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Long-Term Impact of Professional Development Project on the Pedagogical Content Knowledge of University Faculty

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Paper presented at the NSEUS national conference on Research Based Undergraduate Science Teaching Conference II, Bryant Conference Center, University of Alabama, Tuscaloosa AL May, 21-22, 2012

Abstract

This study explored the long-term impact of a ten year professional development project geared towards science education reform on the pedagogical content knowledge of university faculty that participated in this project. On-site case studies were completed with 35 faculty instructors teaching entry-level undergraduate science courses at 19 higher education institutions. The sample was selected from a national population of diverse colleges and universities that had undergone reform in one or more of their undergraduate science courses. The data collection protocol involved classroom observations, interviews, semi-structured interviews, and field notes from multiple instruments and sources. Data were collected during on-site visits from university faculty instructors and their undergraduate students. Quantitative and qualitative analysis identified variations in faculty instructors' PCK regarding their intended and enacted teaching goals, instruction, and rationale for teaching a specific science concept in observed science lessons. Analysis of quantitative and qualitative data revealed significant pedagogical differences between faculty who participated in the NASA/NOVA professional development project and those who did not. Moreover, the following characteristics regarding the pedagogical content knowledge of faculty instructors who participated in the NASA/NOVA project emerged: (1) content knowledge regarding the science concept taught and observed during instruction; (2) orientations consistent with reform instruction advocated by the *National Science Education Standards* for effective science teaching; (3) purposeful selection of activities that best engender student understanding of specific science concepts; and (4) reflective practitioner.

Keywords: Pedagogical Content Knowledge; Science Education; Science Teacher Education

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Science education reform has been at the forefront of science education research endeavors for several decades. The latest reform endeavors emphasize student outcomes that are emanate from inquiry understandings and abilities, and provide guidance for inquiry-based science teaching and learning (National Research Council [NRC], 1996; 2000; American Association for the Advancement of Science [AAAS], 1990). These endeavors venture to engage students in skills associated with the nature of science which entails students predicting, investigating, testing hypothesis, finding patterns, building explanations, and communicating and justifying ideas. The NSES suggests that these sorts of activities help to facilitate scientific literacy. Scientific literacy is described in reform documents as “the ability to describe, explain, and predict natural; phenomena as well as the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately.” (NSES, 1996, p.22)

The *National Science Teachers Association* (NSTA) standards for science teacher preparation are congruent with the vision of the NSES. According to these standards, “The NSES is a visionary framework for science teaching in precollege education, based upon the assumption that scientific literacy for citizenship should be a primary--if not exclusive--goal of science education at the precollege level” (NSTA, 2003, p. 1).

The *National Science Education Standards* and the *National Science Teachers Association* standards for science teacher preparation recommend that teachers have the content knowledge and pedagogical knowledge needed for effective science teaching to occur. Under Professional Development Standard B, the NSES states that effective science teaching requires more than knowledge of science content and possessing a host of teaching strategies; rather it is the ability of the teacher to integrate their knowledge of science content, curriculum, learning, teaching, and students to facilitate and deepen student understanding of science content. Such knowledge allows teachers to tailor learning situations to the needs of individuals and groups. It is this specialized knowledge, called “pedagogical content knowledge,” that distinguishes the science knowledge of teachers from that of scientists.

There seems to be a rift between reform efforts, teacher education programs, and classroom practice. The missing ingredient appears to be the lack of emphasis placed on pedagogical content knowledge (PCK). Pedagogical content knowledge seems to be the mediating factor between content and pedagogical knowledge. PCK is expert knowledge that resides within the teacher. It is the teacher’s ability to transform specific science content through the purposeful use of instructional strategies, knowledge of students learning difficulties and prior knowledge, and knowledge of the curriculum making it understandable to those being taught. It is this type of knowledge, pedagogical content knowledge, that best informs effective science teaching practice

Current attempts at reform tend to stress unilaterally either content or pedagogy, often providing teachers with an array of non-contextualized, unconnected activities, concepts and demonstrations (Mason, 1999). This situation is what Shulman (1986) described over 20 years ago as the “missing paradigm” in teacher education. Then, Shulman conceptualized the missing paradigm as a blind spot regarding content that characterized research on teaching. The emphasis was placed on issues such as how teachers manage their classrooms, organize activities, and allocate time and turns without placing emphasis on science content knowledge. This study is unique in that the reformed undergraduate science courses examined were a unique blend of content and pedagogy. These courses were the resultant of a ten year professional project, the NASA Opportunities for Visionary Academics (NASA/NOVA), developed to facilitate change in higher education to enhance science, technology, engineering and mathematics literacy of pre-service teachers (Sunal, Wright, & Day, 2004). The purpose of this study was to examine the impact of the NASA/NOVA professional development project on the pedagogical content knowledge of university faculty who participated in the project.

The program's focus was on assisting faculty to develop, implement, disseminate, and sustain innovative science, technology, engineering, and math (STEM) curricula in order to improve the STEM literacy of future teachers by implementing standards- and research-based change nationally in entry-level undergraduate content courses using NASA's unique content. The NASA/NOVA project described types of professional development activities faculty instructors received over the course of 10 years. These activities were framed around the National Science Education Standards (NSES) and helped to inform and shape the pedagogical practices of undergraduate faculty.

One national endeavor to evaluate the impact of the NASA/NOVA professional development project was the National Study of Education in Undergraduate Science (NSEUS). The National Study of Education in Undergraduate Science (NSEUS) examined the critical undergraduate science course characteristics and variations in teaching science content to undergraduates with diverse majors. In an attempt to examine the pedagogical content knowledge of university faculty instructors teaching these reformed courses, I used a portion of the data collected during this multi-year study in which I served as doctoral student investigator.

The overarching research question that was examined in this study was, "What is the long-term impact of the NASA Opportunities for Visionary Academics (NOVA) professional development project on the pedagogical content knowledge of university faculty?" More specifically, the following research questions were examined.

1. Are there observed pedagogical differences between faculty teaching reformed and comparison undergraduate science courses?
2. What are common characteristics regarding the pedagogical content knowledge of faculty instructors of the undergraduate science reform course who participated in the NOVA professional development workshop and those who did not?

Theoretical Framework

Pedagogical Content Knowledge (PCK)

Pedagogical content knowledge (PCK) was first described by Lee S. Shulman (1986) to explicate the transformation of subject-matter knowledge into forms understandable and accessible to the students being taught (Abell, 2007). Shulman suggested that PCK goes beyond knowledge of subject to the dimension of subject matter knowledge for teaching. It includes the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations--in a word, the ways of representing and formulating the subject that make it comprehensible to others (Shulman).

Twenty years after Shulman's conception of PCK, Loughran, Berry, & Mulhall (2006) provided additional insight by describing PCK as an academic construct that is rooted in the belief that teaching requires more than delivering subject content knowledge to students, and that student learning is considerably more than absorbing information for later accurate regurgitation.

They suggested that PCK is the knowledge that teachers develop over time, and through experience, about how to teach particular content in particular ways that will lead to enhanced student understanding (Loughran et al.). Successful teachers then have a special knowledge that informs their teaching of particular content and that special knowledge is encapsulated in PCK. Teachers not only know content but they have a variety of teaching strategies that they use to teach that content for specific reasons. Effective teachers are deliberate in their selection of strategies to be used with particular content (Loughran et al.). They may draw upon student alternative conceptions/misconceptions and their prior knowledge and experiences in order to shape their teaching (Loughran et al.).

Pedagogical content knowledge was explicated by Gess-Newsome (1999) as a construct that falls along a continuum of models of teacher knowledge that may be *Integrative* or *Transformative*. The integrative model implies that PCK does not exist as an exclusive domain of teacher knowledge but rather the extrapolation of knowledge from subject matter, pedagogy, and context domains are melded in classroom practice (Gess-Newsome). The transformative model, however, implies that these knowledge domains (i.e. subject matter, pedagogy, and context) are inextricable and result in a new form of knowledge, PCK. It is this latter model that forms that basis of this current study. Within the context of this study, only content knowledge, pedagogical knowledge, and orientations toward science teaching are considered. Orientations toward Science Teaching are considered in order to understand the underlying goals and rationale for the specific instructional strategies used to teach specific science content.

Orientations toward Science Teaching. Orientations toward science teaching are typically organized according to the emphasis of instruction from purely process or content to those that emphasize the national standard of being inquiry-based (Magnussen et al., 1999). These orientations are described with regard to the goals of science teaching that a teacher with a particular orientation would have and the typical characteristics of the instruction that would be conducted by a teacher with a particular orientation. Nine orientations toward science teaching and the purposes and characteristics of instruction associated with that orientation were proposed by Magnussen et al. These orientations were divided into two categories by Friedrichson (2003): (a) teacher-centered orientations (didactic and academic rigor), and (b) orientations based on the reform efforts of the 1960s (process, activity-driven, discovery) and those based on contemporary reform efforts and associated curriculum projects (conceptual change, project-based, inquiry, and guided inquiry). They cautioned that a particular teaching strategy (e.g., use of laboratory investigations) may be characteristic of more than one science teaching orientation: “this similarity indicates that it is not the use of a particular strategy but the purpose of employing it that distinguishes a teacher’s orientation to teaching science” (p. 97).

Content Knowledge. Content knowledge may be defined as the concepts, principles, relationships, processes, and applications a student should know within a given academic subject, appropriate for his/her organization of the knowledge (Ozden, 2008). Earlier, Schulman drew upon Joseph Schwab’s definition of content knowledge. For Schwab, the structures of the content include both the substantive and syntactic structures. The substantive structure of the content is the organization of concepts, facts, principles, and theories, whereas syntactic structures are the rules of evidence and proof used to generate and justify knowledge claims in the discipline (Abell, 2007).

Pedagogical Knowledge. Pedagogical Knowledge Pedagogical knowledge includes the general aspects of teacher knowledge about teaching such as learning theory, instructional principles, and classroom discipline (Abell, 2007). Mishra and Koehler (2006) described pedagogical knowledge as,

> deep knowledge about the processes and practices of teaching and learning, encompassing educational purposes, goals, values, strategies, and more. This is a generic form of knowledge that applies to student learning, classroom management, instructional planning and implementation, and student assessment. It includes knowledge about techniques or methods used in the classroom, the nature of the learners' needs and preferences, and strategies for assessing student understanding. A teacher with deep pedagogical knowledge understands how students construct knowledge and acquire skills in differentiated ways, as well as how they develop habits of mind and dispositions toward learning. (p. 1026).

Literature Review

Current research regarding the pedagogical content knowledge of undergraduate faculty instructors is sparse. Most studies regarding PCK tend to focus on preservice or inservice teachers. Studies conducted by Kaya (2009), Ozden (2008), Halim and Meerah (2002), Van Driel, De Jong, and Verloop (2002) and Van Driel, Verloop, and De Vos (1998) demonstrated that content knowledge influenced the development of pedagogical content knowledge. Moreover, the relationship among the components of pedagogical content knowledge (PCK) involving the topic ozone layer depletion for preservice science teachers' (PSTs) was examined by Kaya (2009). Within the context of the study, Shulman's model of PCK was used. PCK consisted of content knowledge and pedagogical knowledge. Results from this study revealed that there was a significant inter-relationship between the subject matter and pedagogical knowledge of the PSTs. Also there were significant intra-relationships among the components of the PSTs pedagogical knowledge except for knowledge of assessment. Likewise, Ogletree found that fifth grade teachers lacked the appropriate content knowledge regarding the concept of chemical change.

Preservice teachers were found to expand their PCK by deepening their understanding of learning difficulties and student misconceptions after learning from teaching as they experienced a postgraduate teacher education program (De Jong, Van Driel, & Verloop, 2005; De Jong & Van Driel, 2004; Van Driel, De Jong, & Verloop, 2003). The results of this qualitative study revealed that an extensive, 1-year, training course on teaching chemistry topics, which used particle models for matter, successfully contributed to the development of PCK of the preservice teachers (DeJong et al.).

In a similar study involving interpretive case studies that drew upon classroom observations, semi-structured interviews, chemistry content knowledge surveys, beliefs surveys, and documents as data sources, Faikhamta, Coll, and Roadrangka (2009) examined the impact of a PCK-based methods course on preservice chemistry teachers' PCK, and investigated how they developed and brought their PCK into teaching practice during their teaching field experience. Findings revealed that upon experiencing the PCK-based chemistry methods course, all of the preservice teachers gradually developed their PCK. Preservice teachers had a better understanding of student learning difficulties and took into account student prior knowledge when planning lessons. Similar results were obtained by Hsiao-lin and others (1995).

Methods

Context of the Study

The setting comprised a diverse population of institutions throughout the U.S. These institutions included Historically Black Colleges and Universities (HBCU), master's level (MA) colleges and universities, Hispanic Serving Institutions (HSI), Native American Institutions, and doctoral/research universities based on the Carnegie classification (Sunal, Sunal, Mason, & Zollman, 2008). Faculty instructors at institutions who had participated in the NASA/NOVA professional development project and who taught undergraduate science were invited to participate in the NSEUS study. Faculty were called and emailed to solicit their participation. A sample of 30 institutions was finally selected. Due to attrition and/or the dissolving of courses at some of the institutions, the final sample size resulted in 19 higher education institutions being used for data collection. The institutions that participated in this study were located throughout the nation.

Participants

The participants comprised 35 faculty instructors. The faculty instructors of the reformed courses participated directly or indirectly in the NASA/NOVA program and were implementing reform practices in their respective undergraduate classrooms. Some faculty instructors inherited the reform course from a previous instructor who had participated in the project; thus, the course was a reformed course but the faculty had not participated directly in the NASA/NOVA project and did not necessarily implement standards-based reform practices.

Data Collection

Data collection involved an intense week-long site visit to each of the 19 institutions. As stated earlier, this study was a part of a larger longitudinal study that was conducted over a period of 5 years, 2006-2011. The overarching research question investigated in this study was, "what is the long-term impact of the NASA/NOVA professional development project on the pedagogical content knowledge of university faculty?" The use of both quantitative and qualitative methods strengthened my research design and allowed for the triangulation of data.

The quantitative phase of the data collection included the classroom observations of university faculty instructors. Faculty instructors of reformed and comparison courses were observed at least twice during a week-long site visit using the *Reformed Observation Teaching Protocol,* a criterion referenced test designed to measure the degree of reform in a science classroom (Sawada, Piburn, Turley, Falconer, Benford, Bloom, & Judson, 2002). These observations lasted from 60 to 90 minutes and typically consisted of a lecture, laboratory, or a class that had a combined lecture and laboratory. At least two trained observers observed classroom instruction. The RTOPs were individually scored immediately after the classroom observation and then discussed to resolve any discrepancies between researcher ratings. The labs and lecture were combined to give an average RTOP score for each faculty.

The qualitative phase of data collection used interviews and *Content Representation* (CoRe) and the *Personal and Professional experience Repertoire* (PaP-eRs) instruments. A CoRe provides an overview of how teachers conceptualize the content of a particular subject matter or topic (Loughran, Mulhall, & Berry, 2006). According to Loughran et al. whether or not a particular action by a teacher is illustrative of that teacher's PCK is closely related to the thinking upon which the teacher reasons through and develops the subsequent teaching action.

Pedagogical and Professional experience Repertoires are narrative accounts of a teacher's PCK for a particular piece of science content. Each PaP-eR then "unpacks" the teacher's thinking around an element of PCK for that content, and is based on classroom observations and comments made by teachers during the interviews from which the CoRes were developed. *Pedagogical and Professional experience Repertoires* are intended to represent the teacher's reasoning, that is, the thinking and actions of a successful science teacher in teaching a specific aspect of science content. The function of the narrative is to elaborate and give insight into the interacting elements of the teacher's PCK in ways that are meaningful and accessible to the reader, and that may serve to foster reflection in the reader about the PCK under consideration, and to open the teacher reader to possibilities for change in his/her own practice (Mulhall, Berry, & Loughran, 2003). Interviews were conducted with the faculty instructors immediately following classroom observations lasting anywhere from 60 -90 minutes.

After the classroom observations and interviews were completed for each faculty instructor, a CoRe was constructed from the interviews and a PaP-eR was constructed from classroom observations and field notes to flesh out the goals and rationales for the observed lesson. The CoRe and PaP-eRs were evaluated using a researcher designed PCK rubric to capture rich "*Snapshots*" of PCK for each faculty instructor regarding their orientation toward science teaching, content knowledge, and pedagogical knowledge (See Table S1 for PCK rubric). Since PCK cannot necessarily be gauged from one classroom setting (Loughran et al., 2006), I elicit the term "*Snapshots*" to describe instances of specific events of PCK (See Table S2 for example of a faculty snapshot). Part of the initial design for the rubrics used in this study came from a careful examination of the rubrics designed and used by Ogletree (2007) in her examination of 5th grade elementary teacher's pedagogical content knowledge for states of matter. Ogletree's four rubrics included (1) content knowledge, (2) student thinking, (3) science teacher knowledge, and (4) professional development. The PCK rubric used in this study assesses PCK holistically, rather than assessing the individual components, by providing an overall PCK rating based on a combination of their content and pedagogical knowledge as evidenced in their interviews, CoRe & PaP-eR, and classroom observations.

Prior to the classroom observations and interview, I or one of my colleagues discussed the purpose of the project and the means by which privacy and confidentiality would be established. Once the faculty instructors agreed to continue with participation in the study, a consent formed was signed and stored in a secure location in which the primary investigator of the study had the only access. Each faculty instructor secured student volunteers to participate in the undergraduate student focus groups. The focus groups were interviewed after the classroom observation of the faculty instructor. I or one of my colleagues explained the nature of the study and the means by which privacy and confidentiality would be established to the undergraduate students. We also informed them that their participation in the interview was completely voluntary. Once the students agreed to continue with participation in the study, signed consent forms were received from each student.

Careful examination of the interviews, CoRe and PaP-eRs, and RTOPs using the PCK rubric yielded rich "*snapshots*" of PCK for faculty instructors. The science instruction observed, as well as the information provided in the interviews, provided insight as to the faculty instructor's orientation toward teaching science, topic specific content knowledge, and their rationale for the instructional strategy used to teach that particular science topic.

Data Analysis

Data analysis comprised the use of various quantitative computational procedures as well as the qualitative evaluation of categories from the interviews along with the CoRes and PaP-eRs. Faculty instructors were divided into those who taught the reform course and those who taught the comparison course. Faculty of the reform course participated in the NASA/NOVA professional development project or inherited the course from someone who had previously participated in the project. Characteristics of the reform course related to the *National Science Education Standards* appropriate for science teaching and learning at the undergraduate level. The comparison course was a course of comparable subject and academic level that was not developed through NASA/NOVA professional development workshop. The comparison course was a science course that included a lecture and a lab. In order to determine if there were statistically significant differences between the reform and the comparison course, a Multivariate Analysis of Variance (MANOVA) was performed.

Interviews were coded using a set of predetermined categories to capture "*snapshots*" of the pedagogical content knowledge of faculty instructors. Salient themes emerging from the interviews were also noted. From the interviews and classroom observations, CoRes and PaP-eRs were constructed and evaluated for each faculty instructor to yield a snapshot of PCK. The interview and the CoRe and PaP-eR were analyzed using the PCK framework. The PCK framework was vetted with the literature on PCK and is based upon Shulman's (1986); Grossman's (1990); and, Magnussen, Borko, and Krajcik's (1999) work with PCK.

The PCK framework focused on *Orientations toward Science Teaching (OST)*; *Content Knowledge*; and *Pedagogical Knowledge* (See Table S3 for PCK Framework). The PCK framework was used to develop a PCK checklist for each faculty instructor (see Table 3 for PCK checklist). Based on the components of the checklist, the PCK rubric was used to provide an overall PCK rating for each faculty instructor and each inservice elementary teacher. Inter-rater reliability and validity for the PCK rubric was achieved through consultation with Science Educator Specialists with teaching experience in Kindergarten-Grade16 classrooms. These individuals were experts in their respective fields and had expert knowledge in physics, physical science, biology, and chemistry. Each specialist evaluated the interviews, CoRe and PaP-eRs, and RTOPS of two teachers using the PCK framework, PCK checklist, and PCK rubric to come up with an overall PCK rating for the two teachers. The scores and comments of the specialists were the same as that of the investigator. Using the PCK checklist, interviews, RTOP field notes and the overall PCK rating, a snapshot was written for twelve of the faculty instructors.

Currently, there is no standard means by which to capture or measure an individual's PCK (Friedrichson, Van Driel, & Abell, 2011); however, the investigator used both quantitative and qualitative data from classroom observations, field notes, and interviews in an attempt to capture "snapshots" of PCK. The quantitative analysis of the RTOPs and its corresponding subscales provided insight as to the amount of reform instruction observed during the classroom observations of both faculty and inservice teachers. The RTOP alone did not provide insight as to the teacher's rationale for choosing a particular teaching strategy to teach the science concept observed during a lesson. Pedagogical content knowledge is premised on the ability of the teacher to transform subject matter into a form that is understandable and accessible to students. In part, the ability to transform specific science content is based upon the faculty instructor's knowledge of the prerequisite skills students need for the learning of a particular topic as well as their prior knowledge and experiences. The interviews, along with the CoRe and PaP-eR, allowed the investigator to examine the decision making aspect of teaching practice. That is, why faculty instructors chose certain strategies to teach specific science concepts and what they knew about their students that informed their decisions.

Research Question 1

In order to answer research question number 1, “Are there pedagogical differences between faculty instructors of reform and comparison undergraduate science courses,” an independent *t* test was used to compare the overall means of the reformed and comparison course for the total RTOP score and a multivariate analysis of variance was performed based on the subscales of the RTOP. Each faculty was observed using the RTOP instrument at least two times during the site visit. At least two research team members were present to conduct the classroom visitations. The labs and lecture were combined to give an average RTOP score for each faculty instructor. The RTOP instrument comprised 5 subscales: (a) Lesson Design and Implementation, (b) Propositional Knowledge, (c) Procedural Knowledge, (d) Communicative Interactions, and (5) Student Teacher Relationships. A total of 20 points can be accrued in each subscale with a maximum RTOP score of 100.

Results from the quantitative analysis of data found a statistically significant difference in the total RTOP score between faculty who were instructors of reform and comparison undergraduate science courses, t (33, 2.997), p =.005. [Insert Table 1 here]. Analysis of classroom observations on RTOP subscale scores between reformed and comparison courses found statistically significant group effects (Wilks = .028, $F[5, 29] = 3.756$, $p = .010$). Univariate analyses indicated no significant group effects on the Propositional Knowledge subscale [$F(1, 33) = 2.729$, $p = .108$]. However, Univariate analyses indicated that significant group effects did occur on the Lesson Design and Implementation subscale [$F(1, 33) = 6.242$, $p = .018$], Procedural Knowledge subscale [$F(1, 33) = 6.978$, $p = .029$], Communicative Interactions subscale [$F(1, 33) = 13.298$, $p = .013$], and Student Teacher Relationships subscale [$F(1, 33) = 8.143$, $p = .007$]. [Insert Table 2 here]. These results suggests that the level of reformed teaching in entry-level reformed undergraduate science courses is different from the comparison courses on all RTOP subscales other than the Propositional Knowledge subscale.

The quantitative results of question one were enhanced by qualitative findings emanating from the interviews. Faculty instructors that taught the reformed course taught in a more reformed manner. These faculty instructors were more inclined to suggest that a constructivist approach to classroom practice was the best approach to science teaching and learning. In addition, they were able to provide a rationale as to why constructivist practices were the best approach to science teaching and learning.

Frank had taught Physics for over 25 years and was a part of the original NASA/NOVA team. He said that the physics [*reform*] course that he taught to students was a content course that was aligned with inquiry practices. His other physics courses were more lecture-based. He stated in his that inquiry was the best approach to teaching science.

> I teach this course differently than I teach my regular physics courses. Physics courses are lecture based. . . . Physics [reformed course] is inquiry based. . . . Elicitation addresses prior knowledge and misconceptions. . . . Exploration is the discovery portion. . . . Explanation--students give presentations. . . . (Faculty instructor Frank).

The comments made by the undergraduate student focus group of this faculty instructor corroborated the instructional strategies employed by this faculty,

> At beginning of each unit, [*we*] do brainstorm of all we know or don’t know . . . [*He*] does demos for us . . . they are reinforced by us doing activities . . . occasionally about 20 min of lecture. (Student in focus group from instructor Frank’s course)

A second example of a faculty instructor implementing reform practices was Eleanor. Eleanor had been teaching undergraduate science for over 15 years. She was also a part of the original NASA/NOVA team. She also adhered to a constructivist's approach to teaching. She varied instruction to accommodate the diverse needs of her students. She believed that the teacher should serve as a coach in science teaching and learning. The comments made by the undergraduate student focus group of this faculty instructor supported the statement as to the type of instructional practice used during classroom instruction,

> Case studies really help. Because they are actual people and they tell about the background . . . tell you what's wrong. . . . I like the lab when she let us choose our own lab. We had a topic of homeostasis and we had to come up with our own lab but it was all centered around the same thing but we could pick what we wanted to do but it was not like a standard thing like "you do this and this or here are the directions" (*Referring to cookbook or traditional labs*) . . . it was kind of up to you to do what you want (*How does it make you feel)?* Empowered. . . . (Student in focus group from instructor Eleanor's course)

James was an Adjunct Professor and had over 10 years teaching experience. James was also a part of the original NASA/NOVA faculty professional development project. He believed that science should be taught in a manner that is practical and relevant to students' lives and used activities that demonstrated this belief. Moreover, James believed that activities should reflect how scientists conduct scientific research. The comments of James's undergraduate student focus group relate closely to some of these same statements about this faculty instructor's instructional practices.

> We're doing stuff . . . we are not just sitting there getting lectures . . . using the computer . . . like what we are doing with the virtual river working in small groups . . . interactive stuff rather than sitting there listening to the professor talk to us . . . even the virtual river isn't as hands-on as we get . . . we go outside and do our own project, it is really independent. . . . (*James*) is just overseeing it but we are really doing everything . . . I feel that the experiment that we do with the [*river*] is much higher than what we are learning in the classroom to actually be able to do a bank profile up there is much more difficult than all sorts of other elements factor in . . . (Student in focus group from James' course)

Faculty instructor Bonnie had been teaching for 6 years. Although she was not a part of the original NASA/NOVA team, she attended several professional development workshops geared toward science education reform. She stated in her interview, "I learn a lot from talking with colleagues and attending meetings that discuss science education reform." Bonnie also participated in extensive ongoing professional development that provided training in reform pedagogical practices. Bonnie stated in her interview that the reform course had been developed about 10 years ago. She stated that prior to her teaching the class it was a traditional quantitative physics course. Her professional development experiences enabled to teach the course in a more reformed manner.

She believed that the teacher's role in science teaching should be that of a facilitator. She used modeling as an instructional strategy to teach the concept of circuits to her class. Students developed focus questions, made predictions and claims, and provided evidence about the model credibility. Students were able to explain circuits as well as troubleshoot as to why circuits may or may not work. The undergraduate student focus group corroborated the statements put forth by this faculty instructor. The students reported that the instructional strategies employed by this faculty instructor helped them to understand the practicality of science concepts, the scientific process, and the mechanism by which circuits work in the manner that they do,

> I never thought of electricity and magnetism as science before this course. Yeah. I never made the link that those things were part of science. They seemed just mechanical. . . . I'll remember circuits from working with them. . . I know it works, but now I'm starting to get a grasp on how and why it works . . . I'm thinking more about the scientific process. In lab we always go through the process. . . . (Student in focus group from instructor's Bonnie's course)

Faculty instructors of the comparison course taught in a more traditional manner. These faculty instructors were more inclined to spend the majority of the class time lecturing to their students. Laboratory instruction involved the use of "cookbook" labs that were separate from the lecture. In addition, faculty instructors of the comparison course did not attend professional development workshops for improving their science teaching and they did not collaborate with other colleagues about science education reform. Many of the faculty instructors stated that there was no administrative support for improving science instruction for their undergraduate students. Adam had been teaching the comparison course, physical science, for 5 years. He stated in his interview that the majority of the professional development workshops that he had participated in were geared toward scientific research. He also stated that the administrative personnel did not support professional development workshops that are geared toward science teaching. Adam lectured for the entire class period with no student interaction.

> I try to engage students as much as I can. I use Blackboard to post my notes so that they can spend class time concentrating on what I am saying rather than copying down information. . . . There is a lack of administrative support for faculty to collaborate with one another, and to have pedagogical professional development rather than just research support. (Faculty instructor Adam)

The undergraduate student focus group corroborated the statements put forth by this faculty instructor. The students stated that Adam's observed lesson was typical for this class and that the laboratory activities seemed to have nothing to do with the science concept taught during the lecture.

> It is kind of the same. We lecture over the chapter. I don't think the labs have anything to do with what we have in lecture. . . . Simpler concepts are presented in a more complicated way. . . . I can work the problem in one step and he wants us to do many steps. (Student in focus group from instructor's Adam's course)

Karen had taught the comparison course for 10 years. She had participated in workshops for homework, clickers, and student learning. Karen knew that science teaching and learning should be hands-on and engaging; however, she said that she did not have the time to set up laboratory or hands-on activities because of time. When asked about how she approached teaching science, she stated,

> 10% of the time you can make it relevant; the remainder has to be memorized . . . use of the board and overheads . . . on-line simulations and cartoons are very helpful. . . . I want to do group work but I don't have time. . . . I mainly straight lecture . . . I use the on-line homework. . . students like it now that it is in line with the lectures.(Faculty instructor Karen)

The comments of the Karen's student focus group relate closely some of these same statements about this faculty instructor's instructional practices.

> She makes us memorize stuff, which is actually helpful. It gives us a good foundation. If we didn't have to memorize some of this stuff we wouldn't do as well in upper-division chemistry. . . . She always reviews what we did the class before . . . and she gives us her notes, so we can put our own notes in and don't have to spend a lot of time just copying. . . . The packets are really helpful. . . . I hardly touch the book because everything I need is in my notes. (Student in focus group from instructor's Adam's course)

Research Question 1 provides evidence that faculty instructors of the reformed undergraduate science course who participated in the NASA/NOVA professional development workshop or some equivalent taught in a reformed manner consistent with the NSES. The faculty instructors of the reformed undergraduate science course shared the following characteristics: possessed strong content and pedagogical knowledge, attended ongoing professional development geared toward reformed pedagogical practices, collaborated with their colleagues, and reflected on teaching practice.

Research Question 2

Research question two asked what common characteristics exist regarding the pedagogical content knowledge of faculty instructors of the undergraduate science reform course who participated in the NOVA professional development workshop and those who did not.

Qualitative analyses allowed the researcher to delineate characteristics of faculty instructors with expansive topic-specific PCK. Twelve faculty instructors were analyzed regarding topic specific PCK. Since PCK is topic specific and resides within the individual, faculty instructors were not compared to each other. Snapshots were developed only for the faculty instructors who had participated in the NASA/NOVA professional development project [Insert Table 3 here]. Interviews, CoRes and Pap-eRs, and field notes from classroom observations from the faculty instructors were analyzed using a researcher developed PCK framework based on pre-selected categories.

The categories comprising the PCK framework were *Orientations toward Science Teaching* (OST), *Content Knowledge* (CK), and *Pedagogical Knowledge* (PK). Once the interviews, CoRes and Pap-eRs, and field notes of faculty instructor's had been analyzed, a PCK checklist was completed for each faculty instructor. Once the PCK checklist was completed, a PCK rating was given for the faculty instructors using the researcher developed PCK rubric. Snapshots were developed for the faculty instructors using the completed PCK checklist to determine the extent of their pedagogical content knowledge regarding the science concept taught during the observed lesson. Again, these ratings were not used to compare faculty instructors but rather to gauge the extent of the PCK for the specific science concept taught and observed to delineate common characteristics of these faculty instructors. Snapshots of faculty instructors are described in the proceeding section. Again, the purpose of these snapshots is to provide an overall description as to the pedagogical content knowledge of the faculty instructors.

Snapshot One: Frank

Frank had taught Physics for over 25 years and was a part of the original NASA/NOVA team. His RTOP score was 77.5. He said that the particular course that he taught was a content course that was aligned with inquiry practices. His other physics courses were geared toward physics majors and were more lecture-based. He believed that inquiry was the best approach to teaching science. Frank used the 5-E learning cycle to teach the concept of magnetism. He believed that the 5-E learning not only allowed for students to engage in inquiry but that it also elicited their prior knowledge and misconceptions regarding the concept of magnetism.

He used several hands-on activities during the observed lesson to teach this concept. Frank stated that the objectives for this concept were aligned with the state standards for Kindergarten-5th grade. Frank was an avid participant in professional development workshops geared toward science education reform and facilitates workshops on reform as well. He also collaborated with other science faculty instructors who were interested science education reform. Franks purposefully selected instructional strategies based on what he knew about student learning difficulties and their prior knowledge. He also reflected on his prior experiences with teaching this topic and used this information in planning his lessons. Frank believed that using the 5-E learning cycle allowed him to accommodate these learning difficulties and misconceptions while building on student's prior knowledge. Frank's PCK rating was *Advanced.*

Snapshot Two: Calvin

Calvin had 30 years teaching experience and was a part of the original NASA/NOVA team. Calvin stated in his interview that an inquiry-oriented approach was the best approach to science teaching and learning. He stressed the importance of science content that is relevant and instruction that facilitates scientific literacy.

Calvin's observed lesson dealt with isomers and nomenclature. Calvin used models to represent isomers so that students could conceptualize what is often considered an abstract concept. He stated in his interview that his students' understanding of isomers and nomenclature would guide the direction of the lesson. In reflecting on his previous experience in teaching this concept, he knew that students had difficulties in understanding isomers in terms of molecular and structural formulas and knew that models could assist in facilitating student understanding of this concept. Calvin participated in extensive professional development workshops geared toward science content and pedagogy. He maintained collaboration with his colleagues and other science specialists and he was a reflective practitioner. Calvin achieved a PCK rating of *Advanced*. His RTOP score was 89, indicating that 89% of his observed classroom instruction was reformed.

Snapshot Three: Bill

Bill had over thirty years of science teaching experience at the undergraduate and graduate level. He was a part of the original NASA/NOVA team. Bill placed emphasis on content. Although he believed that students should have opportunities to conduct scientific investigations and explore science concepts he viewed these sorts of activities as separate from the lecture. Students must be know and understand the science content. During his observed lesson, Bill lectured the entire class period with little student engagement or input. Bill presented an overwhelming amount of information and informed students that everything covered in class would be on an upcoming test. The observed lesson was characteristic of teacher as the dispenser of knowledge rather than facilitator.

Bill received a 36 on his RTOP indicating that 36% of the observed lesson was reformed. The only professional development workshop that Bill attended was the NASA/NOVA workshop. Bill stated in his interview that he had taught this topic several times and knew that students would have a difficult time conceptualizing the molecules because it was an abstract concept. Bill did not use his knowledge of students learning difficulties and prior knowledge to select instructional strategies that would best engender student understanding of this concept. Bill's PCK for cellular respiration was *Emerging*. Although Bill had been teaching for over thirty years he was not a reflective practitioner and did not allow student misconceptions and prior knowledge regarding cellular respiration to facilitate instruction.

Snapshot Four: Gerald

Gerald was a faculty instructor with 15 years teaching experience. He was a part of the original NASA/NOVA team. Gerald believed that a hands-on approach is the best approach to science teaching and learning. He stated in his interview that science content should be relevant and facilitate scientific literacy.

The observed lesson on classification revolved around students working in small groups to classify snack chips. Gerald said that the main ideas of the lesson was to acclimate his students to classifying items based on their physical properties by designing a means by which to classify the snack chips. He said that he has taught this topic for many years so he knew that it would help students in their understanding of classification and put them at ease for the upcoming assessment. When planning the lesson, Gerald said that he considered his students' various learning modalities; however, this was more of a global statement rather than specific to the topic of classification. Gerald received a PCK rating of *Proficient*. His RTOP score was 70, indicating that 70% of the observed lesson was reformed. Gerald's sources of PCK appear to stem from his knowledge of content, years of teaching experience with this topic, and the NASA/NOVA training,

Snapshot Five: John

John had been teaching undergraduate science for over 20 years. He also had five years teaching experience in kindergarten-8th grade. John was an original part of the NASA/NOVA team who believed that lecture and lab are inseparable. He believed that instructors should model how they want their students to learn. He stated in his interview that students understand science as a process and that instruction should guide them in that direction. He believed that students should have opportunities to make predictions, collect and analyze data, and present their findings to their peers. John also believed students should have opportunities to use the knowledge and skills gained from the learning of science concepts in novel context. He believed that these sorts of activities facilitated critical thinking. During his observed lesson on classification, students used a computer program to create a virtual zoo. Students selected their animals and had to come up with their own classification scheme and criteria to classify their animals and provide a rationale for their work. Students had to present this information to their peers online.

John's RTOP score was a 77 indicating that 77% of his observed lesson was reformed. John was an avid participant in professional development workshops geared toward science education reform and constantly collaborated with his colleagues and inservice teachers regarding reform practices. He was a reflective practitioner who allowed student's prior knowledge and misconceptions to guide instruction. He stated in his interview that he considers lessons learned from his previous experience in teaching this concept to also guide his instruction. John's PCK for classification was *Advanced*. John's sources of PCK appear to stem from participation in ongoing professional development workshops geared toward science education reform, NASA/NOVA training, reflecting on teaching practice, years of experience in teaching this topic, and ongoing collaboration with science and science education colleagues and inservice teachers.

Snapshot Six: Eleanor

Eleanor had been teaching science for over 15 years. Eleanor was a part of the original NASA/NOVA team. She adhered to a constructivists approach to science teaching and learning. She varied instruction to accommodate the diverse needs of her students. She believed that the teacher should serve as a coach in science teaching and learning. Eleanor used a variety of instructional strategies to teach about the circulatory system to address the various learning modalities of her students. She was a reflective practitioner and considered her students' misconceptions and prior knowledge regarding the circulatory system. She emphasized the importance of connecting the science content to the lives of her students.

Eleanor received a PCK rating of *Advanced*. Her RTOP score was an 80, indicating that 80% of her observed instruction was reformed. Eleanor purposefully chose specific activities to teach the circulatory system. Eleanor said that these activities related to the lives of her students and facilitated scientific literacy. Eleanor used small group instruction to assuage student's fear of science in addition to learning from their peers. Eleanor's sources of PCK were the NOVA training, ongoing participation in professional development workshops, years teaching experience, constantly reflecting on her teaching, and collaboration.

Snapshot Seven: James

James was an adjunct professor and had over 10 years teaching experience. He was also a part of the original NASA/NOVA faculty professional development project. He believed that science should be taught in a manner that is practical and relevant to students' lives and used activities that demonstrated this belief. James's observed lesson revolved around drainage and discharge. When reflecting on the teaching of this science concept, he considered his students' prior knowledge and misconceptions when deciding on the strategies to be used teach the drainage and discharge. He recognized his students' misconceptions and his own misconceptions regarding drainage and discharge and he talked about the learning difficulties associated with the teaching of this topic.

James achieved a PCK rating *of Advanced*. His RTOP score was 85, indicating that 85% of his lesson was reformed. James' sources of PCK appear to stem from his NOVA training, his participation in ongoing professional development workshops, ongoing collaboration with colleagues, science educators, and inservice teachers, and his years of teaching experience with this topic.

Snapshot Eight: Kelvin

Kelvin was an adjunct professor who had over 10 years teaching experience. He was a part of the original NASA/NOVA professional development project. Kelvin believed that science should be taught in a manner consistent with inquiry instruction in order to facilitate science as a process.

Kelvin believed that students should have opportunities to participate in science investigations that required them to ask questions, formulate hypotheses, make predictions, collect and analyze data, and present their findings based on evidence. He stated in his interview that students have different learning styles and so he tries to accommodate these learning styles through using a variety of instructional strategies. During his observed lesson, students watched a video regarding decomposition, completed an activity that required them to identify the stage of decomposition that their [logs] were in while working in their cooperative groups, and wrote an essay about this concept. When planning the lesson on decomposition Kelvin stated that he took into account his students various learning styles, their prior knowledge, and misconceptions regarding decomposition. He also stated that he reflected a lot on problems that arose from teaching this topic with previous students. Kelvin received a PCK rating of *Advanced*. He received an 80 on his classroom observation, indicating that 80% of his observed instruction was reformed. Kelvin attended myriad professional development workshops geared toward science education reform and mentored inservice teachers that had completed his course and were science teachers. His sources of PCK appear to stem from the NASA/NOVA training, ongoing professional development workshops, collaboration, reflection, and years of teaching experience with this topic.

Conclusions and Implications

Thirty-five faculty instructors participated in this study. The faculty instructors of the reformed courses originally participated in the NASA Opportunities for Visionary Academics professional development program between 1996 and 2005. Twenty-one faculty instructors taught the undergraduate reformed science course. Of the 21 faculty instructors, 12 participated in the NOVA professional development project, while the remainder of the faculty instructors replaced the original NOVA instructors. Fourteen faculty instructors taught the comparison course. Quantitative data were collected through classroom observations conducted with each faculty instructor. The quantitative data were supported with qualitative data derived from interviews, field notes, and observations which resulted in CoRes and PaP-eRs for each faculty instructor, as well as, interviews with undergraduate student focus groups. All data were analyzed to determine the impact of the NASA/NOVA professional development project on the pedagogical content knowledge of faculty instructors and to delineate characteristics common to this group of university faculty.

Quantitative and qualitative analyses of faculty instructor's data revealed that pedagogical differences do exist between faculty instructors of reformed undergraduate science courses and those who taught the comparison course. Faculty instructors who had participated in the NASA/NOVA professional development program or comparable workshops taught in a significantly reformed manner as evidenced in their classroom observations. Faculty instructors teaching reformed science courses designed lessons that allowed for student exploration of the science concepts and that solicited students' prior knowledge and understandings about that concept. Faculty instructors of the reformed course achieved a mean score of 70.81 for total RTOP score, and faculty instructors of comparison courses achieved a mean score of 49.28. Faculty instructors of reformed courses achieved a mean rating of 12.65 out of a possible 16.00 for lesson design and implementation, while faculty of comparison courses achieved a mean score of 8.38. Faculty teaching reformed science courses exhibited a deeper understanding of how to use procedural knowledge to facilitate scientific reasoning through using activities that allowed students to manipulate information, arrive at conclusions, and evaluate knowledge claims. Faculty of reformed courses achieved a mean rating of 12.62 for the procedural knowledge subscale, while comparison faculty achieved a mean score of 8.16.

Faculty instructors with PCK ratings of *Advanced* (n=6) shared the following characteristics: (1) strong science content knowledge; (2) orientations congruent with the *National Science Education Standards* for effective science teaching and learning; (3) purposeful selection of activities to teach specific science topic that would best engender student understanding; (4) ongoing professional development geared toward science education reform; (5) collaboration with scientists, science educators, and inservice teachers; (6) reflective practitioners; and (7)years teaching experience. In addition, faculty instructors intended goals of the lesson were consistent with the enacted goals observed during instruction.

Faculty instructors with PCK ratings of *Proficient* (n=1) shared the following characteristics: (1) strong science content knowledge; (2) NOVA training; (3) knowledge of student learning difficulties and prior knowledge but not necessarily used to guide instruction regarding topic; (4) ongoing professional development geared toward science education reform; (5) some collaboration with scientists and science educators, and (6) years teaching experience. Although this faculty instructor had evidence of content knowledge regarding classification and had taught this particular topic for many years, he did not discuss student learning difficulties associated with this topic based on his prior experiences. He said that he used this activity because it helps students to understand the basics of classification but not necessarily deepen their understanding of this topic. Only one faculty instructor received a PCK rating of *Emerging*. It was somewhat difficult to gauge the level of PCK for this faculty instructor because of his strong content knowledge regarding the concept of cellular respiration and his years teaching experience. Although this faculty knew the content and had been teaching this topic for several years, he maintained his lecture-based teaching approach, rather than adjust instruction to accommodate student learning difficulties and their prior knowledge. His belief about science teaching and learning was reflected in his teaching style. He believed that students must know and understand content if they were going to teach it.

Qualitative analyses of the undergraduate student focus group interviews substantiated the findings of data obtained from faculty instructors. The undergraduate student focus groups from the reform course reported that their instructors engaged them in science by having them do investigations that required them to ask questions, make predictions, experiment, and discuss their findings with their peers. Also, students from the undergraduate student focus groups said that experiences in the reformed course enabled them to (1) understand science as a process, (2) conceptualize difficult science concepts through models and investigations, (3) apply science concepts learned in class in novel situations, and (4) reflect on their learning and think about how they could use the knowledge and skills gained in their future teaching practice.

Faculty instructors who taught the comparison course focused more on content rather than pedagogy. The following themes emerged from the qualitative analysis of interviews and CoRes and PaP-eRs of faculty instructors of the comparison course: (1) teacher-centered (lecture was the dominant mode of instruction), (2) little student discourse, and (3) lecture and laboratory were separate. Regarding pedagogical content knowledge, faculty instructors of comparison courses did not consider student misconceptions and/or learning difficulties when selecting instructional strategies to teach specific science concepts. These faculty instructors had strong evidence of content knowledge but did not possess the pedagogical knowledge needed to transform science content for student understanding. In addition, faculty instructors teaching the comparison course did not attend professional development to improve science instruction and did not collaborate with other colleagues regarding science education reform. Qualitative analysis of the interviews from the undergraduate student focus groups from the comparison course corroborated the instructional practices observed for the faculty instructors of the comparison course. Students stated that faculty instructors of the comparison courses spent the majority of the class time lecturing and giving notes. They also stated that they were unable to make the connection between the science content discussed during the lecture to the laboratory investigations. Overall, quantitative and qualitative analysis of data revealed that faculty instructors of the comparison course employed a traditional approach to science teaching and learning.

Implications

Scholars on pedagogical content knowledge have demonstrated that the growth and development of PCK is influenced by: subject matter knowledge (Van Driel, De Jong, and Verloop, 2002; De Jong, Van Driel, and Verloop, 200); learning from teaching in authentic settings (Van Driel et al., 2002; De Jong et al., 2005; Mason, 1999; Van Driel et al. 1998); having opportunities to examine misconceptions associated with the learning of specific science concepts (Van Driel et al., 2005; Park and Oliver, 2008); and to reflect on teaching practice (Bryan & Abell; 1999; De Jong, Van Driel, & Ver Loop, 2005; Joyce & Showers, 2002; Loughran, 2002; Loughran, Mulhall, & Berry, 2008; Nilsson & Van Driel, 2008; Osborne, 1998; Schon, 1983; Shulman, 1987). Moreover, scholars on pedagogical content knowledge suggest that teacher education programs be reconceptualized in a way that integrates courses subject matter knowledge, pedagogy, and authentic teaching experiences (Van Driel et al., 2005; Mason, 2009).

Shulman (1987) argued that, historically, teacher development and education programs have stressed the art of teaching at the expense of content knowledge (Mason, 1999) and this is still the case at many institutions across the nation. Preservice teachers typically take their methods courses in isolation from their required science content courses. This has been the controversy and hence a major criticism of these programs in that they provide future teachers with an array of noncontextualized, unconnected activities, concepts and demonstrations (Mason). As stated earlier, the undergraduate science reform courses examined in this study were unique in that it they were a combination of science content and pedagogy. These courses were taught by science content specialists who participated in the NASA/NOVA project to improve the way they taught science to their students. If teachers are to transition from "teaching in theory" to "teaching in action" then they must have opportunities to use science content knowledge and pedagogical knowledge learned throughout their teaching education programs in authentic settings. In order for teacher education programs to provide future teachers with experiences, then science educators must also investigate barriers that impede the successful implementation of reform. Moreover, science educators and higher education administrators must consider ways of possibly restructuring teacher education programs to reflect the National Science Education Standards and National Science Teacher Association standards for the preparation of science teachers incorporating science content courses that embody effective science teaching and learning.

Work on the research project was supported by a grant from the National Science Foundation, ESI-0554594, titled Undergraduate Science Course Reform Serving Pre-service Teachers: Evaluation of a Faculty Professional Development Model. The opinions expressed in this paper are those of the authors and do not necessarily reflect those of the Foundation. Correspondence should be sent to: Dennis Sunal, dwsunal@bama.ua.edu

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