that she was the least effective at teaching the closer they were to their specialty. When I inquired as to who they transform their content for and what tools they employed, the conversations returned to rethinking their material from a student perspective. You must consider your audience, one faculty member commented. What is your purpose and to whom are your communicating? The necessity of one-on-one teacher-student interaction was believed to be critical. Said another way, it is important that teachers be able to instantly read their audience.

Knowledge of Students

Initially experts see the framework of their content as the central focus for teaching. This is often misaligned with actual student learning processes and paths. As Nathan et al. (2002) point out, expert blind spot is the inability to perceive the difficulties of novices (Healey, 2005; Hrepic, Zollman, & Rebello, 2007). According to Shulman (1986), expertise in content, knowing how to do, and knowing how a student learns specific material, and the organization of content to facilitate learning, represents actual PCK. Modifying content according to the learners' needs requires knowledge of your students' level and abilities as well as how they learn. Knowing the level and background of your student body, then considering them when developing course material could alleviate some of the frustration and barriers that exist in the lecture halls (Henderson & Dancy, 2007). Faculty developed a myriad of tools and techniques for use in the classroom. Though they were not from research-based literature, many fit within the best practices paradigm. Developing a caring, connected, and open classroom where students felt comfortable and valued, and being treated like they mattered was articulated by several of the faculty. The sentiment that "I am on their team" sums up this need to make connections. This type of student centered view also extended to the awareness of students during class. This demonstrated by teachers watching their student's reactions and responding with breaks, or change of pace, or ‘stop and question’. Being able to know your content deeply enough to teach flexibly and teach ‘with the students not to them’ is important. This is also shown by the ability to focus on the class and to ‘read their faces’ for instant feedback and then to be able to respond to the challenges, keeping their attention. Small group work is also a utilized tool for student engagement and one that many faculty commented on and incorporated in their courses. This interactive ability did not only arrive with years of teaching since, several newer faculty spoke of the importance of this type of teaching.

Educational Support

Though many of the teaching tools conform with the literature, faculty reported not utilizing science and mathematics based educational literature. The dismissal and disregard for science and mathematics education and literature as well as university supplied educational sessions is confirmed between the statistical data and the interviews I strongly recommend developing small group teaching circles and or individual science and mathematics experts paired with science and mathematics experts to form support units. These education experts will then provide and guide faculty in developing and, infusing new teaching tools into specific courses. The groups or pairing should be long term as well, at least three semesters of the same course, in order to slowly infuse best teaching practices and to work with, not against a teacher’s individual style. The onus is on the educator to learn about the teacher’s content and style and develop supportive tools, not to try to overhaul any one faculty member’s course.

Teaching Issues

A major issue that presented itself during the interviews focused on the students' lack of basic skills such as reading and or background knowledge that faculty believe were significant teaching issues. The statistical and interview data concur on this point. Awareness of student knowledge including background is a major component of effective teaching. Knowledge of students includes their abilities as well as difficulties and marks the first step to developing PCK skills. Without a clear understanding of the ever changing student body any teaching cannot hope to be effective. This cornerstone of PCK led to a line of questioning relating to how the content experts; without pedagogical training, obtain any knowledge of their students. The overwhelming and seemingly essential source of knowledge about students evolved from the grading of exams quizzes and assignments. With large classroom sizes grading can become an enormous time requirement, but the essential knowledge of the ever changing student body is gleaned from this activity. Computer grading assistance or graduate student grading removes this necessary teacher knowledge and should be discouraged.

The next major source of student insights emerged from the interactive nature of actual teaching. Faculty commented that students are their best teachers. Watching their faces and listening carefully to their questions, the faculty are able to glean subtle cues to their engagement level.

Nearly 92 % of faculty agreed or strongly agreed that they were confident in their ability to teach successfully. Correlation analysis relating to demographic information and knowledge of students and teaching practices was conducted. The first statistically significant result indicated that faculty who taught while obtaining a Ph.D. were less confident in their ability to teach successfully. Though this seemed counter intuitive initially, upon extensive interviews with twenty-one faculty it was revealed that those individuals who were self-reflective and had a variety of teaching experiences tended to look back and contemplatively self-analyze their efforts. This leads to a more insightful self-critical view of their efforts, which leads to constant improvements and modifications. Though the effectiveness of their modifications was not analyzed, awareness of teaching and student interactions appears to play a role in PCK development.

Overall, teaching knowledge was primarily acquired during the graduate school time, as assistants. As mentioned previously, 83 % of the sample taught while obtaining their doctorate degree and 81 % intended to enter an academic career; although only 54 % received training in teaching. Though they were not in charge of creating lessons, choosing the order of material, methods or assessments, this informal training seems to have provided faculty with the extent of their training experiences. The lack of formal training in pedagogical techniques speaks to the commonly held thought that having been a student provides us with the necessary skills to be a teacher. This seems to be the case as so few faculty have formal training. This position is unusual since only 14 % agreed/strongly agreed that they teach as they were taught. This low percentage was explored during the interviews and revealed that the majority possess negative perceptions about the teaching acumen of their former professors; an ‘I can do better’ philosophy prevailed. Yet obtaining any significant form of professional teacher training or skills ranked last and next to last in tools used to develop teaching lessons.

How faculty members learned to teach was explored during the interview portion of the study and revealed a wide array of paths, the details of which were presented in Chapter 5. Learning to teach rarely took the form of formal pedagogical training. When formal training occurred it was later in the career and by choice and was generally dismissed as ‘useless’. Faculty members overwhelmingly disagree that they teach as they were taught yet this anti-model often provided sufficiently negative models to spawn change. Textbooks represent a consistent source of teaching knowledge. This was confirmed in both the statistical and interview portions of the study.

Currently many universities offer a wide and rich array of educational support for faculty and teaching. Programs range from broad sweeps of university teaching tools to individualized specific course mentoring. The barriers that keep the educational experts apart from the content specialists are firmly in place. These barriers have been explored in the literature, and are surmountable, starting with a shift in the value of teaching in the research driven science and mathematics fields. Several faculty members have obtained university offered pedagogical training but with limited success. The support was either “too broad”, “not related to my course or level”, and simply “too theoretical”. Science and mathematics specialists were hoping to obtain skills or tools that could be implemented in to their specific courses and were generally disappointed. As a result many of the intended support routes are unvalued as “this education stuff is nonsense”.

Summary Comments

Data from the open-ended questions and the interviews corroborated well with the statistical analysis as they relate to the two major research questions on several points and conflicted with others. The myriad of components that comprised a faculty member's overall path into the methods of teaching included everything from parents, to spouses to the occasional colleague mentor, but mostly included textbooks and overwhelmingly the students themselves. Though content experts have an extensive and deep history of being students themselves, 83 % claim not to teach as they were taught. Yet it is their experiences as students that qualify them to be teachers. Eighty-three percent cite actual teaching as their major sources of teaching knowledge. The complete lack of value in the profession of teaching and the necessary skill set that can and should be taught was echoed in both the statistical analysis and the interviews. University teaching sessions and educational research-based literature ranked at the bottom of all measures for use and value. The skills necessary to teach were gleaned from anywhere other than formal pedagogical standards.

The portion of faculty that had received training (54 %) was more insightful and reflective of their own teaching representing a major development of PCK skills. Initial experiences teaching and transitioning moments are commonly articulated as becoming aware of students and their difficulties. The shift from content centered teaching to a student centered focus marked a major transition for most faculty members. The average number of years of teaching for the entire sample was fourteen years, representing considerable time to gain the necessary student insights as long as the switch to a reflective, student centered view was achieved. Not all faculty members seemed to have been self-aware regardless of the number of years of teaching. The necessary components and tools that facilitated this essential transition seemed to be actively engaging with students. The one-on-one interactions, grading of assignments and exams, and a genuine desire to see yourself and job purpose as to teach. The small percentage (12.5 %) that considered their main position at the university as a researcher did not develop the skills to turn their attention toward the student's needs.

The tools used to support teaching varied greatly and were not well reflected in the quantitative analyses. The quantitative measure was modified from the existing literature and could not sufficiently identify the myriad of tools and insights that faculty members elaborated on during the 20 interviews. What was corroborated was the complete lack of educational teaching tools, such as formal university sessions and educational literature, and the overwhelming use of textbooks to guide courses depth and organization. While the literature appears to indicate that the use of textbooks for students is waning, faculty appear to rely heavily upon their structure and content for teaching. Further study into the science and mathematics educators' role in the development of textbooks seems warranted.

Recommendations

Considering all of the data collected for this study, there are several recommendations that I believe can be derived from the results. Each of these is presented below with a brief rational.

Recommendation # 1: I propose that education experts should be charged with connecting with all STEM departments, with the goal to serve as one-on-one mentors and guides for developing new courses, supporting new faculty and supporting existing faculty to integrate research-based best teaching practices into each course. I further propose that each STEM department have as a full-time faculty member a content expert within their field who is also an education expert.

Rationale: Both the quantitative and the qualitative data showed that the math and science instructors who participated in the study did not value and did not use the educational material developed by science and math educational experts. Professional teaching skills need to become a mandatory component of tenure packages, as well as just cause for merit and financial rewards. The onus is on the science and mathematics educational experts to break down the barriers and meet the needs of the content experts.

Recommendation # 2: I propose that any newly appointed faculty members who are teaching a large lecture section, effectively influencing hundreds of young potential scientists, act in an apprentice manner for one full year much the way physicians engage in a residency.

Rationale: An experience faculty member can work with them on the behind the scenes decision making process such as course content order and chooses of assignments, assessment development, classroom interactions and management, With guidance they can be charged with developing a particular unit and most importantly they can participate in the creating and grading of assignments. This will allow them to understand the material from a student's knowledge base. They can also reflect on intended teaching content and that which is actually transmitted.

Recommendation #3: I propose that all faculty participate in the creation and grading of exams, assignments and homework of at least the majority of students in their sections.

Rationale: As faculty members are experts in their field, they typically had different and less difficult experiences as undergraduate students; and so may not have faced the same challenges, misconceptions or difficulties that their current population encounters. Awareness of student struggles triggers a mindset change in how teaching and assignments are designed. This expert-novice gap, known as the expert blind spot theory, stems from the distinct thinking strategies held by experts that are domain specific and are misaligned with the learning order and path for novices.

Delimitations and Limitations

The limited sample size, voluntary nature of the participants, and single urban university limit the potential for the generalizability of results. The transformation of content knowledge may have content specific components and therefore needs a greater lens shown on specific subjects instead of a broad view of content specialties. The questionnaire and interview measure may not be sufficiently focused and refined to identify the distinct factors of PCK. The wide range of years of teaching experience may be too broad to accurately measure the changes that occur. Identification of generic processes by which content experts unpack difficult subject matter and learn about science students may enable future novice teachers to develop the necessary teaching skills with greater efficiency.

This study has boundaries worth noting. The research focused on a sample set of data collected from a post-secondary urban institution. The sample of science faculty was chosen to concentrate the research on science, with the intention of comparing non-science faculty in the future. The sample represents the 2012 distribution of gender, years teaching and background training. This sample may not represent the distribution of all science faculty presently teaching at urban universities, or the path taken in deconstructing content knowledge for teaching.

Ethical Issues

There are several ethical issues that I was aware of at the outset of this study. I am currently a member of the science faculty at both universities (the pilot and the main study samples) though I have little to no contact with the majority of faculty. Nonetheless, disclosure of my position was mandatory and may have influenced the instructors' responses. Participation was voluntary and anonymous, unless a follow-up interview was conducted. All data were coded to remove all personal identifiers except gender. Transcripts of the interviews were also coded for anonymity so that both inter-rater analysis and committee members were unaware of the identities except gender. The identification code was kept at a separate location.

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APPENDICES

APPENDIX A IRB APPROVAL DOCUMENT

TEMPLE UNIVERSITY

Office for Human Subjects Protections
Institutional Review Board
Medical Intervention Committees A1 & A2
Social and Behavioral Committee B

Student Faculty Conference Center
3340 N Broad Street - Suite 304
Philadelphia, Pennsylvania 19140
Phone: (215) 707-3390
Fax: (215) 707-9100
e-mail: irb@temple.edu

Certification of Approval for a Project Involving Human Subjects

Protocol Number:	**20563**
PI:	**DUCETTE, JOSEPH**
Approved On:	23-Apr-2012
Review Date:	23-Apr-2012
Committee:	B BEHAVIORAL AND SOCIAL SCIENCES
School/College:	EDUCATION (1900)
Department:	EDUCATION:PSYCHOGICAL STUDIES (19040)
Project Title:	The transformation of science content knowledge into teaching content by University faculty

In accordance with the policy of the Department of Health and Human Services on protection of human subjects in research, it is hereby certified that protocol number 20563, having received preliminary review and approval by the department of EDUCATION:PSYCHOGICAL STUDIES (19040) was subsequently reviewed by the Institutional Review Board in its present form and approved on 23-Apr-2012 with respect to the rights and welfare of the subjects involved; appropriateness and adequacy of the methods used to obtain informed consent; and risks to the individual and potential benefits of the project.

In conforming with the criteria set forth in the DHHS regulations for the protection of human research subjects, and in exercise of the power granted to the Committee, and subject to execution of the consent form(s), if required, and such other requirements as the Committee may have ordered, such orders, if any, being stated hereon or appended hereto.

It is understood that it is the investigator's responsibility to notify the Committee immediately of any untoward results of this study to permit review of the matter. In such case, the investigator should call the IRB at (215) 707-3390.

This is the Certificate of Approval. Supplemental documentation will follow under separate cover. Enrollment may not begin until all documents have been reviewed and processed by the IRB and received by the study team.

ZEBULON KENDRICK, Ph.D.
CHAIRMAN, IRB

APPENDIX B – PILOT QUESTIONNAIRE

One of the critical issues that all teachers face is how to present the material in a coherent and understandable way to students. This is true at all levels of education, but is perhaps even more critical at the college level. All college instructors have a significant background of content knowledge about their fields. What college instructors often do not have is any specific training in how to translate this content knowledge in ways that make the material accessible to students. In education, this is called Pedagogical Content Knowledge. The purpose of my research is to gain a better understanding of Pedagogical Content Knowledge by investigating how instructors develop this ability.

THANK YOU FOR TAKING THE TIME TO SUPPORT MY RESEARCH

Please state the college in which you primarily teach.____________________

Please circle your gender.

MALE FEMALE

Are you currently tenured or tenure track?

YES NO

Please state how many years you have been teaching

full-time at LaSalle University.___________

Have you taught at another college/ university prior to LaSalle?

YES NO

If Yes, for how many years.______________________

Please state the year in which you completed your PhD._________

Did you obtain your doctorate with the intension of entering an academic career?

YES NO

Did you teach during the years that you acquired your doctorate degree?

In what capacity (TA etc.)________________

Did you receive any specific training that relates to teaching?

YES NO

Please comment.____________________________

If Yes, Please answer the following 2 questions:

1) **This experience impacted my current teaching.**

   Strongly Disagree - Disagree - Neutral - Agree - Strongly Agree

2) **I learned a lot during this time about how students learn my subject material.**

   Strongly Disagree - Disagree - Neutral - Agree - Strongly Agree

Please answer the following questions:

I look at my content material from the students view.

Strongly Disagree - Disagree - Neutral - Agree - Strongly Agree

Limited time constraints influence my choice of content material.

Strongly Disagree - Disagree - Neutral - Agree - Strongly Agree

I am confident in my ability to teach successfully.

Strongly Disagree - Disagree - Neutral - Agree - Strongly Agree

I have reduced the depth of content material over the years.

Strongly Disagree - Disagree - Neutral - Agree - Strongly Agree

I have received instruction in student learning styles or how people learn.

Strongly Disagree - Disagree - Neutral - Agree - Strongly Agree

At the end of a subject unit, I reflect with intension to modify future sections.

Strongly Disagree - Disagree - Neutral - Agree - Strongly Agree

Students have great difficulty learning the basic concepts of my course.

Strongly Disagree - Disagree - Neutral - Agree - Strongly Agree

Students are disconnected from my content material.

Strongly Disagree - Disagree - Neutral - Agree - Strongly Agree

Students have misconceptions that are difficult to change.

Strongly Disagree - Disagree - Neutral - Agree - Strongly Agree

Students do not commit enough time to my course.

Strongly Disagree - Disagree - Neutral - Agree - Strongly Agree

I grade all assignments/tests myself.

Strongly Disagree - Disagree - Neutral - Agree - Strongly Agree

I often modify a class after grading an assignment/test.

Strongly Disagree - Disagree - Neutral - Agree - Strongly Agree

I use the textbook as a guide to content order.

Strongly Disagree - Disagree - Neutral - Agree - Strongly Agree

I learn a lot about how to teach from listening to my student's questions.

Strongly Disagree - Disagree - Neutral - Agree - Strongly Agree

I teach this course the way it was taught to me.

Strongly Disagree - Disagree - Neutral - Agree - Strongly Agree

Ranking from 1 (highest) to 10 (lowest) the strategies used to develop (transform) subject knowledge according to how useful you think they are.

Making notes from the textbooks ______

Asking colleagues ______

Searching the internet ______

Reading science education research ______

Reading misconception literature ______

Reading textbooks ______

Grading exam papers ______

Grading homework _____

Using information from university sessions _____

Using notes from your schooling of the same subject _____

Do you consider yourself a researcher or teacher? Researcher Teacher Both Equally

What portion of your time is spent on teaching including grading prep etc. versus research in your field? _____________

When thinking about your expert content area, how do you decide what content material to include in your undergraduate courses?

What difficulties or challenges do you face when deciding what content to include/exclude?

What is the most important factor you consider when planning a lesson or unit?

What factors distinguish science knowledge of teachers from that of scientists?

Would you consent to a brief interview?

If No, thank you for helping with my research. Please tear off this last page before returning the survey, it will ensure complete anonymity.

If Yes, thank you. And please provide your preferred contact information.

APPENDIX C - REFERENCES FOR PILOT QUESTIONNAIRE

QUESTION NUMBER	QUESTION	PURPOSE	AUTHORS
Question 1	Did you receive any specific training that relates to teaching? If Yes: This experience impacted my current teaching. I learned a lot during this time about how students learn my subject material	Pedagogical background and impact on current teaching	Akerson, Medina, & Wang, 2002; Kapyla, Heikkinen, & Asunta,2009; Lee, & Luft 2008; Park, 2011; Park & Oliver 2008
Question 2	I look at my content material from the students view		Atay, Kasliosky, & Kurt, 2010; Lee, 2005 dissertation
Question 3	Limited time constraints influence my choice of content material		Kapyla, Heikkinen, & Asunta, 2009; Park, 2011; Park & Oliver 2008.
Question 4	I am confident in my ability to teach successfully		(Kind, 2009b).
Question 5	I have reduced the depth of content material over the years		Park, 2011; Park & Oliver 2008
Question 6	I have received instruction in student learning styles or how people learn		Akerson, Medina, & Wang, 2002; Kapyla, Heikkinen, & Asunta, 2009; Lee, & Luft 2008; Park, 2011; Park & Oliver 2008
Question 7	At the end of a subject unit, I reflect with intension to modify future sections		Atay, Kasliosky, & Kurt, 2010; Halim & Meerah, 2002; Park, 2011; Park & Oliver 2008
Question 8	Students have great difficulty learning the basic concepts of my course		Kapyla, Heikkinen, & Asunta, 2009
Question 9	Students are disconnected from my content material		Park, Jang, Chen, & Jung, 2011
Question 10	Students have misconceptions that are difficult to change		Halim & Meerah, 2002

Question 11	Students do not commit enough time to my course		
Question 12	I grade all assignments/tests myself		Kind, 2009
Question 13	I often modify a class after grading an assignment/tests		Kind, 2009; Park, Jang, Chen, & Jung, 2011
Question 14	I use the textbook as a guide to content order		Kind, 2009
Question 15	I learn a lot about how to teach from listening to my student's questions		Atay, Kasliosky, & Kurt, 2010; Halim & Meerah, 2002; Kind, 2009
Question 16	I teach this course the way it was taught to me		Davis, 2004
Question 17	Ranking from 1 (highest) to 10 (lowest) the strategies used to develop (transform) subject knowledge according to how useful you think they are: Making notes from the textbooks Asking colleagues Searching the internet Reading science education research Reading misconception literature Reading textbooks Grading exam papers Grading homework Using information from university sessions Using notes from your schooling of the same subject		Kind, 2009
Question 18	Do you consider yourself a researcher or teacher	Researcher Teacher Both Equally	Davis, 2004; Rohaan,Taconis, & Jochems, 2009; 2011
Question 19	What portion of your time is spent on teaching including grading prep etc. versus research in your field		(Kind, 2009; Park, Jang, Chen, & Jung, 2011).

Question 20	When thinking about your expert content area, how do you decide what content material to include in your undergraduate courses?		Davis, 2004; Park & Oliver, Rohaan,Taconis, & Jochems, 2009; 2011
Question 21	What difficulties or challenges do you face when deciding what content to include/exclude		(Atay, Kasliosky, & Kurt, 2010; Davis, 2004; Rohaan,Taconis, & Jochems, 2009; 2011).
Question 22	What is the most important factor you consider when planning a lesson or unit?		(Atay, Kasliosky, & Kurt, 2010; Davis, 2004 ; Halim & Meerah, 2002)
Question 23	What factors distinguish science knowledge of teachers from that of scientists?		(Maskit, 2011, Park & Oliver, Rohaan,Taconis, & Jochems, 2009; 2011)

APPENDIX D - QUESTIONNAIRE FOR THE MAJOR STUDY

One of the critical issues that all teachers face is how to present the material in a coherent and understandable way to students. This is true at all levels of education, but is perhaps even more critical at the college level. All college instructors have a significant background of content knowledge about their fields. What college instructors often do not have is any specific training in how to translate this content knowledge in ways that make the material accessible to students. In education, this is called Pedagogical Content Knowledge. The purpose of my research is to gain a better understanding of Pedagogical Content Knowledge by investigating how instructors develop this ability.

THANK YOU FOR TAKING THE TIME TO SUPPORT MY RESEARCH

Please circle your gender.

MALE FEMALE

How many years have you been teaching at Temple University.___________

Are you an Adjunct NTT Tenure/T-Track

Please state the year in which you completed your PhD._________

Did you obtain your doctorate with the intension of entering an academic career?

YES NO

Did you teach during the years that you acquired your doctorate degree?

In what capacity (TA etc.)________________

Have you received any specific training that relates to teaching?

YES NO

Please comment.____________________________

If Yes, Please answer the following 2 questions:

3) **This experience impacted my current teaching.**

   Strongly Disagree - Disagree - Neutral - Agree - Strongly Agree

4) **I learned a lot during this time about how students learn my subject material.**

   Strongly Disagree - Disagree - Neutral - Agree - Strongly Agree

Please answer the following questions:

I look at my content material from the students view.

Strongly Disagree - Disagree - Neutral - Agree - Strongly Agree

Limited time constraints influence my choice of content material.

Strongly Disagree - Disagree - Neutral - Agree - Strongly Agree

I am confident in my ability to teach successfully.

Strongly Disagree - Disagree - Neutral - Agree - Strongly Agree

I have reduced the depth of content material over the years.

Strongly Disagree - Disagree - Neutral - Agree - Strongly Agree

At the end of a subject unit, I reflect with intension to modify future sections.

Strongly Disagree - Disagree - Neutral - Agree - Strongly Agree

Students have misconceptions that are difficult to change.

Strongly Disagree - Disagree - Neutral - Agree - Strongly Agree

Students do not commit enough time to my course.

Strongly Disagree - Disagree - Neutral - Agree - Strongly Agree

I often modify a class after grading an assignment/test.

Strongly Disagree - Disagree - Neutral - Agree - Strongly Agree

I use the textbook as a guide to content order.

Strongly Disagree - Disagree - Neutral - Agree - Strongly Agree

I teach this course the way it was taught to me.

Strongly Disagree - Disagree - Neutral - Agree - Strongly Agree

Ranking from 1 (highest) to 10 (lowest) the strategies used to develop (transform) subject knowledge according to how useful you think they are.

Making notes from the textbooks ______

Asking colleagues ______

Searching the internet ______

Reading science education research ______

Reading misconception literature ______

Reading textbooks ______

Grading exam papers ______

Grading homework ______

Using information from university sessions _____

Using notes from your schooling of the same subject _____

Do you consider yourself a researcher or teacher?

Researcher Teacher Both Equally

What portion of your time is spent on teaching including grading prep etc. versus research in your field? _____________

As you think back on your science teaching career:

How has your teaching changed over the years? What factors/events where the most influential in changing your teaching? AND how has your teaching transformed?

What factors have remained stable about your teaching?

Would you consent to a brief interview?

Thank you. And please provide your preferred contact information.

APPENDIX E - INTERVIEW QUESTIONS

I am interested in the process by which you transform your expert content knowledge in order to teach.

I would like to discuss your thinking process and stages of planning to teach a course or lesson. LEE dissert

What about a discipline does a teacher need to know in order to teach?

When you plan your lesson what do you consider first?

How do you decide what to teach and what not to teach for a course?

What do you consider when you are actually teaching?

Do you make similar choices when teaching outside of your specific content area?

How do you decide on these particular strategies?

What difficulties or challenges have you encountered when converting your expert content material into teaching a lesson?

What do you feel is the most influential problem teaching your discipline? Kapyla 2009

What are your strengths as a science teacher?

How did you acquire those strengths?

What are your weaknesses?

What obstacles do your encounter when you teach?

What are the specific ways that you ascertain students understanding or confusion?

Could you tell me what are the reasons for learning science in college Park Oliver diss

What do you think makes science difficult for students?

How do you address these difficulties?

What factors distinguish science knowledge of teachers from that of scientists?

What are the characteristics that demonstrate a science teacher's expertise LEE

How has your teaching changed over the years? Rubin 1989/Kapyla 2009

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++

If additional time or 2nd interview??

Tell me about a particular lesson or unit in a semester long course.

Why did you choose to include this particular unit or lesson?

How did you decide how to teach this material?

When you developed your lesson on this unit what assumptions did you make about the students learning and knowledge of this topic

Where you aware of any particular misconceptions or student difficulties with this material

Do you have alternative ways of teaching this unit? explain

When you generating ideas of how to teach, where do these ideas come from.

What is your ultimate goal for the students from this lesson?

APPENDIX F - REFERENCES FOR QUESTIONNAIRE

QUESTION NUMBER	QUESTION	PURPOSE	AUTHORS
Question 1	Did you receive any specific training that relates to teaching? If Yes: This experience impacted my current teaching. I learned a lot during this time about how students learn my subject material	Pedagogical background and impact on current teaching	Akerson, Medina, & Wang, 2002; Kapyla, Heikkinen, & Asunta,2009; Lee, & Luft 2008; Park, 2011; Park & Oliver 2008
Question 2	I look at my content material from the students view		Atay, Kasliosky, & Kurt, 2010; Lee, 2005 dissertation
Question 3	Limited time constraints influence my choice of content material		Kapyla, Heikkinen, & Asunta, 2009; Park, 2011; Park & Oliver 2008.
Question 4	I have reduced the depth of content material over the years		Park, 2011; Park & Oliver 2008
Question 5	At the end of a subject unit, I reflect with intension to modify future sections		Atay, Kasliosky, & Kurt, 2010; Halim & Meerah, 2002; Park, 2011; Park & Oliver 2008
Question 6	Students have misconceptions that are difficult to change		Halim & Meerah, 2002
Question 7	Students do not commit enough time to my course		
Question 8	I often modify a class after grading an assignment/tests		Kind, 2009; Park, Jang, Chen, & Jung, 2011
Question 9	I use the textbook as a guide to content order		Kind, 2009
Question 10	I teach this course the way it was taught to me		Davis, 2004
Question 11	Ranking from 1 (highest) to 10 (lowest) the strategies used to develop (transform) subject knowledge		Kind, 2009

	according to how useful you think they are: Making notes from the textbooks Asking colleagues Searching the internet Reading science education research Reading misconception literature Reading textbooks Grading exam papers Grading homework Using information from university sessions Using notes from your schooling of the same subject		
Question 12	Do you consider yourself a researcher or teacher	Researcher Teacher Both Equally	Davis, 2004; Rohaan,Taconis, & Jochems, 2009; 2011
Question 13	What portion of your time is spent on teaching including grading prep etc. versus research in your field		(Kind, 2009; Park, Jang, Chen, & Jung, 2011).
Question 14	When thinking about your expert content area, how do you decide what content material to include in your undergraduate courses?		Davis, 2004; Park & Oliver, Rohaan,Taconis, & Jochems, 2009; 2011

APPENDIX G – STATISTICAL ANALYSIS OF JOB PURPOSE

Total Sample	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Mean
I am confident in my ability to teach successfully	48.6%	43.1%	8.3%	0.0%	0%	4.40
Students do not commit enough time to my course	26.4%%	47.2%	9.7%	11.1%	5.6%	3.76
Students have misconceptions that are difficult to change	14.1%	31.0%	26.8%	25.4%	2.8%	3.28

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Mean
At the end of a subject, I reflect with intent to modify future sessions	25.7%	55.7%	12.9%	4.3%	1.4%%	4.00
I look at my content material from a student's view	27.8%	52.8%	8.3%	11.1%	0%	3.97
I use the textbook as a guide to content order	18.3%	57.7%	14.1%	9.9%	0%	3.85
Limited time constraints influence my choice of content material	26.4%	47.2%	9.7%	11.1%	5.6%	3.78
I often modify a class after grading an assignment or test	12.5%	43.1%	19.4%	23.6%	1.4%	3.42
I have reduced the depth of content material over the years.	8.3%	20.8%	26.4%	44.4%	9.7%	2.83
I teach this course the way it was taught to me	2.8%	11.3%	25.4%	60.6%	19.7%	2.37