INVESTIGATING A REDESIGNED PHYSICS COURSE FOR FUTURE ELEMENTARY TEACHERS

by

CLAUDIA FRACCHIOLLA

B.S., Universidad Simón Bolívar, 2004
M.S., Colorado State University, 2012

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Curriculum and Instruction
College of Education

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2016

Abstract

There is a growing concern that the number of students graduating with a STEM major in the U.S. is insufficient to fill the growing demand in STEM careers. In order to fulfill that demand, it is important to increase student retention in STEM majors and also to attract more students to pursue careers in those areas. Previous research has indicated that children start losing interest in science at the elementary level because science is taught with a focus on learning vocabulary and ideas rather than learning through inquiry-based techniques. A factor that affects the quality of science education at the elementary level is the preparation of elementary teachers. Many elementary teachers feel unprepared to teach science because they lack adequate content knowledge as well as the pedagogical content knowledge (PCK) for teaching the subject. Previous studies of teacher preparation in science identified some areas with which pre-service teachers need assistance. One of these areas is understanding children's ideas of science. To address that issue, this dissertation investigates whether the use of an instructional approach that teaches physics phenomena along with an understanding of how children think about the physical phenomena promotes changes in students' knowledge of children's ideas and use of those ideas in instructional and assessment strategies. Results indicated that students who were explicitly exposed to knowledge of children's ideas more often incorporated those ideas into their own microteaching and demonstrated higher levels of sophistication of knowledge of children's ideas, instructional strategies, and assessment strategies that incorporated those ideas. This research explores an instructional model for blending physics content and pedagogical content knowledge.

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Acknowledgements

I have innumerable people that have helped and supported me to become who I am today and therefore reach the goals that I have set for myself. Obviously, I would not be here without my parents. Not only because they decided to have me, nurture me, and love me, but also because they have always encouraged me to go further. Since I was a little girl my parents always fed my curiosity and desire to learn. More often than not they did not know how to answer the many questions I had, but that never stopped them from always motivating me to ask more questions. My dad loves to brag about how his idea of buying popular science magazines was what inspired me to go into physics. I won't deny it is true, so thanks dad for that.

I have to thank my sister, because even though she has never fully understood me – a nerdy, shy big sister – she has always been there for me in every way she possibly can, she has never lost faith in me, even when she has tried more times that I can remember to make me cool (like her). Also need to thank my whole family, they are quite a bunch. They have loved me above all and accepted me for who I am. Their acceptance has given me the confidence to not be afraid of being different and speak my mind. In a world where the institutional structures and systems are set to penalize those who think outside of the box, challenge the status quo, or simply look different; the power of believing in oneself is a rare commodity and I do not think I would have that confidence if it was not for my family.

My husband is my biggest source of strength and an example to follow. He has been by my side since the very beginning, even putting his dreams a side for a while to help me pursue mine. I could have never made it without him. Even though I like to pretend that I am a super strong independent woman, the truth is that I depend more on him than what he realizes. Thanks for believing in me, even through the super rough times, thanks for accepting me the way I am and follow me in the crazy path I sometimes like to go down to. You are my rock. Of course, life would not be the same without my amazing and faithful companion, Otto (my dog).

To my amazing friends, Steph, Jess^2, and Erica, I am so lucky to be able to count on you. We have been through the wringer together, but we have always managed to get up and keep our heads high, after a couple of glasses of wine, some tears and ranting. To my friends, Naty, Vero, Javi, and Millan, who even in the distance have had a constant presence in my life, always showing up to give support and send their love through FaceTime or Whatsapp.

I have to recognize the trust that many teachers and professors throughout my life have put in me; they have given me the strength and confidence to achieve my goals. They have taught me more than what books can teach you, they have taught me persistence, they have taught me respect is not imposed by hierarchies, that even though I am little my ideas are still valid and I should make myself heard if I truly believe in what I have to say. Finally, I have to say thanks to Sanjay and Dr. Spears for taking the time and having the patience to coach me to become a stronger researcher.

It has been a long and very bumpy road and there is still a long way to go, but I am confident that I will get to wherever I decide to go because I have an amazing team of people by my side. Gracias totales!

Chapter 1

Introduction

The importance of strengthening STEM education in public schools is currently at the center of discussions in education reform. The discussions have focused on a push for science early in schools, since there is a concern that children in several other countries are outperforming U.S. children (Ripley, 2013; Zhou, Peverly, Boehm, & Lin, 2000; Zhou & Peverly, 2004). Several reports such as *A Framework for K-12 Science Education* (National Research Council (NRC), 2011), *A Blueprint for Reform: The Reauthorization of the Elementary and Secondary Act* (Duncan & Martin, 2010) state that to improve science programs researchers and educators need to develop teacher education programs that will motivate teachers to go into STEM education, retain them, and prepare them to teach science. Based on these reports, some initiatives are being developed to improve teacher education programs that, in turn, will improve STEM instruction in K-12; increase and sustain public and youth engagement with STEM; improve the STEM experience for undergraduate students; reduce the gender and racial gap in STEM fields; and design graduate education to address the changing economic challenges (Honey, Pearson, & Schweingruber, 2014).

Framing the Problem

Prevalent issues in STEM education, even though those are more evident at the high school and college level, start at the elementary level (Loughran, 2007a). There is evidence that children at the elementary level are naturally curious and show interest in science, but the interest starts to decay as they go through the education system (Dewey, 1938; George, 2000; Perrodin, 1966; Harlem & Qualter, 2004). The problem is that elementary teachers struggle with teaching science because they have negative views toward science and do not feel comfortable teaching it (Jones & Carter, 2007; Loughran, 2007b). It is important to develop courses for future elementary teachers that change their attitudes toward science, help them understand elementary children's ideas about science, and also model effective strategies to teach science in ways that promote elementary children's engagement in science (Jones & Carter, 2007; Loughran, 2007b).

STEM fields have long been considered of great importance to the nation's economy and security. For many decades the United States has constantly strived to maintain the lead in scientific and technological innovation (National Science Board (NSB), 2010). In the past few years the performance of U.S. elementary and secondary students in mathematics and science has fallen below their peers in nations such as Finland, South Korea, and Norway (Fleischman, Hopstock, Pelczar, & Shelley 2010; Ripley, 2013). Furthermore, the rate at which U.S. undergraduates choose STEM majors is lower than those of several key developed countries according to the National Science Board (2010). The U.S. Department of Education (DoEd) in collaboration with the Institute of Education Sciences (IES) explored the factors that influence STEM attrition (Chen, 2013). The report shows evidence linking STEM attrition to students' attitudinal factors such as motivation, confidence, and beliefs about their capacity to learn STEM subjects (Burtner, 2005; Huang, Taddese, & Walter, 2000).

Research has shown that at the primary level children hold positive feelings about science, but their attitudes decline as they progress through the grades (George, 2000; Simpson & Oliver, 1985). Some of the factors that lead to this decline were found to be that students' science self-concept deteriorates due to lack of teacher encouragement and peer attitudes toward science (George, 2000). Another possible reason for children's declining interest in science may be how most sciences courses are taught. Especially at the elementary level, learning about science is often reduced to learning new vocabulary (Newton & Newton, 2000).

The current demands for accountability in education, maximizing outcomes and developing students' capacity for critical thinking, design and modeling has changed the landscape of K-12 education (Honey, Pearson & Schweingruber, 2014). Among the agents of change were the *National Science Education Standards* (National Research Council (NRC), 1996) and more recently the *Next Generation of Science Standards* (NRC, 2013), both of which provide guidelines for K-12 science instruction. But as some researchers (Rodriguez, A. 1997; Rodriguez, E. M. 1998) pointed out, these guidelines are not enough. There is research that demonstrates that elementary teachers do not feel comfortable teaching science (Jones & Carter, 2007; Loughran, 2007b). In fact, research (Skamp, 1993; Tilger, 1990; Woodbury, 1995) shows that elementary teachers avoid teaching science by limiting the time they teach it, and that when they teach science they focus more on biology instead of physics. Teachers also tend to use teacher-centered strategies that allow them to maintain control of the content and direction of class for the majority of the time. Some of the reasons for elementary teachers' avoidance of teaching science are that elementary teachers do not have (or believe they do not have) sufficient science subject matter knowledge and lack the pedagogical content knowledge with which to teach science (Harlem, 1997; Jones & Carter, 2007; Loughran, 2007b). Elementary school teachers have low confidence to teach science, low self-efficacy in science and science teaching; and they avoid teaching it (Harlem, 1997).

A common solution to the problem has been to add more science content courses to the course load for elementary teacher preparation (Morrell & Carroll, 2003; Roth, 1996; Skamp & Muller, 2001). However, research has shown that adding content alone is not sufficient to improve teachers' self-efficacy in science and to develop the confidence to use more student-centered and inquiry-based teaching strategies (Morrell & Carroll, 2003; Roth, 1996; Skamp & Muller, 2001).

Studies focused on professional development programs in science for pre-service and novice teachers have found that content knowledge alone does not guarantee a better teacher. Mikeska, Anderson, and Schwarz (2009) are elementary teacher educators who have been engaged for several years in design-based research working with pre-service and novice elementary teachers to better understand the process of learning to teach while developing tools that help the pre-service teachers connect the ideas they were introduced to in their methods courses to the problems they encounter in their classroom. Through the creation of what the researchers refer to as a dialogic third space, pre-service teachers and novice teachers openly shared what they believed were the major difficulties they confronted while teaching science in the elementary classroom. The researchers recorded the sessions and interviews. Through analysis of these conversations over several years, Mikeska and colleagues identified a set of commonalities in the difficulties expressed by teachers. They found that there are three main factors that need attention in order to prepare pre-service teachers who feel better equipped to teach science: (1) facilitating future elementary teachers' engagement with science, (2) enabling future elementary teachers to develop instructional strategies with which to teach science, and (3) constructing future elementary teachers' understanding of children's ideas of science.

Based on findings from this research it seems that reforms of science courses for future elementary teachers, should focus on: (a) challenging pre-service teachers' attitudes and beliefs about learning and teaching science, (b) facilitating their engagement in science, and (c) helping them develop instructional strategies to teach science that incorporate their understanding about children's ideas of science (Jones & Carter, 2007; Mikeska et al., 2009). These courses should also afford future teachers opportunities to put into practice their new understandings of how to learn and teach science, so they can experience teaching science through more student-centered, inquiry-based strategies, and transfer what they learned in their teacher training courses to their classrooms (Jones & Carter, 2007). Finally, science courses for future teachers should provide pre-service teachers with opportunities to learn about common students' preconceived ideas and the nature of those preconceived ideas in order to be able to use appropriate instructional strategies to overcome those preconceived ideas (Russell & Martin, 2007). The focus of this dissertation was an exploration into the extent to which a redesigned physics course for elementary education majors addressed some of the aforementioned issues.

Motivation for Current Study

Previous research on teacher preparation in science (Mikeska et al., 2009) has identified three main issues with which teacher educators must help elementary pre-service teachers: (1) facilitating their engagement in science, (2) developing instructional strategies with which to teach science, and (3) understanding children's ideas of science. The latter has been shown to be the most difficult to grasp for future teachers (Harlow, Bianchini, Swanson, & Dwyer, 2013). Understanding children's ideas of science has been relevant even in classrooms that emphasize active learning as a key element of the curriculum (Harlow et al., 2013). This last issue is the focus of this dissertation.

As far back as the late 1800s it was believed that the only requirement to teach was deep subject matter expertise on the topic to be taught. But the 1980s brought new perspectives. The importance of knowledge of course management and teaching strategies became prevalent in teacher education programs. Policies on teacher evaluation implemented in the 1980s focused on teachers' ability to manage a classroom. This represented a shift in the perspective on teacher evaluation and what was important in order to be an effective teacher (Shulman, 1986).

In the current literature on teacher effectiveness, teacher quality, and teacher evaluation, it is possible to find different definitions of what those words mean (Strong, 2011). According to Strong (2011), there is no agreement on what the term quality means when it follows the word teacher, as in teacher quality. The word quality is tied to words like value, but the value of something often lies in the eyes of the beholder. In the literature on teacher quality the meaning changes depending on the perspectives or interests of the writer. Some of the characteristics that different researchers attribute to a teacher's quality are: qualifications, personal attributes such as kindness and flexibility, pedagogical skills and practices including instructional and assessment strategies, verbal ability, strong content knowledge, enthusiasm, high expectations for students, preparation for class, and good classroom management skills, just to mention a few (Strong, 2011; Darling-Hammond, 1999; Stronge, 2002; 2010; Tucker & Stronge, 2005).

Even the most common frameworks and rubrics for teacher evaluation such as the ones by Marzano (2011) or Danielson (2011) concentrate on professional knowledge, planning and use of instructional, assessment, and classroom management strategies. Newer tools for teacher evaluation, such as the Classroom Assessment Scoring System (CLASS) from the MET project (Kane & Staiger, 2012), Center for Research on Education, Diversity and Excellence (CREDE) (Dalton, 1998; Tharp, Estrada, Dalton, & Yamauchi, 2000) or Sheltered Instruction Observation Protocol (SIOP) (Kareva & Echevarria, 2013) concentrate more on the child and how the teacher provides a safe environment in which children can express themselves and incorporate elements of children's lives into the lessons. Although these tools do not focus on evaluating strategies for teaching science specifically, they provide general guidelines for best teaching practices.

However, none of these research-based tools address the issue of understanding children's knowledge, ideas and beliefs as a characteristic of good teaching.

Darling-Hammond (2000) published research on teacher effectiveness based on teacher ratings and student achievement gains. She used a mixed methods approach using data from states' surveys on teaching policies, case studies, the School and Staffing Survey (SASS) and the National Assessment of Educational Progress (NAEP) to examine how teacher qualifications and other characteristics relate to student achievement. Her findings identified common characteristics that have a higher correlation with students' achievement, suggesting what it means to be a good teacher. These characteristics can be found in the standards for the National Board for Professional Learning Standards (Ingvarson & Hattie, 2008). Among those characteristics is the understanding of learners and their development. Although this is one of the few mentions of the importance of teachers' knowledge of students' ideas, there are other studies (Darling-Hammond, 2013) that have shown the connection between teachers' knowledge of students' ideas and students' learning. Strong (2011) published a book in which he reviewed studies of research on teacher quality found in peer reviewed journals or books that had received several citations. The first set of studies aimed to identify what variable(s) had the largest impact on student achievement. The studies all identified teacher quality as the single most important variable. The second stage of Strong's analysis was to identify which characteristics of good teaching had more influence over students' achievement. After systematically reviewing different studies on teacher quality, Strong identified teachers' knowledge about students' ideas on that content as a key variable of teachers' quality that impacts students' achievements (Strong, 2011).

Research in the late 1980s identified one of the main reasons for elementary teachers' deficiency of knowledge about students' ideas of science. Science content courses for elementary education majors were typically taught in the disciplinary departments and in general did not incorporate pedagogical strategies of how to teach that specific content (Shulman, 1986; 1987). Shulman expressed his opinion about the matter by saying: "Mere content knowledge is likely to be as useless pedagogically as content free skill" (Shulman, 1986, p. 8). Shulman also offered a new lens through which education researchers could look at teacher quality. Moving away from both extremes of purely content or purely pedagogy, Shulman and colleagues started referring to that compendium of knowledge as teacher knowledge, those kinds of things that teachers learn through experience in the classroom. Teacher knowledge, thus defined, was a precursor to pedagogical content knowledge (PCK).

McDermott (1990) expressed the opinion that one of the main reasons for the lack of well-prepared elementary and middle school science teachers was that universities did not provide adequate preparation for these elementary education majors. She argued that traditional science lectures did not attend to the needs of future elementary and middle school teachers because there was too much material that was often not relevant to them. Further, the courses were often taught in a traditional lecture format that did not help teachers develop the reasoning ability necessary for handling students' questions in the classroom. McDermott (1990) stressed the need for developing special science courses for elementary and middle-school teachers.

Several attempts have been made to design such courses for pre-service elementary school teachers. Among the most well-known are a course that uses a learning cycle model (Karplus & Butts, 1977) for a large enrollment course (Zollman, 1990), *Physics by Inquiry* (PbI)

(McDermott, 1996), and *Physics for Elementary Teachers* (PET) (Goldberg, Robinson, & Otero, 2006; Goldberg, Robinson, Kruse, Thompson, & Otero, 2009). These courses emphasized conceptual development, reasoning skills, using evidence to support claims, and reflections about learning. A newer model of PET is *Physics for Everyday Thinking* (Harlow, 2010), which emphasizes what Harlow and colleagues refer to as *learning about learning* (LAL). LAL includes experiences in which elementary education majors analyze children's ideas, explicate ideas on the nature of science, and then reflect on the relationship between the nature of science and the process of learning science. However, in both the older and newer PET models there is no explicit discussion about the importance of understanding children's ideas about science and how an understanding of those ideas should be used in the design of instructional strategies (Rebello & Zollman, 2013).

In summary, there seems to be a relationship between teacher knowledge of students' ideas and student learning (Strong, 2011). Most programs for future elementary school teachers do not have content courses that help prospective teachers develop the content knowledge along with an understanding of children's ideas about the content (McDermott, 1990; Rebello & Zollman, 2013).

Context of Present Study

The study was conducted in a large enrollment physics course – *Concepts of Physics* -- for elementary education majors at a public U.S. mid-western university. The participants in the study were students enrolled in this course, the majority of whom were elementary education majors in their first or second year of college. Most had been exposed to elementary classrooms through early field experiences in their freshmen year of college, but the majority had very limited exposure to physics at the time they took this course. The course was a large enrollment course, approximately 170 students, offered only during the fall semester each year. The course met twice a week for 75 minutes of lecture and twice a week in the activity center for laboratory work. Students were assigned a set of activities that they could do at their own pace. They had two sets of activities to complete each week and had two days in which to complete each set. More details about the design of the course and student demographics can be found in Chapter Three.

The *Concepts of Physics* course was restructured in order to integrate pedagogical content knowledge into the core of the course (Rebello & Zollman, 2013). Called the pedagogical learning bi-cycle (PLB), this design is based on a two-layered adaptation of Karplus and Butts' (1977) 3E learning cycle to combine content knowledge (CK) with the development of pedagogical content knowledge (PCK) as defined by Shulman (1986; 1987); i.e. integrated learning physics concepts with learning children's ideas about those concepts. The intent of the restructured physics course was to increase in elementary education majors' engagement in science by providing them with opportunities to not only implement the knowledge of children's ideas, but also understand the importance of knowledge of children's ideas and help them see the relevance of science in their future careers. A more detailed description of the modification made by the PLB model is given in Chapter Three.

Research Questions

The purpose of this study was to investigate whether a redesigned physics course for elementary education majors addressed some of the challenges pertaining to preparing future elementary teachers to teaching science as identified by Mikeska et al. (2009): facilitating their understanding of elementary children's ideas of science, and enabling them to see the relevance of what they learn in the course to their future classrooms. More specifically the research questions are:

1. *How does evidence of incorporation of three categories of PCK – knowledge of children ideas (KCI), use of these ideas in instructional strategies (UIS), and use of these ideas in assessment strategies (UAS) – by students enrolled in a redesigned physics course for elementary education majors that explicitly integrates knowledge of children's ideas; compare with such evidence provided by students who were enrolled in a previous version of this course that did not explicitly integrate knowledge of children's ideas?*

2. *To what extent does the level of sophistication of three categories of PCK – KCI, UIS, and UAS - in students' micro-teaching and final project video change through a semester in the redesigned physics course for elementary education majors?*

Definition of Terms

Baseline vs. redesigned: For the purpose of this research, baseline and redesigned referred to the course. The baseline course is the Concepts of Physics course delivered in Fall 2011. The redesigned course is the Concepts of Physics course delivered in Fall 2014.

Children's ideas about science: In the context of this study, children's ideas about science refer to preconceived or incomplete ideas children may have about science concepts (Driver, Guesne, Tiberghien, 1985; Stephans, 1994).

Explicit incorporation: Explicit incorporation of children's ideas in students' artifacts refers to the presence of children's ideas in the micro-lesson and final project. In each conceptual unit a list of children's ideas associated to the physics content being studied in that unit was provided. Students were asked to identify one idea and integrate it into the instructional and assessment strategies developed for micro-lesson and final project.

Invented idea: For the purpose of this research, an invented idea was an idea attributed to elementary children by students in the *Concepts of Physics* course. It was assumed that these ideas were based either on the personal experiences of the elementary education majors or on other literature that was not provided as course material.

Knowledge of children ideas (KCI): It is the first category of PCK measured in this study. In light of the current study, KCI means reference to children's ideas. KCI was evaluated in three levels. Level zero indicated that there was no children's idea present in the student's artifact. Level one indicated that a children's idea was present in some manner. Finally, level two indicated that a children's idea was clearly stated.

Level of sophistication: It refers to a measurement of the incorporation and use of children's ideas in students' microteaching and final project. Rubrics were developed to assess students' artifacts on a level of sophistication from zero, did not incorporate children's ideas, to two, clearly incorporated children's idea.

Micro-teaching: Micro-teaching refers to an elementary education major teaching training technique first developed in the Stanford University Secondary Teacher Education Program (Allen, 1966). In the context of this project, students presented a short piece of what and how they would teach children a particular topic. More specifically, the requirements included that students identified a children's idea to be addressed and developed instructional and assessment strategies to address the idea stated. The students created five to seven minute videos in which they either enacted the lesson or described how the lesson would be taught.

Pedagogical Content Knowledge (PCK): Specific knowledge that teachers have about a particular topic that might help them to better facilitate children's learning of the topic. In this study, PCK referred to three categories: *knowledge of children ideas* (KCI), *use in instructional strategies* (UIS), and *use in assessment strategies* (UAS).

Students: In the context of this study, students refer to all students that were enrolled in the Concepts of Physics course. Although the majority of the students were elementary education majors (more than 80%), not all of them were.

Use in assessment strategies (UAS): It is the third category of PCK that was measured in this study. For the purpose of this study UAS refers to whether the assessment is designed to invoke children's idea and whether children's ideas had changed as a result of the instructional strategy. UAS was measured in three levels. Level zero indicated that either no children's idea was specified or that there was no assessment strategy. Level one indicated that an assessment strategy was present, but it was unclear how it addressed the children's idea. Finally, level two indicated that an assessment strategy was present and it clearly addressed children's idea.

Use in instructional strategies (UIS): It is the second category of PCK measured in this study. It refers to incorporation of children's ideas in instruction. Children's ideas are demonstrably addressed through an activity and an alternative accurate scientific idea is introduced through an activity. UIS was scored according to the level to which children's ideas were present in the instructional strategy design. Level zero indicated that there was no children's idea stated or that the children's idea was not incorporated into the design of the instructional strategy. Level one indicated that the children's idea was present, but it was unclear how it was incorporated into the design of instructional strategy. Level two indicated that a children's idea was clearly incorporated into the instructional strategy design.

Research Approach

A quasi-experimental design was used to explore changes in students' levels of PCK in their lesson plan designs, critiques, and micro-teaching. Two sources of data were analyzed. The first source of data consisted the levels of PCK found in students' final project, consisting of a lesson plan, a critique of a peer's lesson plan, and a video. The second source of data consisted of the levels of PCK found in micro-lessons students created at the end of each conceptual unit – three in total. Instances of students referring to children's ideas and the clarity with which they used those ideas in the data sources were coded using rubrics.

To determine if the redesigned physics course influenced students' incorporation of children's ideas about science in their lesson design, a quasi-experiment was performed with between and within group analyses. For the between-subjects' analysis, data collected from the redesigned course and the baseline course were compared. Both courses were taught by the same instructor and had the same student demographics Students were administered the same assessments with identical guidelines and resources. The analysis explored whether changes in students' levels of PCK had changed in the redesigned course compared to the baseline course. For a within-subject analysis, a comparison of the micro-lessons and final project video students in Fall 2014 recorded throughout the semester was performed. The analysis explored whether students' levels of PCK had changed across time.

Dissertation Organization

The following chapters provide a more in-depth description of the research, theoretical frameworks, methods, and data analysis used in the study as well as a discussion of the results. Chapter Two presents a review of the literature of the theoretical framework supporting this project and previous research that investigated similar questions. In this chapter the implementation of those frameworks and how those apply to the research are explained. Chapter Three presents a detailed description of the research design and the methodology used to carry out the study. This included full descriptions of the population, development and testing of the data collection instruments and analysis methods, and an overview of the data analysis procedures, which will include descriptions of reliability and validity for the instruments used as well as limitations and delimitations of the study. Chapter Four includes a detailed description of the data, the methodology used to analyze the data as well as a presentation of the results for each data source. Finally, Chapter Five contains the discussion of the results and answers to the research questions, as well as limitations encountered, impact of the research and future work.

Chapter 2

Review of the Literature

This chapter provides a brief review of relevant empirical and theoretical research in the area of pedagogical content knowledge. All existing research on pedagogical content knowledge is not discussed because doing so is beyond the scope of the study. Instead, only research that is most relevant to the present study are described. The physics course for elementary education majors was redesigned to incorporate features that the research presented in this review has shown to be key elements to facilitate the development of students' pedagogical content knowledge.

Pedagogical Content Knowledge

"Mere content knowledge is likely to be as useless pedagogically as content free skill" Shulman, 1986. p. 8.

It has been said that teachers are the most important factor in student learning, but it is not clear which specific characteristics about teachers most affect student learning (Aaronson, Barrow, & Sander, 2007; Goldhaber & Brewer, 2000; Hanushek, 1992; Kane & Staiger, 2012). There have been several research studies (Darling-Hammond, 2013; Stronge, 2010; Strong, 2011; Tucker & Strong, 2005) that tried to identify what characteristics impact teacher effectiveness. Among the findings it appears that teacher knowledge about children's ideas and content as well as knowledge and implementation of pedagogy are common characteristics that affect teacher effectiveness (Strong, 2011).

During the late 1980s Shulman and collaborators were studying the nature of teacher knowledge, the special knowledge that teachers possess (Shulman, 1986). Shulman and collaborators introduced the concept of pedagogical content knowledge (PCK), which represents discipline-specific pedagogical knowledge; i.e. knowledge that goes beyond the content itself and includes the knowledge needed for teaching that particular subject (Shulman, 1986). Since the construct of PCK was proposed, it has been a major topic of research and debate in the teacher education community (Abell, 2008; Magnusson, Krajcik, & Borko, 1999; Park & Oliver, 2008).

In this study PCK refers to PCK in the context of physics. The next sections provide an overview of the development of PCK as a construct, how is PCK defined, previous research involving PCK, as well as the impact of PCK on teacher preparation programs.

The Origins of PCK

Shulman first started thinking about PCK when he was a student in an undergraduate course about biological science and the philosophy of science at the University of Chicago. The professor teaching the course was Joe Schwab who worked on a project called *The Biological Science Curriculum Study* (BSCS). During the course they talked about the structure of subject matter organization of knowledge and how people understand it as well as how the structure of the content changes depending on whether it is used for teaching or inquiry (Shulman, 2012). Shulman also mentioned that they discussed the meaning of the word discipline, which comes from the word disciple that means those who learned. Discipline means how the content is organized in order for people to learn. This helped Shulman develop the idea that perhaps disciplines do not have just one structure, but many structures depending on the learner (Shulman, 2012).

In a later research project Shulman and collaborators studied how physicians work, think, and solve problems (Elstein, Shulman, & Sprafka, 1978). In an effort to identify if there were a generic cognitive skill called "diagnostic ability" Elstein, Shulman, and Sprafka (1978) studied outstanding interns and observed how these interns solved complicated medical problems. However, they found that no such construct as diagnostic ability could be identified. In fact, the results showed that diagnostic knowledge and competence were domain specific. When presented with complicated cases outside of their field of specialization, the interns were not able to provide a good diagnosis (Elstein et al., 1978). This led Shulman to think that maybe there is no such a thing as generalized teaching ability (Shulman, 2012). Years later, Shulman worked at the Institute for Research for Teaching (IRT) at the University of Michigan on a project that focused on teacher behavior. During the process of the research Shulman realized that a weakness of the project was that it ignored teacher thinking (Shulman, 2012). The project seemed to assume that teaching skills were generic, similar to diagnostic ability. These experiences prompted Shulman to begin work on PCK (Shulman, 2012).

During the late 1980s Shulman and collaborators at Stanford University conducted a multi-year case study called the Teacher Knowledge Project. They studied how teachers learn to teach within specific content areas in order to understand what teacher knowledge is and what it involves (Shulman, 1986). The plan was to investigate where the transition from being an expert student; (i.e. the student who clearly understands her roles, expectations, and how to navigate the environment) to a novice teacher occurred and what factors facilitated that transition. Shulman and colleagues studied novice teachers in several disciplines (Biology, English, Math and Social Studies), starting at their practicum year up through their first year or two as teachers. Shulman and colleagues followed the teachers into their classrooms and conducted regular interviews to identify what understanding of concepts and orientations teachers used to support their comprehension of the particular topic they were teaching (Shulman, 1986). As the researchers probed teachers' knowledge, understanding, and transmission of content, it became clear that a new theoretical framework was needed to evaluate the different domains and categories of teachers' content knowledge.

Shulman (1986) decided that before continuing the research he and his colleagues needed to answer questions such as: how do teachers prepare to teach something they have not taught before? How does learning for teaching happen? How do teachers deal with deficiencies in curriculum materials? How do teachers take materials from books and use them in classroom instruction? While looking for answers to these questions through observations of novice teachers the construct of pedagogical content knowledge (PCK) emerged.

PCK Emergence

According to Shulman (1986) there are three categories of content knowledge for teaching: *subject matter content knowledge* (SMCK), *pedagogical content knowledge* (PCK) and *curricular knowledge (CK)*. SMCK refers to the knowledge of facts and concepts about the subject, the understanding of the structures of the subject, and why the subject is organized in such manner (Shulman, 1986). Shulman defined PCK as that specific knowledge that teachers have about a particular topic that allows them to explain it, know how children are thinking about it, and predict children's struggles, among other things. In Shulman's words, "PCK goes beyond the knowledge of subject matter to the dimension of subject matter for teaching"

(Shulman, 1986, p. 9). Finally, CK refers to understanding the materials and tools available to teach the subject, knowing what students may be learning in other courses at the same time (horizontal curriculum) and what they were taught in previous courses or will be taught in future courses (vertical curriculum) (Shulman, 1986).

Shulman described SMCK and CK as the categories of content knowledge for teaching that have been traditionally emphasized, while he referred to PCK as the *missing paradigm* (Shulman, 1986, p. 7). PCK has been referred as a “bridge” between content knowledge and the practice of teaching (Ball, Thames, & Phelps, 2008, p. 389). While content knowledge corresponds to the knowledge of the subject itself and pedagogical knowledge relates to knowledge of methods and practices of teaching, pedagogical content knowledge makes the connections between how the specific content can be challenging to students, what ideas students may have about the topic and how to help students learn that specific subject (Shulman, 1986). It includes knowledge about how students learn the subject, prior ideas that students bring to the classroom, alternate forms or representations, ideas with which students struggle, and appropriate strategies to address these ideas and facilitate learning (Shulman, 1986).

Models of PCK

Since the development of Shulman’s model of PCK other researchers have developed different versions of the model for teacher knowledge (Ball, 2000; Etkina, 2010; Grossman, 1990). There are many models of PCK but describing them all is beyond the scope of this dissertation. In this section, only the most commonly used models, one of which forms the basis of the framework used in this research study, are described. More information about other models of PCK can be found in the complete taxonomy of PCK models developed by Veal and MaKinster (1999).

The two most common models of PCK are integrative and transformative. The integrative model was originally proposed by Grossman (1990). In this model PCK is the integration of two domains: Subject Matter Content Knowledge (SMCK) and pedagogical knowledge (PK). Venn diagrams most commonly represent the integrative model graphically as the merger between CK and PK. Shulman's original definition of PCK falls within the integrative model.

Shulman's original model of teacher knowledge included general pedagogical knowledge, subject matter knowledge, and pedagogical content knowledge. Grossman (1990) added a new category, knowledge of context (KofC), which refers to the knowledge and beliefs of the teaching community and students' background. Figure 1 shows a diagram of the relationships among the teacher knowledge domains of teacher knowledge.

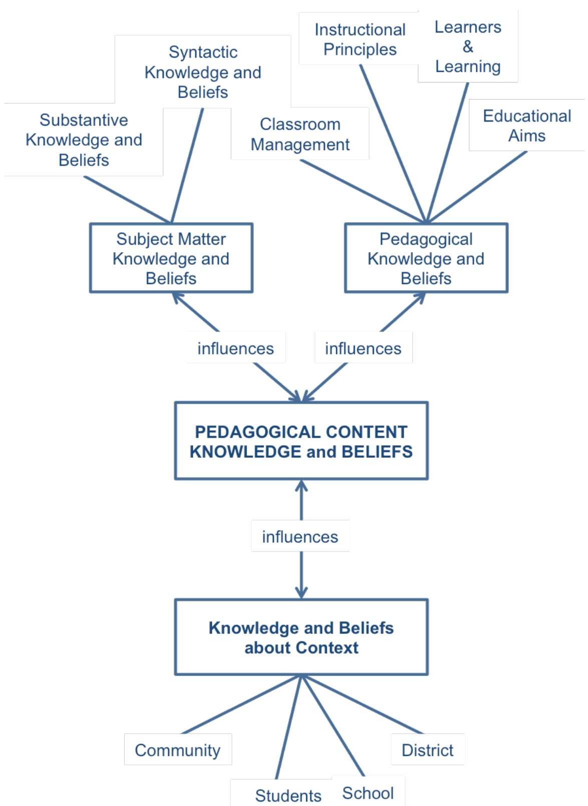

Figure 1. Model of relationships among domains of teacher knowledge (modified by Grossman, 1990).

Magnusson and colleagues (1999) developed a model of PCK specific to science consisting of five different components:

- *Orientation Toward Teaching*: Knowledge of why and how we teach, such as the beliefs teachers have about the role of problem solving, labs, etc.
- *Curriculum Knowledge*: Knowledge of what classes the children have already had prior to this course, what classes they are taking simultaneously (horizontal knowledge), and what classes they will take in the future (vertical knowledge). Also included is the knowledge of sequence of topics that will enable students to progress to a better level of understanding and independence.
- *Children's Prior Knowledge*: Knowledge of children's ideas, preconceptions, and children's difficulties.
- *Instructional Strategies Knowledge*: Knowledge of different methods of teaching, i.e., alternative methods by which to teach a topic, and knowing how to adapt the teaching style to help students learn.
- *Knowledge of Assessment Methods*: Knowledge of the different ways to assess conceptual understanding based on the knowledge of children's ideas.

In the area of physics teaching, the work of Etkina (2010) is one of the most relevant for the current study. She used an adaptation of Grossman's (1990) and Magnusson and colleagues' (1999) model of teacher knowledge to design a teacher-training program for high school physics teachers, resulting in the model shown in Figure 2.

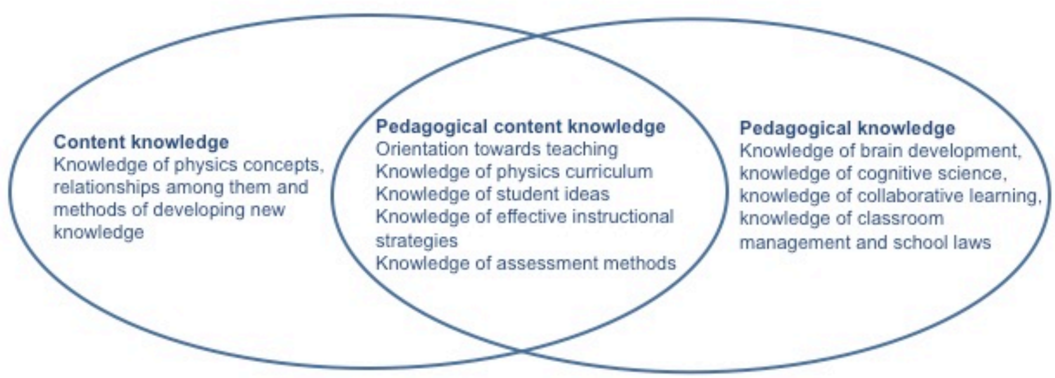

Figure 2. Diagram of an integrative model of PCK specific to physics (Etkina, 2010).

Researchers in a variety of disciplines have proposed integrative models of PCK: Mishra and Koehler (2006) proposed Technology PCK (TPCK) where subject matter knowledge is integrated with knowledge of media for instruction. Fernandez-Balboa and Stiehl (1995) proposed an integrative model of PCK consisting of five components: subject matter, knowledge students' ideas, knowledge of instructional strategies, knowledge of the teaching context and one's teaching purposes. Cochran, DeRuiter and King (1993) proposed a model that integrated teachers' understanding of subject matter content, students' characteristics, pedagogy and the environmental context of learning. Even though the details and subcategories of these models are different, they have in common the knowledge of students' ideas as a key ingredient of what constitutes PCK.

The second category of PCK models is known as transformative models. In this type of model, PCK is seen as a transformation of knowledge from other knowledge categories independent of subject matter knowledge. It is a knowledge a teacher acquires separately from the knowledge of how to teach. This type of model is most commonly used in the subject area of mathematics, known as Mathematical PCK (MPCK); but other researchers have used transformative models of PCK in different fields. VanDriel, Verloop, and de Vos (1998), as well as VanDriel, Beijaard, and Verloop (2001) combined PCK with what they called *craft* *knowledge*, which they defined as the knowledge that teachers have about their teaching practice. Figure 3 is a diagram of a transformative model of MPCK with all the different categories (Ball et al., 2008). The different categories that comprise the transformative model of PCK are not discussed in detail because it was not relevant to the present study.

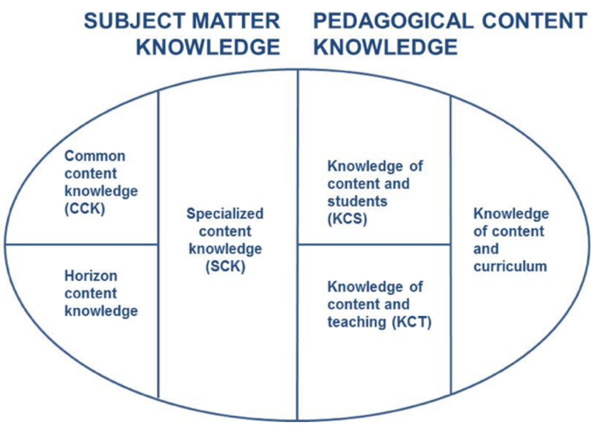

Figure 3. Diagram of a transformative model of PCK (Ball et al., 2008).

The current study used a model based on the integrative model of PCK, in which PCK is the integration of content and pedagogical knowledge. In this study the researcher chose to use the integrative model because previous research has shown that the boundaries between content knowledge and pedagogical content knowledge gets blurred as levels of content knowledge increases, as well as when the levels of teachers' expertise increases (Kleickmann et al., 2015). However, in the transformative model, the definition of PCK is that is knowledge that is transformed from other teacher knowledge categories. Given results of previous research that demonstrated the correlation between the CK and PCK, the definition of PCK seems consistent with how it is presented in the integrative model.

PCK in the Classroom

"[T]he currently incomplete and trivial definitions of teaching held by policy community comprise a far greater danger to good education than does a more serious attempt to formulate a knowledge base" Shulman, 1987, p. 20.

PCK has been described as creating a bridge between subject matter knowledge and the teaching of subject matter (Ball, 2000; Ball et al., 2008). An important issue has been whether PCK is a personal construct that develops over years of practice or whether PCK can be learned through teacher preparation programs. A common thread in different models of PCK is the teacher understanding of children's prior knowledge. VanDriel and colleagues (2001) believed that teachers' knowledge of children's ideas is one of the elements of PCK that could be developed through teacher preparation programs.

There have been several efforts by science education researchers to implement curriculum changes in science courses for teachers, although most of these efforts are in courses for secondary teachers (Abell, 2008; Doster, Jackson, & Smith, 1997; Etkina, 2010; Mellado, 1998; Zembal-Saul, Starr, & Krajcik, 1999). In physics, Zollman (1990), McDermott (1996), Goldberg and colleagues (2006), and Harlow (2010) redesigned content courses for future elementary teachers. The goal of these courses was to help future elementary teachers think of physics as an active process of inquiry in which they can participate instead of an established list of facts to memorize. Even though these efforts contributed positively to the preparation of future elementary teachers, it is unclear how they explicitly addressed future teachers' PCK (Rebello & Zollman, 2013).

Measurement of PCK

According to Borowski et al. (2012), there are four key issues in the PCK literature: 1) the nature and assumptions of PCK, 2) models of PCK; 3) measurement of PCK; and 4) contexts for studying PCK. Previous sections have addressed the first two of these issues. This section provides an overview of the different perspectives of how to measure PCK.

In a publication that discusses a summary of research presented at the PCK Summit in Colorado in 2012, Borowski and colleagues (2012) discussed whether the measurement of PCK should be based on knowledge or an artifact of practice; whether PCK should be measured as a holistic construct or whether different elements of PCK should be measured separately; and finally, whether measurement of PCK should be domain or topic specific. They reviewed research on PCK in the areas of physics, chemistry, and biology for pre-service and in-service secondary teachers in three different countries: Germany, U.S.A, and the Netherlands. Table 1 summarizes the studies and their findings.

Table 1.
Different ways to investigate teachers' PCK.

Assumptions	Germany	USA	Netherlands
Nature of PCK	Goal: find which components of PCK have a greater impact on students' learning and motivation	Goal: determine whether academic content knowledge, pedagogical knowledge, and PCK are related and how these influence teacher practices	Goal: investigate the evolution of PCK in a small number of experienced science teachers while developing a new curriculum.
Participants and Context	279 secondary teachers[1] biology, physics, general science in-service and pre-service.	40 high school biology in-service teachers in a summer professional development program.	Nine in-service secondary science teachers (three in physics, three in chemistry, and three in biology) developing curriculum for a new course on public understanding of science that used student centered teaching strategies.
PCK model Measurement	Transformative Paper and pencil questionnaire of multiple-choice and short answer questions to test CK and PCK.	Integrative Paper and pencil biology test to measure content knowledge. Reflection paper, interviews, and classroom observation to measure PCK.	Transformative Interviews over three years to measure PCK. Example Questions: What were your main objectives in teaching the topic? In what activities and what sequence, did your students participate? What was your role as teacher? Did your students' need specific previous knowledge? What was successful for your students? What difficulties did you see? On what topics, and how did you assess students? Did they reach the learning goals?
Findings	Professional knowledge is a multidimensiona l construct separated into CK, PK, & PCK. These constructs are related but different.	• Professional development had a positive impact on teacher knowledge, skills, and practice. • PCK can be improved • There is significant correlation between ACK, PCK, PK, and CK. • There is no significant correlation between PCK and student achievement.	• Two types of PCK were identified among teachers: 1) Teachers focused on explaining the content, 2) Teachers promoted students' understanding of nature. • Teachers' type of PCK did not change over time. • Development of PCK seemed determined by knowledge of goals and objective of teaching the topic in the curriculum.

Note: Adapted from Borowski et al., 2012

[1] The study says secondary German teachers. It is unclear whether this is the same as high school in the U.S.

Borowski and colleagues concluded that there are correlations between the different categories that conform to what teacher knowledge is (CK, PK, PCK, ACK) for both the integrative and transformative models of PCK. However, the boundaries between these categories can be different depending on how those categories are measured and the levels of expertise of the teachers. In particular, the studies demonstrated that teacher knowledge and specifically PCK exist in a continuum.

Sadler, Coyle, Smith, Miller, Mintzes, Tanner, & Murray (2013) studied the PCK of K-8th science teachers using a 47-item multiple-choice test bank based on hundreds of studies in the science education research literature on student misconceptions. They sampled 30,594 K-8 students and 353 teachers. In addition to taking the multiple-choice test, teachers were asked to predict what common misconceptions their students would struggle with and common incorrect answers their students would provide. By comparing the teachers' predictions of students' responses to the multiple-choice test with students' actual responses to the test items, Sadler and colleagues were able to obtain a measurement of the teachers' PCK. They reported that for the most part teachers overestimated their students' understanding and this was more prevalent for the 5^{th} - 8^{th} grade levels.

Kleickmann et al. (2015) studied the level of connectedness between PCK and CK for two groups of mathematics teachers with different mathematical expertise levels. To operationalize connectedness, the authors defined PCK and CK as latent variables that are free to move depending on different factors such as the teacher's expertise. To measure PCK, Kleickmann and colleagues (2015) developed a test that contained three scales: *knowledge of mathematical task, knowledge of students' misconceptions, and knowledge of mathematics-specific instructional strategies*. The questions provided the teachers with different scenarios from which they were asked to detect, predict, or analyze a typical student error, the sources of misunderstandings based on mathematical knowledge, and list different ways to solve a task. The CK assessment consisted of an in- depth background knowledge of secondary level mathematics curriculum. To determine the structure of knowledge, Kleickmann and colleagues (2015) used confirmatory factor analysis, with PCK and CK conceptualized as latent variables based on different indicators. They reported that when comparisons were done across all teachers, i.e. across all levels of expertise, PCK and CK could be identified as two different constructs and the correlation between them was greater than 60%. When data was stratified by levels of teachers' expertise, results indicated that the higher the level of expertise the greater the correlation between PCK and CK (larger than 80% when teachers had 10 or more years of expertise). Therefore, Kleickmann and colleagues (2015) concluded that PCK and CK could be different constructs for novice teachers with lower mathematical skills, but that this difference diminished with stronger content knowledge.

A different approach to measuring PCK was presented in a study by Beyer and Davis (2012), who investigated how pre-service elementary teachers in a science methods course developed and applied their PCK. To measure PCK Beyer and Davis asked pre-service teachers at the beginning and end of the course to analyze three lesson plans that focused on helping fourth and fifth grade children learn about the melting process. In particular, pre-service teachers were asked to identify and describe strengths and weaknesses of the lesson plan and what modifications they would make to address the weaknesses. By looking at the teachers' reports and how the teachers identified and discussed the weaknesses in the lesson plans and the reasoning they provided for those modifications, Beyer and Davis (2012) were able to identify changes in pre-service teachers' elements of PCK such as knowledge of assessment methods, science curriculum, and instructional strategies.

A study done in a science teaching methods course at Florida International University (Molina, Fernandez, & Nisbet, 2011) explored the effect of participation in microteaching lesson study (MLS) on elementary pre-service teachers' pedagogical content knowledge. To measure the effects of the MLS intervention the researchers gave a pre and post-test to determine elementary pre-service teachers' pedagogical content knowledge and attitudes toward the MLS. To measure the PCK the authors developed questions based on Shulman's framework (1986). Molina and colleagues (2011) asked questions designed to show pre-service teachers' knowledge of the most useful representations, examples, analogies, illustrations, or explanations for the most regularly taught topics in elementary mathematics. They also asked questions to determine pre-service teachers' knowledge about what makes learning of specific topics easy or difficult for students, including knowledge of preconceptions that students bring to the classroom (Molina et al., 2011). PCK was also measured by analyzing the lesson plans that pre-service teachers had created. The researchers used a rubric called CALMA (Creating and Analyzing Lessons from the Point of View of Mathematical Activities) to assess PCK from the lesson plans. CALMA was designed to measure levels of mathematical richness of the lesson plans using criteria such as introduction of a concrete phenomenon and development of mathematical nature of the phenomenon; knowledge of related mathematical problems and solutions; and concreteness of mathematics in broader contexts, which includes development, creativity and appreciation of mathematics (Molina et al., 2011). These criteria indicated the levels of PCK related to knowledge of curriculum, instructional strategies and assessment, as well as content specific knowledge for teaching mathematics. The latter is the category of the MPCK model that relates to knowledge of children's ideas.

Molina and colleagues' (2011) preliminary findings from all three sources of data (pre and post-test, as well as CALMA) indicate that participation in micro-teaching helped the pre-service elementary teachers deepen their content and pedagogical content knowledge. As part of the measurement of attitudes toward MLS researchers also analyzed responses from a feedback survey in which participants responded to a series of Likert-type statements designed to gauge their perceptions of the experience of creating micro-lessons (Molina et al., 2011). Results of the survey revealed that pre-service teachers valued the work in a group, positively responding to the questions in the survey that asked them about the extent to which working in group helped broaden their knowledge and understanding of their teaching strengths (Molina et al., 2011).

Implications of Literature for the current study

This study focused on a redesigned physics course for elementary education majors (Fracchiolla & Rebello, 2014; Rebello & Zollman, 2013). The course was redesigned to infuse PCK into the core of the course. The goal of the course was that the elementary education majors recognize the importance of physics as well as understanding the importance of knowledge of children's ideas about physics. This study concentrated on determining if the redesigned course promoted changes in three elements of the future teachers' PCK: knowledge of children's ideas (KCI), use of these ideas in the design of instructional strategies (UIS), and use these ideas in the design of assessment strategies.

In the current study, a combination of different artifacts presented in previous studies was used to measure PCK. The use of micro-lesson studies was implemented to determine changes in the students' levels of PCK throughout the semester. Students completed a final project at the end of the semester which included a lesson plan, a video demonstrating how they would implement the lesson plan or enact the actual lesson, and a critique of one of their peers' lesson plans or videos. These assessments were used to determined changes in students' levels of PCK between a redesigned courses and a previous version of the same course before it was redesigned. In the following chapters a more in-depth description of the course, data sources, and analysis is provided.

Chapter 3

Research Design

The context of this study was a redesigned physics course for future elementary teachers. To determine the extent to which the redesigned physics course impacted students' levels of PCK, a quasi-experimental design was used. In particular, this study was driven by two research questions:

1. *How does evidence of incorporation of three categories of PCK – knowledge of children ideas (KCI), use of these ideas in instructional strategies (UIS), and use of these ideas in assessment strategies (UAS) – by students enrolled in a redesigned physics course for elementary education majors that explicitly integrates knowledge of children's ideas compare with such evidence provided by students who were enrolled in a previous version of this course that did not explicitly integrate knowledge of children's ideas?*
2. *To what extent does the level of sophistication of integration of three categories of PCK – KCI, UIS, and UAS – in students' micro-teaching and final project video change throughout a semester in the redesigned physics course?*

This chapter starts with a detailed description of the original course and the redesigned course, including the setting and structure. This is followed by a description of the sampling methods and an overview of the participants' demographic characteristics. Then a description of the instrumentation used for data collection is presented as well as the connection of the different data sources to the research questions. Finally, the methods used for data analysis are provided.

Description of the intervention

This section contains a description of the original *Concepts of Physics* course, defined as the baseline course, the model upon which the redesigned course was based, along with a comparison of the baseline and redesigned courses.

The Original Concepts of Physics Course

Concepts of Physics is a physics course for elementary education majors taught at a large U.S. mid-western land-grant university. The course was created in the early 1970s by Dean Zollman (1990; 1994) to specifically meet the needs of elementary education majors. Zollman adapted Karplus and Butts' (1977) Learning Cycle (Exploration, Concept Introduction, and Application) for use in a large enrollment course (Zollman, 1990). The course met on Mondays, Wednesdays and Fridays for 50-minute lectures. Students went to the 'Activity Center' (Zollman, 1974) twice a week. The 'Activity Center' was open for several hours throughout the week so that it was accessible to students at their convenience. Experimental stations were set up in the 'Activity Center'.

Students completed the 'Exploration' phase in the 'Activities Center' between Monday and before lecture on Wednesday. The 'Exploration' phase included a series of activities in small groups migrating from one station to another and recording their observations. The students were not expected to have had any prior exposure to the underlying concepts at this stage. Students were provided with a worksheet that included questions that focused on asking the students to make observations and describe their experiences.

The ‘Concept Introduction’ phase occurred in the lecture on Wednesdays, when the instructor asked students to recall their observations in the ‘Exploration’ phase and then introduced concepts that would enable the students to make sense of the phenomena that they had observed in the Activity Center. Students returned to the ‘Activity Center’ for a second time between the Wednesday and Friday lectures to complete the ‘Application’ activities. These activities were similar in format to the ‘Exploration’ activities. But because students had been exposed to the concepts in the lecture on Wednesday, they were expected to answer the questions in light of these concepts. For instance, the ‘Application’ activity questions might have asked the students to not just describe the outcome of a collision between two carts but also explain the outcome in terms of the law of conservation of momentum. Students returned to the lecture on Friday and again on Monday. On these two days, the instructor reviewed the ‘Application’ activities and summarized the main ideas covered during that week.

An important feature of the course was the use of hands-on activities that were inexpensive to create and that used a selection of everyday artifacts with which students were familiar. Zollman combined these hands-on inexpensive activities with more high-tech alternatives so that students in the *Concepts of Physics* course could be exposed to emergent instructional technologies. Some of the high-tech alternatives were the use of microcomputer based laboratories (MBL) and probe-ware. In the late 1990s, instructional technologies, such as ‘ClassTalk’ system (Zollman, 1997), which was a pre-cursor to wireless clickers, were introduced into the *Concepts of Physics* course to foster the development of an interactive learning environment in the lectures as well as in the activities (Zollman, 1997).

The Pedagogical learning bi-cycle model

In 2012, Rebello and Zollman started to redesign the *Concepts of Physics* course to explicitly integrate pedagogical content knowledge into the core of the course (Rebello & Zollman, 2013). The purpose of the redesign was to enable students in the course to recognize the relevance of learning physics concepts in order to teach science as well as understand the relevance of knowledge and perceptions that children in their future classrooms could have about physics concepts.

The redesigned course was based on a model known as the pedagogical learning bi-cycle (PLB) (Rebello & Zollman, 2013). This model (Figure 4) was first presented in a proposal to the National Science Foundation (Rebello, 2011). The PLB model consists of a two layered 3E (Exploration, Explanation and Elaboration) learning cycle. The model combines a Learning Cycle specific to content knowledge (CK) with a Learning Cycle specific to pedagogical content knowledge (PCK) (Shulman, 1986) linked by a metacognitive reflection (MR) bridge (Rebello, 2011; Rebello & Zollman, 2013). The MR is an activity given to students between the first and the second week of the cycle designed to engage them in reflecting on their learning.

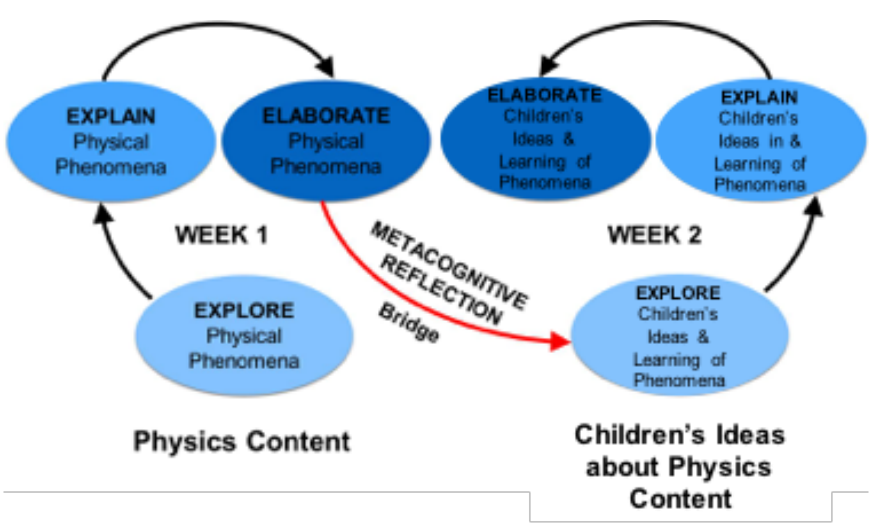

Figure 4. Pedagogical Learning Bi-cycle (PLB).

The first week of the PLB model addresses students' conceptual knowledge (CK) and it is the same general format as the original *Concepts of Physics* course. The second week of the bi-cycle addresses students' PCK. Students also go through a 3E Learning Cycle, but in their experiences in the laboratory and lecture are focused on children's ideas about the concepts addressed during the first week. During the 'Exploration' part of the cycle, the students watch classroom vignettes in which elementary children are expressing their ideas of physics concepts relevant to those learned by students in the previous week. The students are asked to interpret the children's ideas in light of their own understanding of the concepts. During the 'Explanation' part of the cycle students discuses their interpretations of children's ideas and are introduced to research on children's prior knowledge of the particular content. Finally, in the 'Elaboration' part of the cycle the students are asked to develop a micro-lesson to teach the concepts they learned in the previous week, taking into consideration children's ideas of the concept. The students demonstrate their micro-lessons in a five- to seven-minute video in which the students are asked to describe or enact an activity that addresses children's ideas. In these videos, students are expected to clearly identify a children's idea they are going to address, design and describe an instructional strategy that incorporated the children's idea to be addressed, and also describe an assessment activity that they would use to determine whether the designed activity addressed the children's idea.

Redesigned Concepts of Physics Course as Implemented

The PLB model was not implemented as it was initially described in the NSF proposal (Rebello, 2011). Changes between the proposed model and the implementation were mostly due to time constraints, feedback from students and improvements to the model. It took three iterations of the implementation of the PLB until the final design implemented in 2014 was reached. In each of the iterations of the course, modifications were made based on the instructor's experience and feedback from the students in the course.

The main differences between the model proposed and the implementation of the redesigned course were:

- Each "bi-cycle" was three full weeks of instruction, two weeks of learning physics concepts were followed by a week of learning children's ideas. The three-week format allowed for completion of three conceptual units: Force and Motion (F&M), Circuits and Magnets (C&M), and Heat and Light (H&L). See Appendix A for a detailed schedule of the course as it was taught in the redesigned course.
- In the modified implementation of the PLB the MR was not explicitly put into practice. Instead, guiding questions were included on the 'Elaboration' activity of the content week. The purpose of the questions was to engage students in reflecting on the concepts they just learned; how their responses in the 'Elaboration' phase compared to their original ideas in the 'Exploration' phase; if there were changes, why there were changes; what they believed were children's ideas about the concepts they were discussing; and how those ideas could compare to their original ideas.
- Micro-lessons were required at the end of each conceptual unit, which replaced the activities of the 'Elaboration' phase of the second cycle of the PLB. The micro-lessons were intended to be an intermediate step to help students develop the confidence and maturity to create a full lesson plan.

- Instead of in-class presentations of the lesson plans students were required to create a video in which they described or enacted the activities proposed in their lesson plan.

Comparison of the Baseline (Fall 2011) and Redesigned (Fall 2014) Courses

The *Concepts of Physics* course taught during Fall 2011 resembled the original course, but only one 3E Learning Cycle was implemented. Unlike the original course, the Fall 2011 course included brief descriptions of children's ideas about science in some of the lectures during the 'Explanation' phase. Besides the brief descriptions of children's ideas, there were no further discussion or activities pertaining children's ideas of science during the 'Exploration' and 'Elaboration' phases. Table 2 summarizes the main differences between the *Concepts of Physics* course during Fall 2011 and Fall 2014.

Table 2.
Differences between the baseline and redesigned Concepts of Physics course.

	Fall 2011	Fall 2014
Pedagogical Model	3E Learning Cycle	Pedagogical Learning Bi-Cycle (Rebello, 2011)
Discussion of children's ideas in lecture	0.7% of the total number of PowerPoint slides in the course lectures contained information about children's ideas. These slides were embedded along with other slides that focused on physics content	12.0 % of the total number of PowerPoint slides in the course lectures contained information about children's ideas. Rather than being embedded along with physics content, a separate phase of the PLB ('Explanation' phase of the 2nd cycle) was dedicated to the presentation of these ideas in the lecture.
Activities regarding children's ideas	None	Activities that incorporated or discussed children's ideas were part of the 'Exploration' and 'Elaboration' phases of the second cycle of the PLB
Final Project reading materials	Readings about children's ideas were provided to support students' creation of the lesson plans	Readings about children's ideas were provided to support students' creation of the micro-lessons and lesson plans.
Final Project requirements regarding children's ideas	Students were asked to clearly indicate the children's ideas that they addressed in the lesson plan	Students were asked to clearly indicate the children's ideas that they addressed in the lesson plan

Participants

Participants in this study were 278 undergraduate students enrolled in the *Concepts of Physics* course during the Fall of 2011 and Fall 2014. The sampling method used was convenience sampling. The demographic data related to students' gender, major, and year in school is part of the information given to instructors at the beginning of each semester through an online roster and is summarized in Table 3.

Table 3.
Demographic information for baseline and redesigned courses.

	Fall 2011	Fall 2014
# of Participants	110	168
Gender	Female 90.0% Male 10.0%	Female 92.9% Male 7.1%
Year in School	Freshmen 27.4% Sophomores 43.5% Juniors 19.0% Seniors 10.1%	Freshmen 3.7% Sophomores 67.0% Juniors 23.9% Seniors 5.5%
Majors in College	Elementary Education 76% Other Education 6% Art, Business, Health 18%	Elementary Education 80% Other Education 10% Art, Business, Health 10%

A chi-square test was performed to determine if there were any statistically significant difference in gender distribution of the two courses. Results of the test indicated there was no statistical difference. A one-way ANOVA was performed to determine if there were statistically significant differences in the participants' distribution of year in school and major between the two groups – Fall 2011 and 2014. Results showed that there were no statistically significant differences between the student samples in the baseline and the redesigned course. For more detail on the demographic and statistical analysis see Appendix B.

Prior to engaging in data collection, students in both Fall 2011 and Fall 2014 students gave informed consent consistent with the university's Institutional Review Board (IRB). All participants were aware of the nature of the research, their rights, and protocols used to obtain information from them. A copy of the IRB approval letter can be found in Appendix C.

Instruments and Data Sources

The data sources included two types of materials created by students: (1) videos, and (2) written artifacts. In the baseline course, all of the data sources were written artifacts: final project lesson plan and critique. In the redesigned course, the data sources consisted of four videos (3 micro-lessons and one final project video) and two written artifacts (final project lesson plan and critique). The following subsections present a detailed description of each data source and how it was collected.

Videos

Student created videos were collected only in the redesigned course in Fall 2014. These were used to assess the level of sophistication of PCK students demonstrated in the micro-lessons (ML) and final project video (FPV). A detailed description of each of type of student-created video is presented below.

Micro-Lesson (ML) Videos

At the end of each conceptual unit, students were required to create a video of about five to seven minutes long, called a micro-lesson (ML). In the ML, groups of three to five students either described or enacted an activity to be taught to elementary children related to one of the topics covered in that conceptual unit. Some groups gave guided instructions on how the lesson should be taught, i.e., they described what activities they had planned and how they were going to assess children's learning. In some cases, students enacted the activities they would use with elementary children. One of the students impersonated the "teacher" and the other students impersonated "elementary school children". Students recorded their MLs with cameras that were provided or with cellphones and/or iPads that they provided by themselves. Figure 5 shows the instructions given to students to create their ML videos. The rubric and coding scheme for analyzing the micro-lessons is presented in the analysis section.

➢ **<u>MICRO LESSON</u>: Work in groups of 2-5 to complete the following activity.**

- Go back to the discussion we had in class about kids' ideas of force and motion. Pick one of those ideas that kids typically have that might be incomplete and/or incorrect.
- Use: COMPUTER SIMULATION (above) **OR** HANDS-ON MATERIALS (provided on the table).
- Prepare a brief **exploration** type of activity for the kid to do to address kids' ideas. You will have the kid observe or do something that will contradict the kids' ideas.
- Prepare a brief **explanation** that will help them develop new understanding that addresses the incorrect or incomplete ideas they may have previously had. This can include a list of questions that you might ask kids to help them build their understanding, including direct instruction by you.
- Create a short video (max 7 minutes) demonstrating your micro lesson. **In the video you should hold a placard indicating clearly written in block letter's everyone's first and last name in the group. This should be held up for about 10 seconds** as a record of who is in the movie.

Figure 5. Instructions given to the students to create the micro-lessons.

Final Project Video (FPV)

The final project video (FPV) was part of the final project students presented at the end of the course in the redesigned course. Like the MLs, the FPVs were created in groups. As with the MLs, some groups gave guided instructions on how the lesson should be taught, while others enacted the lesson. Even though the guidelines for the FPV asked for more details and longer videos than the MLs, the FPVs had durations of approximately five to seven minutes.

Written Artifacts

The written artifacts collected were Lesson Plans and Critiques for the Final Project from both the Fall 2011 (baseline) and Fall 2014 (redesigned) courses. The same instructor taught both courses and the same guidelines were given to students to create the lesson plans and critiques for the final project in both the Fall 2011 and Fall 2014 courses. See Appendix D for the final project guidelines used in both the baseline and redesigned course.

Final Project Lesson Plans (LPs)

Students worked in groups of three to five to create a complete lesson plan for a 50-minutes class on one of the topics learned during the semester. Students were instructed to design an age-appropriate lesson plan that incorporated children's ideas about physics in one of the topics discussed during the semester.

Final Project Critique

Each student was required to write a one-page critique of a specific group's lesson plan that was randomly assigned to them. To critique the lesson plan, students were advised to use the criteria (See Figure 7) used to grade the lesson plan provided in the instructions. Examples of the students' critiques can be found in Appendix E.

You and your group will be graded on the lesson plan as a whole which means you will all receive the same number of points. The criteria are:

- Feasibility of learning goals for a 50-minute class and the age-group of the kids (6 points)
- Alignment of assessments with the learning goals (6 points)
- Alignment of the lesson plan and the goals (6 points)
- Appropriateness of the materials used (6 points)
- Alignment of lesson with children's ideas of science (10 points)
- A clear distinction of the phases of the 3E learning cycle (10 points)
- Overall clarity of the proposal (6 points)

Figure 6. Criteria given to students during Fall 2011 and Fall 2014 to critique their peers' lesson plans.

Analysis of PCK

Table 4 shows each of the research questions connected to the corresponding data source that was used to answer the question as well as the method for data analysis.

Table 4.
Research Questions, Methodology and Alignment with Data Source.

Research Question	1. How does evidence of incorporation of three categories of PCK – knowledge of children ideas (KCI), use of these ideas in instructional strategies (UIS), and use of these ideas in assessment strategies(UAS) – by students enrolled in a redesigned physics course for elementary education majors that explicitly integrates knowledge of children's ideas; compare with such evidence provided by students who were enrolled in a previous version of this course that did not explicitly integrate knowledge of children's ideas?	2. To what extent does the level of sophistication of integration of three categories of PCK – KCI, UIS, and UAS – in students' micro-teaching and final project video change throughout a semester in the redesigned physics course?
Methodology	Quantitative: Quasi-experimental design to test the effect of exposure to an instructional model that emphasizes knowledge of children's ideas about science in the students' categories of PCK	
Data Sources	• Lesson plans (groups) • Critiques (students)	• Micro-lessons (groups) • Final Project Video (groups)
Type of Analysis	Rubric Fisher's Exact Test	

To address these research questions, three categories of PCK – knowledge of children's ideas about science (KCI), use of these ideas in instructional strategies (UIS), and use of these ideas in assessment strategies (UAS) – were investigated. To do so, the micro-lesson videos the students created throughout the semester as well as the lesson plans, final project videos and critiques created in the final project were examined. The researcher looked for instances of students referring to children's ideas and how those ideas were incorporated in the micro-lesson videos, lesson plans, final project videos and critiques.

Rubrics

Two rubrics were created to measure the students' level of PCK with regard to KCI, UIS, and UAS. The first rubric was developed to evaluate the micro-lesson videos, lesson plans, and final project video. The second rubric was developed to evaluate the critiques.

A first version of the rubric was developed by Rebello and Zollman (2013). This rubric was used to evaluate the extent to which students used children's ideas in their lesson plan and critiqued their peers' use of children's ideas in their lesson plans. The rubric consisted of four levels: level zero indicated that there was no mention of children's ideas in the artifacts; level one indicated that children's ideas were mentioned, but not addressed in the design of the activities; level two indicated that the designed activities incorporated children's ideas, but the assessment activity did not; finally, level three indicated that both the design of activity and assessment addressed children's ideas (Rebello & Zollman, 2013).

A separate rubric to evaluate the critiques was developed by a committee involving four researchers: a graduate student from the Department of Curriculum and Instruction, the principal investigator of the grant, another student of the physics education research group, and the researcher of the study. This rubric also consisted of four levels: level zero indicated that the student did not mention the group's use (or not) of children's ideas; level one indicated that the student commentated whether or not a children's idea was mentioned in the lesson plan; level two indicated that the student discussed how the group used (or not) children's ideas in the lesson plan; finally, level three the student provided opinion on how those children's ideas were used in the lesson plan and if it was appropriate or not (Fracchiolla & Rebello, 2014).

In Fall 2013 these rubrics were tested on the lesson plans and critiques submitted by students who completed the course in Fall 2013. The results of that analysis were presented at the 2013 American Association of Physics Teachers (AAPT) Summer Meeting and the 2013 Physics Education Research (PER) Conference (Fracchiolla & Rebello, 2014). Reviewers of the PER conference paper suggested that the overall measure of PCK be broken down into specific categories. These suggestions led to revised versions of the rubrics which clearly separated the three categories of PCK – KCI, UIS, and UAS- measured in this study. To add another measure of validity, a researcher who was unfamiliar with the study but had completed Ph.D. in Curriculum and Instruction focused on teacher evaluation examined the rubric. All changes were implemented into the final version of the rubric used in this research (Table 5 and Table 6).

Table 5.
Scoring rubric for the lesson plans, micro-lessons, and final project videos.

Aspect of PCK	Questions	Level of evidence
Knowledge of children' ideas (KCI)	To what extent did lesson plan/micro-lesson/FPV clearly identify (or not) children's prior ideas?	0 - Not at all 1 - Somewhat 2 – Clearly
Use of children's ideas in instructional strategies (UIS)	Did the lesson plan/micro-lesson/FPV demonstrate the use in instructional strategies that address children's prior ideas identified before?	0 - Not at all 1 - Somewhat 2 - Clearly
Use of children's ideas in assessment strategies (UAS)	Did the lesson plan/micro-lesson/FPV demonstrate use in assessment strategies that take into account children's prior ideas?	0 - Not at all 1 - Somewhat 2 - Clearly

Table 6.
Scoring rubric for the critiques.

Aspect of PCK	Questions	Level of evidence
Knowledge of children' ideas (KCI)	Did the student mention the use (or not) of children's prior ideas on the lesson plan and FPV?	0 - Not at all 1 – Somewhat 2 – Clearly
Use of children's ideas in instructional strategies (UIS)	Did the student mention/discuss (or not) how children's ideas were incorporated into the instructional strategies described in the lesson plan and FPV?	0 - Not at all 1 – Somewhat 2 - Clearly
Use of children's idea in assessment strategies (UAS)	Did the student mention/discuss (or not) how children's ideas were incorporated into the assessment strategies described in the lesson plan and FPV?	0 - Not at all 1 – Somewhat 2 – Clearly

Inter-rater reliability of the rubrics

Before using the rubrics to score the data for the analysis, the reliability of the rubrics was examined by testing the level of agreement between two independent raters given the same data set and using the corresponding rubric. The two raters were the researcher of the study and another researcher who was not part of the project. The researchers independently scored 15% of the lesson plans, critiques. The researchers compared the scores given for each of the artifacts. If there were any discrepancies in scores, those were discussed and another set of data was chosen to be rated. The level of agreement between raters was examined using a Cohen's κ analysis. The Cohen’s κ was calculated for each category evaluated, i.e. the coefficient was calculated for agreement between the researchers’ ratings of levels of KCI, UIS, and UAS separately, and not as one overall score. By doing the analysis for each category independently it was easier to understand where the agreements and disagreements were and correct if necessary. After two iterations an 80% agreement for kappa values between the raters was reached. Table 7 presents the result of the Cohen’s kappa analysis for the reliability of each of the categories evaluated by the rubrics for each of the artifacts. In this case a 95% confidence interval was used with kappa values between 0.504 and 0.848.

Table 7.
Results of Cohen's kappa analysis for the rubrics

PCK Category	KCI		UIS		UAS	
	K	*p*	κ	*p*	K	*p*
ML	0.810	.001	0.543	.028	0.590	.010
LP	0.808	< .001	0.531	.019	0.851	< .001
Critiques	0.652	< .001	0.813	.001	0.743	.005

Agreement between the scores given by the researchers was found for all the categories of PCK for each of the artifacts (LP, ML, and critiques). Therefore, the reliability of the rubrics was established. The artifacts used to determine the reliability of the rubrics were not used in the data analysis.

Statistical Tests

Research Question # 1

To determine the extent to which the redesigned course impacted students' PCK (Research Question #1) a between-subject design was used. The data collected from the redesigned course (Fall 2014) and the baseline course (Fall 2011) were compared. The same instructor taught both courses and students were administered the same assessments with identical guidelines and resources (See Appendix D for complete instructions and description of materials given to students during Fall 2011 and Fall 2014). The main difference between the baseline course and the redesigned course was the second cycle of the PLB that focused on the elements of PCK that related to the knowledge of children's ideas.

For this analysis, a Fisher's exact test was performed instead of an ANOVA. ANOVA was not possible because the data did not meet the assumptions required to do an analysis of variance. In this case the data did not meet the assumption of homogeneity and sphericity. Therefore, the Fisher's exact tests which is equivalent to a chi-squared test to determine statistical significance was used. Fisher's Exact Test provides a measure of how well a given null hypothesis is compatible with the observed data (Cowan, 1998). Fisher's test is a non-parametric test used when sample sizes are as small as 20 or expectancy of frequencies per cell are smaller than five. Even though this is a large enrollment course, some of the artifacts were created by groups of four to five, considerably reducing the expectancy of frequencies per cell to smaller than five.

Prior to conducting Fisher's Exact Test, two assumptions were verified: (i) both dependent and independent variables are categorical variables and (ii) independence of observation (Field, 2013). In this study the independent variable corresponds to whether the course was the baseline or redesigned course. This variable was coded as zero (0) for the baseline course and one (1) for the redesigned course. The dependent variables are the levels of PCK for each category: KCI, UIS, and UAS. Each category has three levels. Independent and dependent variables are ordinal, i.e. variables with two or more categories and the categories can be ranked (Field, 2013). Assumption (ii) assumes that individual observations are independent of each other, e.g., that there are no common outside factors that influence the observations (Field, 2013). Independence of observations is determined by the structure of the experimental design from which the variables are chosen. For this research question the participants being compared were the students enrolled in the *Concepts of Physics* course during two different semesters (Fall 2011 and Fall 2014) separated by 3 years; none of the participants in 2011 were in the 2014 semester. Therefore, independence of observations was met.

Research Question # 2

To determine if there were changes in students' levels of PCK throughout the semester (Research Question #2), a within-subject design was used. The MLs students created during the semester and the final project video were compared to determine changes in students' level of sophistication of the three categories of PCK– KCI, UIS, and UAS – measured using the rubrics. The analysis consisted of a comparison of the levels of the different categories of PCK across time.

This analysis presented some challenges because students worked in groups to create the micro-lessons and FPV, but the groups were not comprised of the same students each time nor did the same number of members make up each group. An appropriate structure of the analysis in this type of a situation is a nested design that examines changes at both the student and group levels. The common type of analysis used for this type of design is the Hierarchical Linear

Model (HLM), used when data is collected at different times, under different conditions that are nested within each participant (Bell, Ferron, & Kromrey, 2008). Two disadvantages of the HLM are that it requires a large sample size and non-categorical data. In this study the data was categorical and did not comply with the required sample size, so only the student level analysis was completed.

To analyze the data for the second research, question a Fisher's Exact Test was used to determine if there was a statistically significant difference across the different times - micro-lessons and FPV- in students' level of sophistication of incorporation of children's idea into their micro-teaching. Fisher Exact Test was used for the analysis to maintain consistency with previous analyses. Fisher's Exact Test, requires that (1) both dependent and independent variables need to be categorical variables, and (2) independence of observations (Field, 2013). The independent variable (time) and dependent variables (the categories of PCK – KCI, UIS, and UAS – measured in this study) were ordinal variables; therefore, the first assumption was verified. The second assumption assumes that individual observations are independent of each other. For this research question the participants are the same, but they were evaluated while collaborating with different group of students, at different moments in time and under different conceptual units. As described by Forsyth (1990), "Groups often exert a strong guiding hand on our attitudes and behavior" (p. 171); which suggests that individuals working with different groups will behave differently according to the influences that the group exerts on them. Therefore, independence of observations was satisfied. However, in order to be conservative in making claims about statistically significant differences between the samples, only effect sizes medium or larger were taken into consideration.

Validity & Reliability

Validity is used to determine whether the proposed research measures what it intended to measure as well as provide the truthfulness of the results. Reliability is related to the consistency of the measurements (Keppel and Zedeck, 1989). The following subsections describe the measures that were taken to maximize validity of the design and reliability of the instruments, while acknowledging the threats to validity that the design did not take into account.

Internal Validity

Internal validity refers to the degree to which the research design controls for extraneous variables so that the variables impacting the results of the study are those being manipulated (Keppel and Zedeck, 1989). Relevant extraneous variables whose impact were minimized included: the instructor, the reading material, and guidelines for the final project. In the case of the extraneous variables that were controlled, the same instructor taught both courses (Fall 2011 and Fall 2014) and the same reading material was provided to the students with which to create their final project. Similarly, the same guidelines for the final project were given to all students.

Those variables that could not be controlled include: students' prior knowledge, time, and theme. An extraneous variable that could not be controlled was students' prior knowledge about content as well as PCK. Unfortunately, a pre-test on physics content and PCK for either Fall 2011 or Fall 2014 was not performed. Lack of such a pre-test prevented the determination of the level of content knowledge (CK) and pedagogical content knowledge (PCK) students brought to the courses. As discussed in Chapter 2, prior research demonstrated that there is a correlation between CK and PCK. The stronger the level of CK an individual has, then the stronger the correlation between that student's level of CK and PCK. Therefore, to have a full understanding of the impact of the course on students' level of PCK it was necessary a pre-test to determine what was students' levels of CK and PCK before they were exposed to the course.

Due to the structure of the class the variables of time and theme could not be controlled. As time progressed during the semester, the topics the students were learning were also changing, which caused for the variables of time and theme to be confounded. In an ideal situation, half the class would have learned about the topics in one order and the other half in a different order to be able to separate the effects of both variables on PCK. When presenting the findings for time, the researcher acknowledges that the results could also have been affected by theme.

External Validity

External validity is related to the degree to which the results of the experiment can be generalized in terms of population, environment, and time. The ability to generalize depends on the diversity of the sample (Keppel and Zedeck, 1989). For this study, the sampling method used was convenience sampling. This undermined the ability to make generalizations from the results of this study, because the sample did not necessarily represent the general population of elementary education majors. Therefore, the type of generalizations that can be made are better applied to population and environments similar to the sample studied; i.e. education majors in a mid-western land grant university. In addition, 20% of the population of the class were not elementary education majors, 10% of those were in a different education program and the other 10% were in business or art majors. This also impacts the type of generalizations that can be made.

A measure taken to strengthen external validity was to examine PCK in terms of three constructs – KCI, UIS, and UAS. Even though reducing the analysis to three categories of the

PCK construct limits the generalizations that can be made to the confines of the operational definitions of PCK given, focusing on those specific elements of PCK assures that comparisons can be made across studies using similar constructs. In one sense focusing on three categories of PCK in the study limits the number of studies with which results can be compared. At the same time specifying just those three categories assures that the results could be more accurately compared to similar studies because it reduces the ambiguity of how the construct of PCK has been defined. Another measurement to strengthen external validity was the use of different sources of data to triangulate results, which reduces the threat of generalizing across measurements.

Reliability

For the purpose of this study the instruments used to collect data were two rubrics. To establish reliability of the rubrics measurements of inter-rater reliability were performed. Two researchers scored 15% of each of the data sources using the corresponding rubrics. The researchers' scores were then compared, and if there were disagreements, those were discussed and a different set of data was scored. Reliability was established once there was 80% agreement in the scores given by the researchers. Details of the Cohen's kappa calculations for inter-rater reliability were given in a previous section.

Limitations of the Design

The purpose of the study was to determine the impact of a redesigned physics course for elementary education majors on students' levels of PCK. As the different sources of data an analysis were described, the limitations of those were pointed out. In this section, a summary of those limitations is presented.

- A limitations of the design comes from what Stake (1995) referred as *petit generalizations*. As it was mentioned above, patterns identified in this study are confined to group of students similar to those from which conclusions were drawn.
- A limitation in the analysis was the lack of pre/post-test on students' content knowledge (CK) and PCK of physics for the baseline and redesigned courses.
- Another external factor apart from the instructor and design of the course that could influence students' CK and PCK which were not under the researcher's control were students' exposure to different teaching and learning strategies. Students spent many years of their life in school before taking this course. Therefore, strategies that they may have used for learning content and for teaching began long before they started this course. Any inferences made about the connections between the course and the science teaching strategies for elementary classrooms may be the results of other experiences.
- Another measurement normally used to compare groups before an analysis to determine the effect of an intervention would have been the students' prior knowledge, however this information was not available for the baseline and redesigned course.

Chapter 4

Analysis & Results

In this study, the extent to which a redesigned physics course affected students' knowledge of children's ideas about science and the incorporation of that knowledge into artifacts created by students throughout the semester - micro-lesson videos and the final project, which included a lesson plan, critique, and video - was investigated. Table 8 describes the data sources, time of collection, number of participants or artifacts that were used in the analysis, and level of analysis.

Table 8.
Description of data sources and number of participants or artifacts per data source and unit of analysis.

Data Source	Description	Time of collection	Number of items (N)	Level of Analysis
Micro-Lessons (ML)	Short videos in which students enacted or described a short activity to address children's ideas relevant to the conceptual unit being discussed	At the end of each conceptual unit (3 conceptual units)	Approx. 160 students, comprising approximately 50 groups per conceptual unit (F2014)	Student Level
Final Project: Lesson Plan (LP)	A three-page lesson plan for a 50-minute class to address one of the children's ideas discussed during the semester	At the end of the semester during Fall 2011 & Fall 2014	51 Groups (F2014) 26 Groups (F2011)	Group Level
Final Project Video (FPV)	Short video to accompany the LP, in which students enacted or described the activity they proposed in the LP to address children's ideas of their choice	At the end of the semester in the redesigned course	51 Groups (F2014)	Student Level
Final Project: Critiques	One-page critique about a peer's LP randomly assigned to them	At the end of the semester during Fall 2011 & Fall 2014	137 Student (F2014) 97 Student (F2011)	Student Level

Children's Ideas

Research on children's ideas completed by Rosalind Driver and co-workers (1985) was used as the main resource for children's ideas about science - the struggles, preconceived ideas, and misconceptions children have about different science topics. This research provides specific examples of children's common misconceptions and also presents children's explanations about the different physics concepts, which help educators understand how those misconceptions are formed. During the second cycle of the PLB, which focused on children's ideas, students in the course were exposed to a sample of those ideas. The guidelines and rubrics for the micro-lessons and final project asked students to choose a children's idea from the available *Concepts of Physics* course literature. One example of a children's idea presented to students in the Force and Motion unit (F&M) was that children think, "forces are to do with living things" (Driver, 1985, p. 91). This means that children believe that only living things can exert forces, as in a hand pushing a car. Non-living objects, such as the surface the car is rolling on, cannot exert forces on other objects. Driver's list of children's ideas (1985) was used for the Forces & Motion and Heat & Light conceptual units.

A second resource was Stephans' Conceptual Change Model (1994). Stephans supplied a list of elementary children's misconceptions. However, Stephans did not provide an explanation or description of the research confirming the misconceptions, the children's scientific understanding of the concepts or why they developed those misconceptions. In this study, Stephans' list of children's ideas (1994) were used in the development of the second cycle of the PLB for the conceptual unit of Circuits and Magnets (C&M) of the *Concepts of Physics* course.

Table 9 provides a complete list of the children's ideas presented for the content unit entitled Force and Motion (F&M). The table includes the children's ideas, a short explanation of what those each idea means, as well as the correct scientific idea. Figure 8 shows the frequency distribution of children's ideas used by groups in developing the micro-lesson for the Force and Motion unit. The most common ideas used by groups were: a) Heavy objects fall faster (26.5%); b) The force runs out (18.4%); and c) The amount of motion is proportional to the amount of force applied (14.3%). The other ideas were each identified by less than ten percent of the groups. All of the children's ideas about Force and Motion presented in Table 9 were mentioned by at least one student. More than twenty percent (22.4%) of the groups did not identify which children's idea they were addressing; therefore, those groups' responses were placed in the None category, which corresponds to the level zero of the knowledge of children's ideas category in the rubrics. See Figure 7 for the distribution of children's ideas used in the Force and Motion unit. Similar detail on the children's ideas presented in the two courses for the two remaining content units, Circuits and Magnets and Heat and Light, as well as the distribution of children's ideas used by students for those conceptual units (micro-lessons two and three) can be found in Appendix F.

Table 9.
List of children's ideas presented in the course for micro-lesson one on the topic of Force and Motion.

Children's Idea	Explanation of Children's Idea	Scientific Idea
Impetus Theory I (Driver, 1985, p. 89)	A force is transferred from one object to another causing movement. When a ball is kicked, the force from the foot is transferred to the ball, which allows the ball to move.	Energy can be transferred from one object to another. In the case of the football, the energy is provided to the ball by the applied force (the kick).
Impetus Theory II - The force runs out (Driver, 1985, p. 89).	Continuing with the previous example of the football, children believe that the football that was kicked eventually stops because the force transferred by the foot ran out.	The force provides the energy to the object necessary to start moving. When the object's energy is transferred to another object or transformed into a different type of energy, then the object will stop moving.
Forces are to do with living things (Driver, 1985, p. 91).	Children believe that only living things can exert forces - the foot that kicked the ball or the hand that pushes the box.	Living (hand or a foot) and non-living things (the surface the object is on) can exert forces.
Constant motion requires a constant force (Driver, 1985, p. 91).	Children believe that a force has to constantly be applied to the object in order for the object to keep moving.	If the net force (sum of all the forces acting on the object) applied to the object is zero, then the object will move with a constant speed. Constantly applying a force would cause the object to accelerate.
The amount of motion is proportional to the amount of force (Driver, 1985, p. 93).	Children think that the harder an object is pushed, then the faster and farther the object will move. In these cases children are associating the idea of motion with acceleration (Driver, 1985).	The net force applied to the object determines its acceleration. If a ball is kicked on a smooth surface, it experiences a greater acceleration than a ball that is kicked with the same force on a rougher surface. The second ball will experience a stronger frictional force in the direction opposite to the movement.
If an object is not moving, there is no force acting on it (Driver, 1985, p. 93).	Children associate force with movement. If they see an object that is not moving, they conclude there is no force acting on it.	If the net force acting on the object is zero, then the acceleration of the object is zero. Therefore, the object could be moving in a straight line at a constant speed or be stationary (Newton's First Law).
If an object is moving, then there is a force acting on it in the direction of motion (Driver, 1985, p. 95).	Similar to the previous idea, children associate force with motion. Therefore, if the object is moving, then there is a force acting on the object in the same direction of motion.	If the net force acting on the object zero, then the object could be moving in a straight line at a constant speed. If the net force is not zero, the object will accelerate in the direction of the larger force.
Heavy objects fall faster	Children believe that the weight of the object determines how fast it will fall. Two objects with identical shapes but different weights will fall at different speeds.	It is not the weight of the object but the air resistance that determines the speed with which the object will fall. Two identically shaped objects of different weights will fall at the same rate if there is no air resistance.

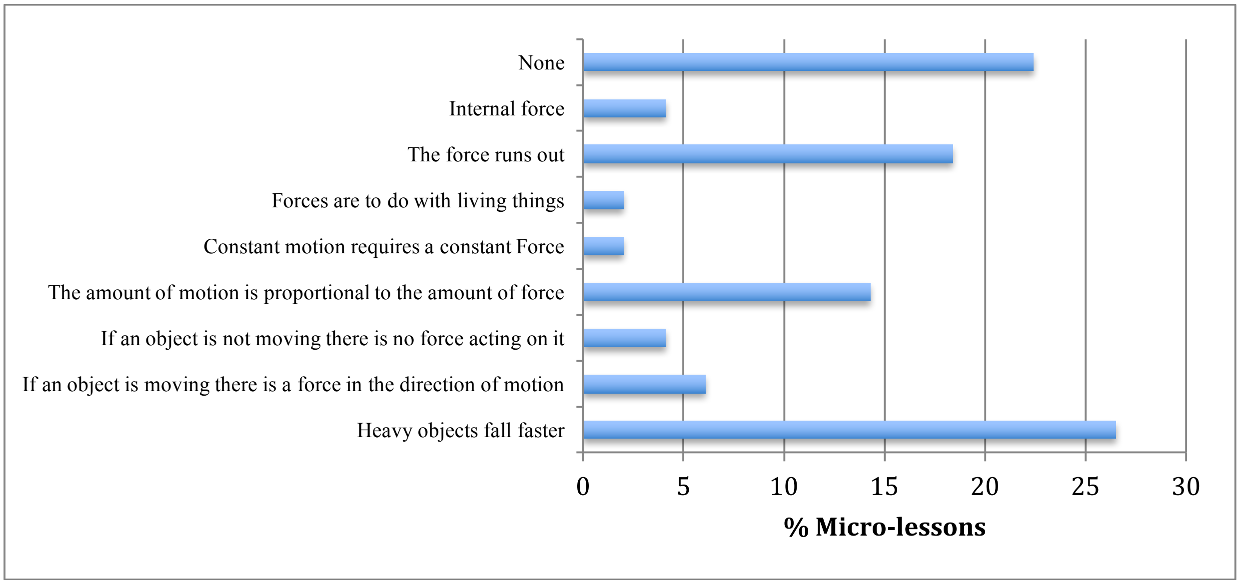

Figure 7. Distribution of children's ideas used by students in micro-lesson one (Force & Motion).

Categories of PCK:

The list of children's ideas provided throughout the course as well as the students' invented ideas were used to determine the degree to which three different categories of PCK - knowledge of children ideas (KCI), use in instructional strategies (UIS), and use in assessment strategies (UAS) – were present in the micro-lessons, lesson plans, final project videos and critiques. The rubrics used to evaluate the extent to which students incorporated children's ideas into the micro-lessons, lesson plans, final project videos, and critiques were presented in Chapter 3 (Table 5 and Table 6). The following section provides more detailed descriptions of each category and examples for each level of the rubrics.

Knowledge of children ideas

The first category of PCK evaluated was knowledge of children's ideas (KCI). The rubric for the micro-lessons, final project videos and lesson plans explicitly asked: To what extent did the micro-lesson (lesson plan or final project video) clearly identify children's prior ideas? Level zero indicates that children's ideas were not mentioned. Level one indicates that students mentioned children's ideas in some manner, but which idea was unclear. An example of level one would be: "We will be exploring the ideas of temperature and heat by exploring how different objects act as insulators. This will challenge students to understand how temperature can be retained and released differently through different objects." By clearly indicating a concept (how temperature can be retained/released) it can be inferred that the students were thinking about children's ideas when they created the lesson plan. But it is not clear which children's idea about heat the students were addressing or which is the children's incorrect idea. Finally, an example of a level two, which indicates that children's ideas were clearly stated, was: "This lesson addresses children's incorrect idea that moving objects stop because the force runs out." In this case, students are clearly indicating which idea of the children's ideas provided during the course they are addressing in their lesson plan.

Students sometimes used invented ideas instead of using one from the list of ideas provided. An invented idea was coded as level one if the idea was mentioned but not clearly articulated by the students. For example, in micro-lesson three, students stated, "children often have difficulties understanding the idea of conduction, convection, and radiation." The students then designed their lesson around explaining what each term means. However, difficulties understanding a concept does not indicate which incomplete or incorrect idea children may have about that concept. It just points out that conduction, convection, and radiation are difficult concepts for children to understand. An invented idea was coded as level two if the idea was clearly stated and articulated. An example of a level two invented idea was included in the final project video. One group chose to address the children's idea that "the mirrors are magical" because in some cases the image looks inverted and in others it does not. This group's idea was coded as level two because the group clearly stated the misconception that children may have about mirrors, i.e. that the reason the reflections of mirrors are inverted in some cases and not in other cases is that mirrors are magical. See Appendix G for a more detailed description of each level of KCI, examples for each level, and an explanation of why that particular example was placed into that level.

Use in instructional strategies

The second category of PCK evaluated was use in instructional strategies (UIS). The rubric for the artifacts specifically asked: Did the micro-lesson (lesson plan or final project video) include an instructional strategy designed to correct the children's idea identified by the students? The data was coded in terms of whether students presented an activity to contradict the incorrect or incomplete idea that children have followed by an activity that reinforced the correct idea. If the activities did not incorporate the children's idea presented or if there were no children's ideas identified (KCI level was zero), then this response was coded as level 0. For example, students were addressing the idea that constant motion requires constant force. The proposed activity starts with asking children to make predictions about what will happen to a car sliding down a ramp if the inclination of a ramp is changed. The children are given some time to predict how the speeds of the cars might differ because of the inclination of the ramp and whether or not the cars would stop after a while. After discussion the children test their theories measuring the times and distances cars travel with different inclinations of the ramp. This activity does not address the idea proposed, that constant motion requires a constant force. Children will observe that the higher the ramp is, then the farther the car would go. But the car eventually stops. The fact that the car stops confirms children's idea that for a car to keep moving there needs to be a force constantly applied to the car.

A code of level one was assigned when the activities proposed in some manner addressed the children's idea identified. For example, the lesson plan is addressing the children's idea that non-moving objects do not have energy. The strategies proposed by the students to address this idea was having children define their initial idea of energy and transfer of energy for a demonstration of transfer of energy by colliding a basketball and tennis ball. Then the children work in pairs on an activity in which a marble is released from different heights and finally as a group play on a slide. It is unclear how those activities would address the children's idea proposed, since it does not seem the students specifically talk about energy in a static situation. A code of level two was assigned if the activities clearly incorporated the children's idea identified.

It is important to remember that the level assigned for this category depended on whether or not a children's idea was coded above level 0 for KCI. If not, it was impossible to evaluate if the instructional strategies were intended to correct any particular misconception and UIS would be automatically coded as level 0. See Appendix G for a more detailed description of each level of UIS, examples for each level, and an explanation of why that particular example was placed into that level.

Use in assessment strategies

The last category evaluated was use in assessment strategies (UAS). Specifically, the rubric asked: Did the micro-lesson (lesson plan or FPV) demonstrate the assessment strategies that measured the success of the instructional strategies in addressing children's ideas. The assessment strategy could be any type of assessment--a quiz, drawing, or any other activity—but it had to be directly related to both the children's idea addressed and the proposed instructional strategies. As with the UIS category, the UAS category was automatically assigned to level zero if the KCI category was a level zero; i.e. if a children's idea was not identified or if the assessment strategy proposed was not related to the children's idea being addressed. A level one was assigned in cases where there was some indication of the use of an assessment strategy to determine whether a children's idea was addressed or not, however it was unclear how the children's idea and assessment strategy were related. For example, the children's idea addressed was non-moving objects do not have energy. The proposed assessment strategy was to use an exit ticket in which children write something they learned during the lesson as well as a question they still had. Even though this is a formative assessment strategy, it does not necessarily provide the specific information the teacher needs to know in order to determine if the children's idea was addressed. Some children may write about the particular idea, but others may just talk about different points that they liked or disliked about the lesson. Finally, a level two was assigned when the assessment strategy clearly aligns with the children's idea addressed and measured whether the idea was addressed or not. See Appendix G for a more detailed description of each level of UAS, examples for each level, and an explanation of why that particular example placed into that level.

Categories of PCK for the Critiques

The rubric shown in Figure 6 was used to rate the level PCK used in the critiques. In this case the questions of the rubric asked whether students recognized the KCI, UIS, and UAS in their peers' lesson plans. For example, the question regarding the KCI category specifically asked: Did the student mention the use (or not) of children's prior ideas on the lesson plan? This question referred to the student acknowledging whether or not her peers stated a children's idea to be addressed in the LP. In a similar manner, the question for the UIS category evaluated whether or not students commented on their peers' use (or not) of the proposed children's idea to design the activities. Finally, the level assigned for the UAS category evaluated whether students their peers' use of children's ideas in their assessment strategies and whether the assessment strategy appropriately measured whether the instructional strategy addressed the children's idea specified. See Appendix G for a detailed description and examples of the different levels of UAS.

Research Question #1:

Research question #1 asked: How does evidence of the three categories of PCK – knowledge of children's ideas (KCI), use in instructional strategies (UIS), and use in assessment strategies (UAS) - in lesson design by students enrolled in a redesigned physics course for elementary education majors that explicitly integrates knowledge of children's ideas compare with such evidence by students who enrolled in a physics course for elementary education majors that did not explicitly integrate knowledge of children's ideas? To answer this research question two different sources of data were used: the final project lesson plans and critiques created by students during Fall of 2011 and 2014. In the following sections a detailed description of both sources of data is given, followed by the presentation of results and description of the findings for those data sources.

Final Project - Lesson Plan:

As mentioned in Chapter Three, the lesson plans (LP) were part of the final project assigned at the end of the course. Groups of three to five students designed a 50-minute lesson plan for an elementary science class. Both courses (Fall 2011 and 2014) used the same guidelines and literature about children’s ideas for the LP. The data gathered from the lesson plans was analyzed at the group level. The scores given to the groups were the same scores assigned to individual members of the group. Using a student level of analysis would have artificially increased the sample size, which in turn could enlarge the effect size.

To create the LP, each group of students chose a conceptual unit (Force & Motion, Circuits & Magnets or Light & Heat) and a children’s idea from the complete list of children’s ideas. In some cases, the groups addressed invented ideas. During both semesters (Fall 2011 and 2014), the most common conceptual units addressed in the lesson plans were Force and Motion (F&M) and Circuits and Magnets (C&M). **Error! Reference source not found.** shows that the most common children’s ideas used by groups in the baseline course were: a) Forces are to do with living things (11.1%); b) The strength of a magnet is determined by its size (8.3%) and; c) The effect of a magnet passes through paper but not thicker objects like wood (8.3%). The most common children’s ideas used by groups in the redesigned course were: a) All metals are attracted to magnets (12.5%); b) The force runs out (10.9%); and c) Constant motion requires constant force (10.9%).

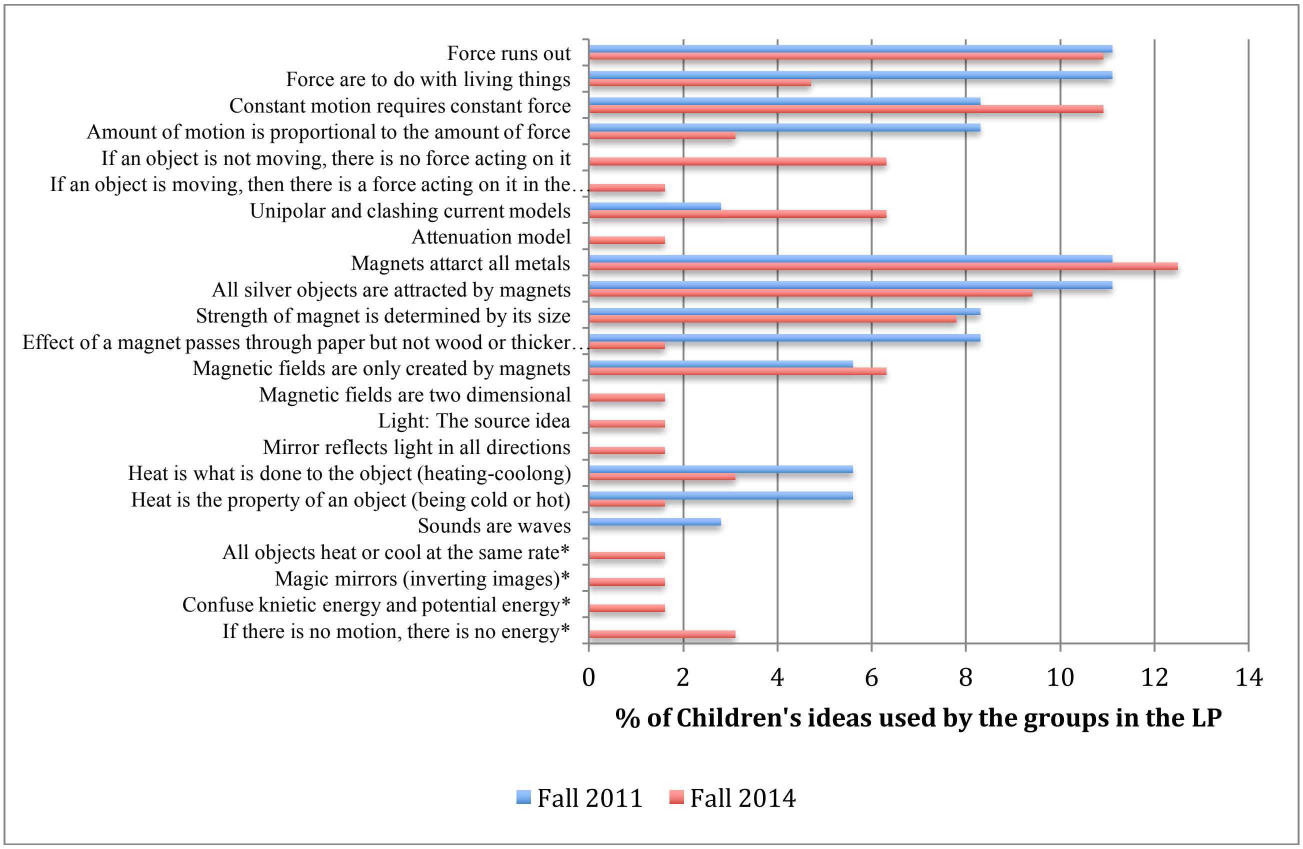

Figure 8. Distribution of children's ideas used by students in the lesson plans.

Error! Reference source not found. shows the distribution of levels of sophistication on knowledge of children ideas (KCI) for the baseline and redesigned course presented in the groups' lesson plans (LP). The percentage of groups' responses placed in level zero showed a decrease of 49.0% between the baseline and redesigned course (from 38.5% to 19.6%), while the percentage of groups' responses placed in level one changed less than 20.0%. The percentage of groups' responses placed in level two showed an increase of more than 50.0% between the baseline and redesigned course (from 42.3% to 64.7%). In fact, the majority of group responses in the redesigned course (more than 60.0%) were placed in level two, which means that the groups clearly indicated the children's ideas they were addressing in their lesson plan.

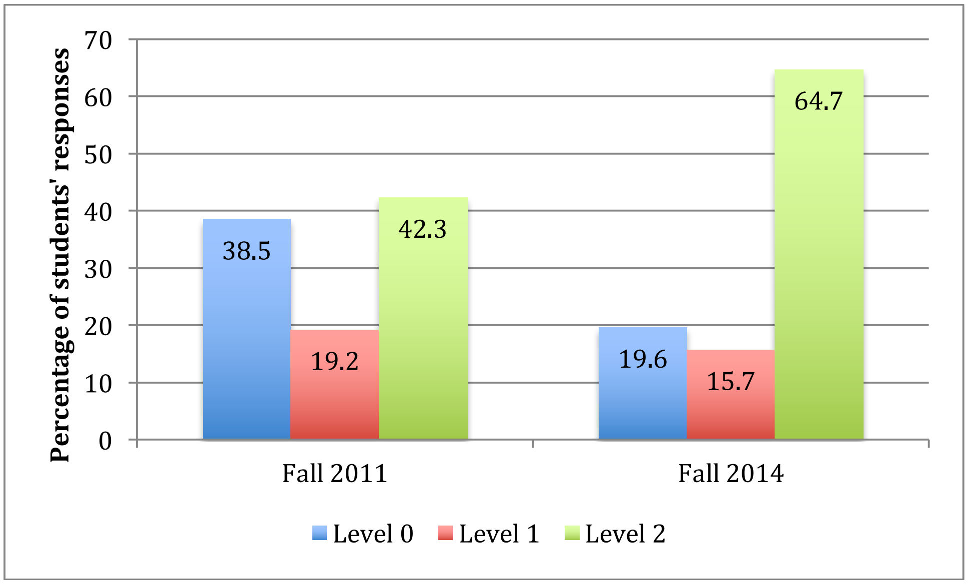

Figure 9. Comparison of the distribution of the level of knowledge of children ideas (KCI) for the groups in the lesson plans between the baseline and redesigned courses.

Error! Reference source not found. shows the distribution of students' levels of sophistication of use in instructional strategies (UIS) for the baseline and redesigned course on the groups' lesson plans (LP). There was a 75.0% decrease in the groups' responses that were placed in level zero between the baseline and redesigned course (from 69.2% to 17.6%). The percentage of groups' responses that were placed in level one showed an increase of 180.0% (from 23.1% to 64.7%) between Fall 2011 to 2014. Also the percentage of groups that were placed in level two showed an increase of more than 120.0% between Fall 2011 (7.7%) and 2014 (17.6%).

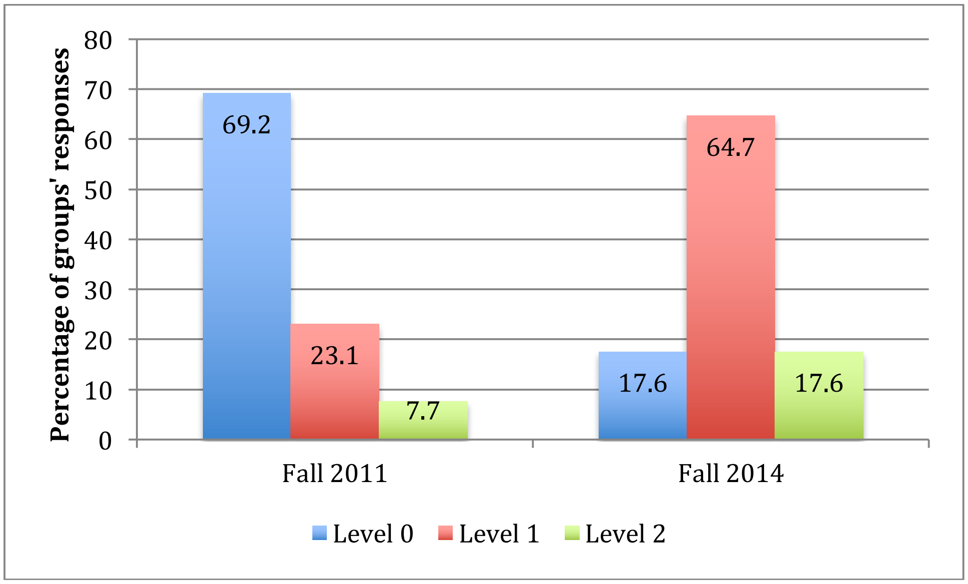

Figure 10. Comparison of the distribution of the level of use in instructional strategies (UIS) for the groups in the lesson plans between the baseline and redesigned courses.

Error! Reference source not found. shows the distribution of students' levels of sophistication of use of children's ideas in assessment strategies (UAS) for the baseline and redesigned course on the groups' lesson plans (LP). The majority of the groups' responses (80.0%) in the baseline did not include an assessment strategy that incorporated the children's idea they chose to address course or there was no children's idea stated. For Fall 2014 only 23.0% of the groups' responses were placed in level zero, which represents a 71.0% decrease between the baseline and redesigned course. There was a 186.0% increase in the percentage of groups' responses placed in level one from Fall 2011 to 2014 (from 19.2% to 54.9%). No groups' responses were placed in level two in the baseline course, but more than 20.0% of the groups' responses from Fall 2014 were placed in level two.

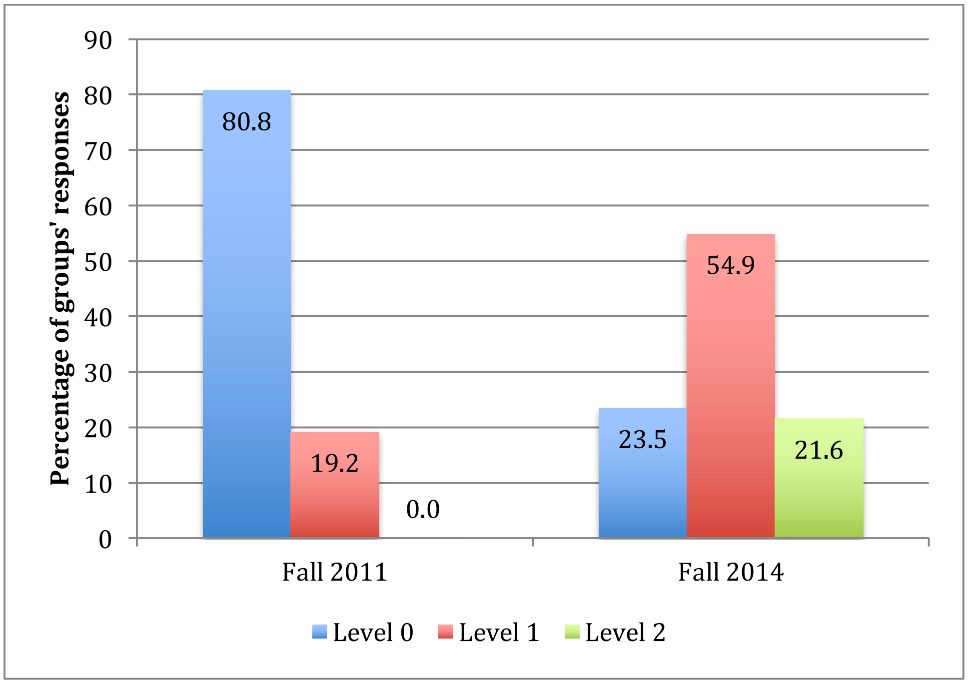

Figure 11. Comparison of the distribution of the level of use in assessment strategies (UAS) for the groups in the lesson plans between the baseline and redesigned courses.

In summary, lesson plans showed an improvement of the groups' level of PCK – KCI, UIS, and UAS - between the baseline and redesigned course. The most significant improvements were seen in students' incorporation of children's ideas in their instruction and assessment strategies.

Final Project - Critiques:

The critiques were the third element of the final project. Each student was randomly assigned a peer group in her course to evaluate. The students were required to write a one-page critique of their assigned peer group's lesson plan and in-class presentation for Fall 2011 or final project video for Fall 2014. As with the lesson plans, the rubric measured the level of sophistication of students' levels of PCK for the categories of KCI, UIS, and UAS. For each category a level zero indicates that the student did not mention the incorporation of children's ideas in her peers' lesson plan, level one indicated that the student mentioned the incorporation of a children's idea in some manner in her peers' lesson plan, and level two indicates that the student clearly mentioned the use or not of children's ideas by her peers.

Error! Reference source not found. shows the distribution of the level of sophistication of KCI in the critiques for the baseline and redesigned course. The majority of students' critiques (59.8%) in the baseline course did not identify whether or not their peers used children's ideas in their lesson plan designs. However, less than two percent of the students' responses in the redesigned course were placed in level zero. The percentage of students' responses placed in level one showed an increase of 190.0% between the baseline and redesigned course (11.3% to 32.8%). Finally, 28.9% of the students' responses in the baseline course were placed in level two, whereas the majority of students' responses (more than 65.0%) were placed in level two during redesigned course, an increase of 127.0%.

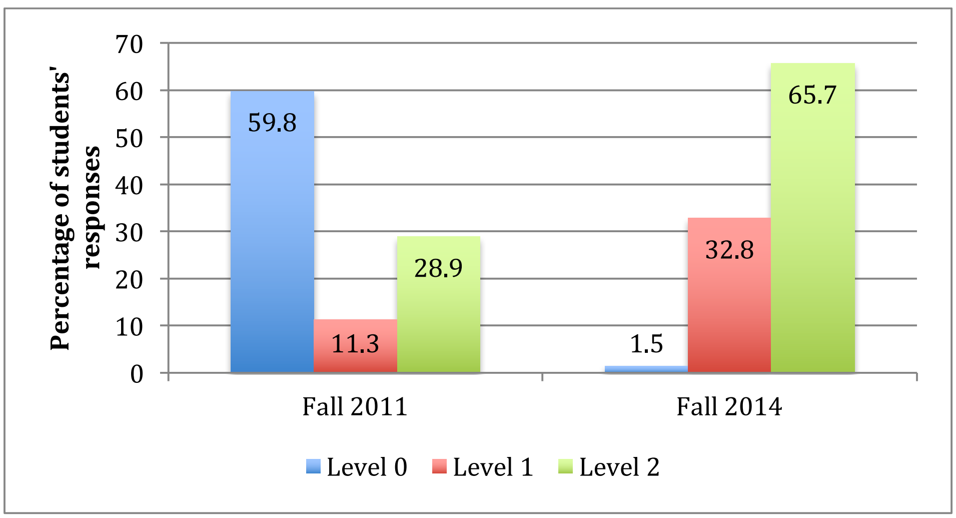

Figure 12. Comparison of the distribution of the level of knowledge of children ideas (KCI) for the students in the critiques between the baseline and redesigned courses.

Error! Reference source not found. shows the distribution of levels of sophistication of IS in the critiques between the baseline and redesigned course. The distribution of levels of sophistication of students' critiques from the baseline course is a mirror image of the distribution of levels of sophistication of students' critiques from the redesigned course. In particular, there was a large decrease (100.0%) in the percentage of students' critiques placed in level zero (from 86.6% in the baseline course to 0.7% in the redesigned course) and a large increase in the percentage of students' critiques placed in level two (from 1.0% in the baseline course to 86.9% in the redesigned course).

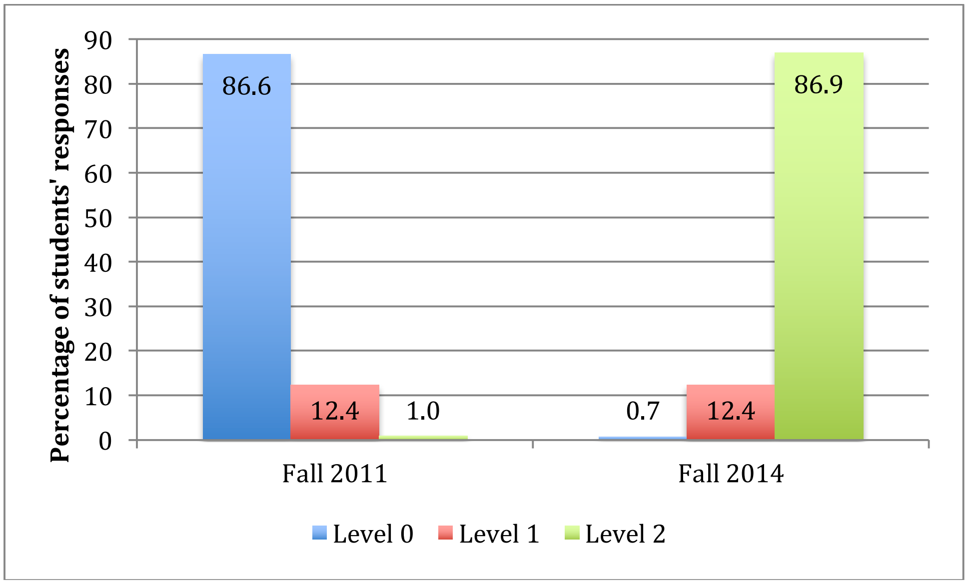

Figure 13. Comparison of the distribution of the level of use in instructional strategies (UIS) for the students in the critiques between the baseline and redesigned courses.

Error! Reference source not found. shows the distribution of levels of sophistication of UAS in the critiques for the baseline and redesigned course. There was an 89.0% decrease in the percentage of students' critiques that were placed in level zero from the baseline to the redesigned course (from 88.7% to 10.2%). At level one, the percentage of students' critiques showed an increase of 162.0% between the baseline and redesigned course (from 10.3% to 27.0%). Finally, there was a large increase in the percentage of students' critiques placed in level two from only one percent during baseline course to the more than 60.0% during the redesigned course.

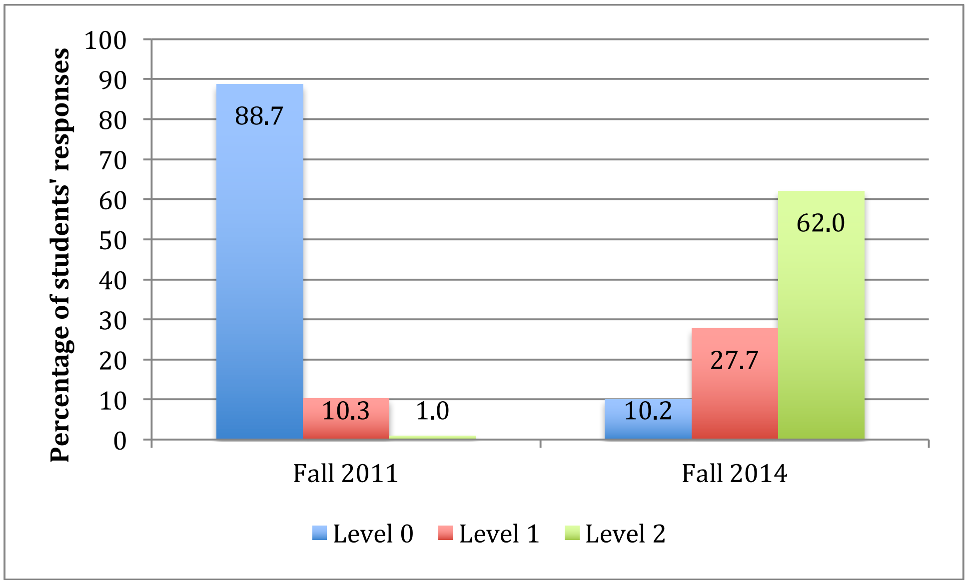

Figure 14. Comparison of the distribution of the level of use in assessment strategies (UAS) for the students in the critiques between the baseline and redesigned courses.

In summary, the students in the redesigned course showed a sizeable improvement in all three categories of PCK – KCI, UIS, and UAS – compared to those in the baseline course. In particular, students in the redesigned course showed higher levels of sophistication in the categories of UIS and UAS than students in the baseline course.

Findings

It was expected that the students enrolled in a redesigned physics course for elementary education majors that explicitly incorporated children's ideas would demonstrate greater evidence of incorporation of those ideas in their lesson planning compared to students enrolled in a physics course for elementary education majors that did not explicitly incorporate children's ideas. Fisher's Exact Test was used to determine whether students' categorical PCK levels differ between the participants in the baseline and redesigned course. The effect size for those PCK categories found to show statistically significant differences was calculated using Cramer's V values. Effect sizes ranged from small (S), to medium (M), to large (L). **Error! Reference ource not found.** contains a summary of the results.

Table 10.
Fisher's Exact Test results for categories of PCK on the lesson plans.

Categories of PCK	χ^2	Degrees of Freedom	Significance	Effect Size
KCI	4.011	2	.139	-
UIS	19.362	2	<.001	0.512 (L)
UAS	23.931	2	<.001	0.557 (L)
N		77[2]		

Results indicated that there was no statistically significant difference in the groups' levels of knowledge of children's ideas (KCI) between baseline and redesigned course. However, there was a statistically significant difference in the groups' levels of use in instructional strategies (UIS) and use in assessment strategies (UAS) with large effects. Groups in the redesigned course more frequently addressed children's ideas in instructional and assessment strategies than groups in the baseline course.

In comparing the groups' levels of sophistication of PCK between the baseline and redesigned courses, each factor of PCK – KCI, UIS, and UAS - was considered separately. In reality, these categories are not independent of each other. To be able to design appropriate instructional strategies or assessment strategies that are based on children's ideas of science, it is necessary to have knowledge of children's ideas of science. Therefore, measurements of UIS and UAS are not completely independent of KCI; i.e. if the KCI category is zero, the UIS and UAS categories would automatically be zero.

An analysis was done to determine if there were any significant differences in the distribution of the levels of groups' responses for the UIS and UAS categories between the

[2] N here represents the total number of groups from the baseline (26) and the redesigned (51) courses.

baseline and redesigned course when controlling for KCI. For this analysis the UIS and UAS categories were studied only for levels one and two of the KCI category, since when the KCI category was zero then the UIS and UAS categories were automatically zero. **Error! Reference ource not found.** shows the frequency distributions of the groups' levels of KCI for the lesson plan for the baseline and redesigned course. As the data is stratified; i.e. the lesson plans are scored and allocated into the corresponding levels of KCI, UIS, and UAS, the number of lesson plans per category (per cell) was smaller.

Table 11.
Frequency distribution of levels of KCI for LP for the baseline and redesigned course.

	Fall 2011	Fall 2014
Level of KCI	Frequency	Frequency
0	10 (38.5%)	9 (17.7%)
1	5 (19.2%)	7 (13.7%)
2	11 (42.3%)	35 (68.6%)
Total	26	51

Error! Reference source not found. compares the percentages of groups' levels of UIS and UAS for the lesson plans when controlling for KCI levels 1 and 2. More details on the distributions of UIS and UAS between the baseline and redesigned course along with comparative descriptions can be found in Appendix H. In general, at KCI level one the groups' lesson plans in the baseline course demonstrated higher levels of sophistication in UIS than those in the redesigned course, while for the UAS category the groups in the redesigned course demonstrated higher levels of sophistication than those in the baseline course. At KCI level two, groups in the redesigned course showed higher levels of sophistication in the design of instructional and assessment strategies that incorporated children's ideas than those in the baseline course.

Table 12.
Comparison of percentages of groups' levels of UIS and UAS for the lesson plans when controlling for KCI levels 1 and 2.

KCI Level			Fall 2011 (%)	Fall 2014 (%)
1	UIS Level	0	40.0	85.7
		1	60.0	14.3
		2	0.0	0.0
	UAS Level	0	100.0	14.3
		1	0.0	71.4
		2	0.0	14.3
2	UIS Level	0	50.0	2.9
		1	33.3	74.3
		2	16.7	22.9
	UAS Level	0	58.3	14.3
		1	41.7	57.1
		2	0.0	28.6

Error! Reference source not found. presents the results of the Fisher's Exact Test for IS and UAS when controlling for KCI at level one and two. Results indicated that for the UIS category at KCI level one there was no statistically significant difference in the distribution of groups' levels of UIS between the baseline and redesigned course. Even though groups in the baseline course showed higher level of sophistication for UIS when KCI was at level one, the difference between the groups' levels of UIS between baseline and redesigned course were not statistically significant. Results for the UIS category at KCI level two indicated a statistically significant difference in the distribution of groups' levels of sophistication of UIS between the baseline and redesigned course, with a large effect. When KCI category was at level two, meaning that the children's ideas were clearly stated, the groups in the redesigned course (22.9%) more frequently designed instructional strategies that clearly incorporated children's ideas (UIS = 2) than those in the baseline course (16.7%). For the UAS category, there was a statistically significant difference in groups' levels of UAS between the baseline and redesigned course at KCI levels one and two, with a large effect size. Groups in the redesigned course more frequently included an assessment strategy in their lesson plans that incorporated children's idea in their design, than those in the baseline course.

Table 13.
Fisher's Exact Test results for UIS and UAS as a function of KCI level 1 and 2 for the LP.

Level of KCI	Categories of PCK	χ^2	Degrees of Freedom	Significance	Effect Size
1	UIS	3.235	2	.152	-
	UAS	8.002	2	.015	0.845 (L)
2	UIS	13.261	2	.001	0.581 (L)
	UAS	9.737	2	.005	0.475 (L)

In summary, results from the analysis of group lesson plans showed no significant difference in groups' levels of the KCI category between the baseline and redesigned course. When not controlling for KCI, the majority of groups in the redesigned course (approximately 60% for both UIS and UAS) were placed in level one, which suggests that children's ideas were incorporated in designed activities and assessments. However, it was unclear how fully those ideas were addressed. In contrast, more than 60% of groups in the baseline course were placed in level zero for UIS and UAS categories, indicating that children's ideas about science were not present in the groups' proposed instructional and assessment strategies. Differences in UIS and UAS were also observed when controlling for KCI. In general, the levels of group responses specific to UIS and UAS improved as the levels of KCI improved. This trend was more evident when KCI was at level two. When controlling for KCI, groups in the redesigned course more often designed instructional and assessment strategies that incorporated the children's idea stated than those in the baseline course.

Results from the Critiques

In Fall 2011, 97 of the 110 (88.1%) students in the course completed the critique, whereas in Fall 2014, 137 of the 168 (81.5%) students completed the critique. The majority of students' critiques in the baseline course (59.8%) were placed in level zero of KCI category, whereas the majority of the students' critiques in the redesigned course (65.7%) were placed in level two of the KCI category. In the case of the UIS category, while the majority of students' critiques in the baseline course (86.6%) were placed in level zero, the same percentage of students' critiques in the redesigned course (86.9%) were placed in level two. Finally, the majority of students' critiques in the baseline course (88.7%) were placed in level zero for the UAS category, whereas more than 50.0% of students' critiques in the redesigned course were placed in level two. In general, this signified that students in the redesigned course discussed the use (or not) of children's ideas in their peers' lesson plans, particularly for the categories of instructional and assessment strategies, more so than students in the baseline course.

A Fisher Exact Test was conducted to ascertain the statistical significance of the observed differences. **Error! Reference source not found.** contains a summary of the results. Results showed a statistically significant difference in the students' levels of PCK for all three categories (KCI, UIS, and UAS) between the baseline and redesigned courses with large effect sizes. In particular, results indicated that students' critiques in the redesigned course showed higher levels of sophistication in the discussion of their peers' incorporation of children's ideas than those in the baseline course.

Table 14.
Fisher's Exact Test results for categories of PCK on the critiques.

Categories of PCK	χ^2	Degrees of Freedom	Significance	Effect Size
KCI	101.618	2	<.001	0.659 (L)
UIS	196.857	2	<.001	0.917 (L)
UAS	147.698	2	<.001	0.794 (L)
N		234[3]		

As with the lesson plans, the distribution of students' levels of sophistication of UIS and UAS were observed as a function of the KCI. **Error! Reference source not found.** shows the distribution of frequencies for KCI of the critiques for the baseline and redesigned course.

Table 15.
Frequency distribution of students' levels of KCI for the critiques for the baseline and redesigned course.

KCI Level	Fall 2011 Frequency	Fall 2014 Frequency
0	58 (59.8%)	2 (1.5%)
1	11 (11.3%)	45 (32.8%)
2	28 (28.9%)	90 (65.7%)
Total	97	137

Error! Reference source not found. compares the percentages of groups' levels of UIS and UAS for the critiques when controlling for KCI levels 1 and 2. More details on the distributions of UIS and UAS for the critiques between the baseline and redesigned course can be found in Appendix H. At KCI levels one and two, students in the redesigned course showed higher levels of sophistication in the design of instructional and assessment strategies that incorporated children's ideas than those in the baseline course.

[3] Here N represents the total number of critiques from the baseline and redesigned courses.

Table 16.
Comparison of percentages of students' levels of UIS and UAS for the critiques when controlling for KCI levels 1 and 2.

KCI Level			Fall 2011 (%)	Fall 2014 (%)
1	UIS Level	0	90.9	2.2
		1	9.1	17.8
		2	0.0	80.0
	UAS Level	0	90.9	11.1
		1	9.1	31.1
		2	0.0	57.8
2	UIS Level	0	67.9	0.0
		1	28.6	10.0
		2	3.6	90.0
	UAS Level	0	85.7	8.9
		1	10.7	26.7
		2	3.6	64.4

Error! Reference source not found. displays the results of Fisher's Exact Test conducted to determine if there was a statistical significant difference in the level of UIS and UAS when controlling for KCI at levels one and two. At level one of the KCI category, results indicated that there were statistically significant differences in the distribution of students' levels of sophistication of UIS and UAS between the baseline and redesigned course, with large effects. When the children's idea in the lesson plan was present but not clearly stated, students in the redesigned course more frequently discussed whether or not the instructional and assessment strategies proposed in the lesson plan incorporated children's ideas than students in the baseline course. At KCI level two, results indicated that there were statistically significant differences in students' levels of sophistication for the UIS and UAS categories between the baseline and redesigned course, with large effects. Students' critiques in the redesigned course more frequently included comments on whether their peers' instructional and assessment strategies incorporated children's ideas than those in the baseline.

Table 17.
Fisher's exact test results for UIS and UAS as a function of KCI level 1 and 2 for the critiques.

Level of KCI	Categories of PCK	χ^2	Degrees of Freedom	Significance	Effect Size
1	UIS	38.126	2	<.001	0.893 (L)
	UAS	25.390	2	<.001	0.719 (L)
2	UIS	89.725	2	<.001	0.869 (L)
	UAS	61.627	2	<.001	0.740 (L)

In summary, for the critiques students in the redesigned course demonstrated higher levels of PCK in all three categories being evaluated. Moreover, results from UIS and UAS when controlling for KCI demonstrate that at both levels one and two, students in the redesigned course more frequently discussed whether their peers had incorporated children's ideas in their design for a lesson plan than the students in the baseline course.

Research Question #2:

Research question #2 asked: To what extent does the level of sophistication of three categories of PCK – KCI, UIS, and UAS - in the students' micro-teaching change throughout a semester in a redesigned physics course for elementary education majors? At the end of each conceptual unit students in the redesigned course were required to develop a micro-lesson (ML). The MLs were short videos, between two to five minutes in length, in which students enacted or described an activity to address children's ideas discussed during that conceptual unit. Although the majority of the micro-lessons (more than 80.0%) were created in groups, data from the micro-lessons could be analyzed at either the student level or the group level. Research on group dynamics (Forsyth, 1990) demonstrates that individuals change their behavior and responses depending on the group with which they are working. Because the members of the groups and number of members per group changed considerably from micro-lesson to micro-lesson, the author of the study chose to present the analysis at the student level.

Error! Reference source not found. shows the distribution of students' levels of sophistication of KCI at the student level. As shown in **Error! Reference source not found.**, as students became more experienced with the micro-lessons, their level of KCI improved. The percentage of student responses placed in level zero decreased across the three micro-lessons, while the percentage of student responses placed in level one increased across the three micro-lessons. In particular, the distribution of students' responses that were placed in level zero decreased 83.0% between micro-lesson one and three (from 25.2% to 4.3%), while the percentage of students' responses placed in level one increased 21.0% (from 37.8% to 45.7%) from micro-lesson one to micro-lesson three. The other notable change was an increase of 44.0% in the percentage of students' responses that were placed in level two from micro-lesson one to micro-lesson two (37.4% to 54.0%).

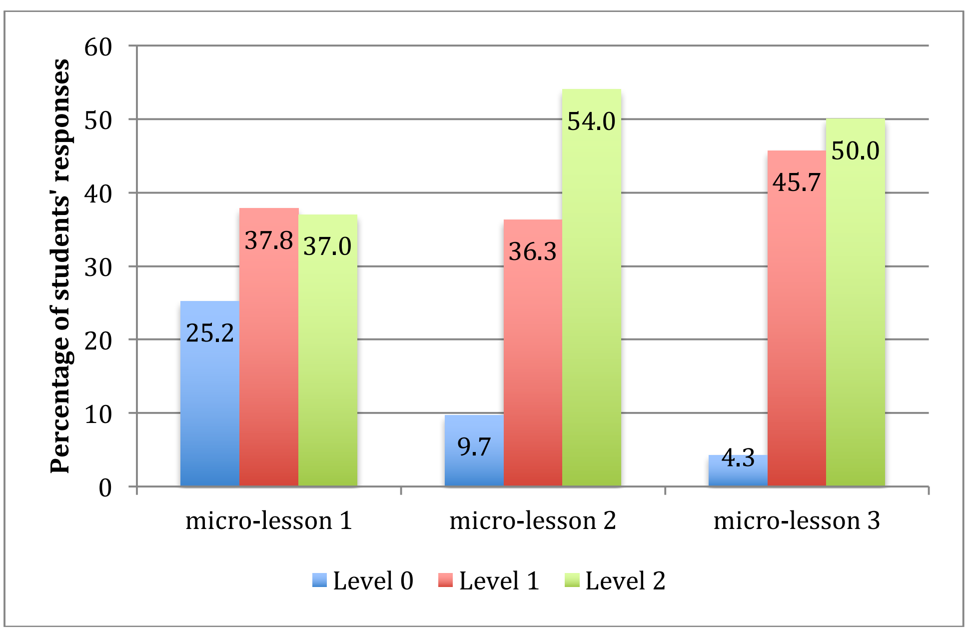

Figure 15. Comparison of the distribution of the level of knowledge of children's ideas (KCI) for the students in the micro-lesson.

Error! Reference source not found. shows the distribution of students' level of sophistication of UIS for the three micro-lessons. The percentage of students' responses that were placed in level zero - indicating that either no children's idea was stated (KCI level zero) or that the instructional strategies used did not incorporate the children's idea proposed - decreases as time progressed. More specifically, there was a decrease in the percentage of students' responses placed in level zero of 54.0% between micro-lesson one to micro-lesson three (from 35.6% to 16.4%). There was an increase of 45.0% in the percentage of students' responses placed in level one from micro-lesson one to micro-lesson three (from 45.9% to 66.4%). The percentage change in students' responses placed in level two for all the micro-lessons was less than 20.0%.

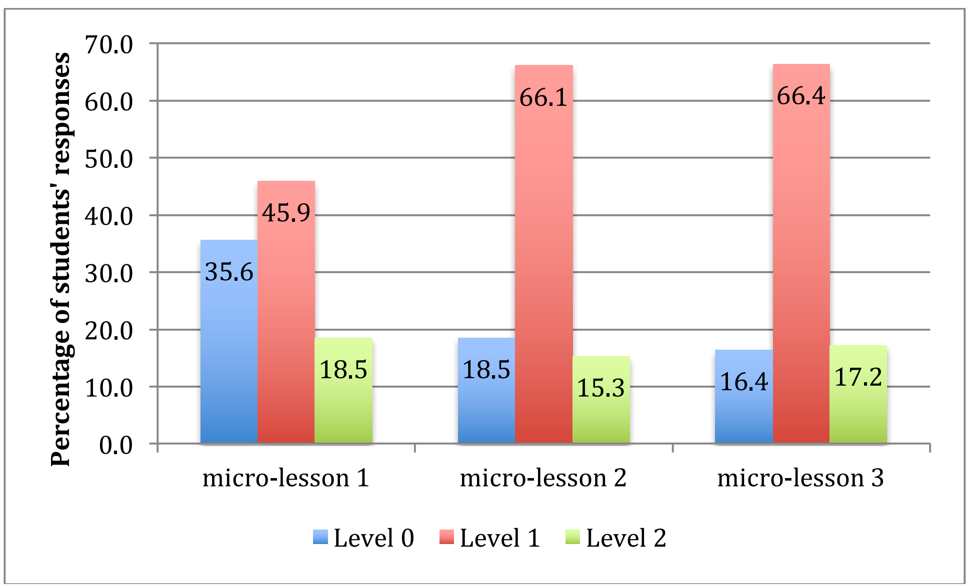

Figure 16. Comparison of the distribution of the use in instructional strategies (UIS) for the students in the micro-lesson.

Error! Reference source not found. shows the distribution of students' level of ophistication of use in assessment strategies (UAS) for the three micro-lessons. For all three micro-lessons the majority of students' responses (more than 50.0%) were placed in level zero. However, there was a decrease of about 15.0% in the percentage of students' responses placed in level zero between micro lesson one and micro-lesson three (from 68.1% to 57.8%). The percentage of students' responses placed in level one fluctuated less than 15.0% over time. Finally, there was an increase of 191.0% in the percentage of students' responses placed in level two from micro-lesson one to micro-lesson three (from 5.9% to 17.2%), but the total percentage of students' responses placed in level two for micro-lesson three still represented less than 20.0% of the total students' responses in the course. Overall, there was a decrease in the percentage of students' responses that were placed in level zero, while there was an increase in the percentage of students' responses placed in level one over time.

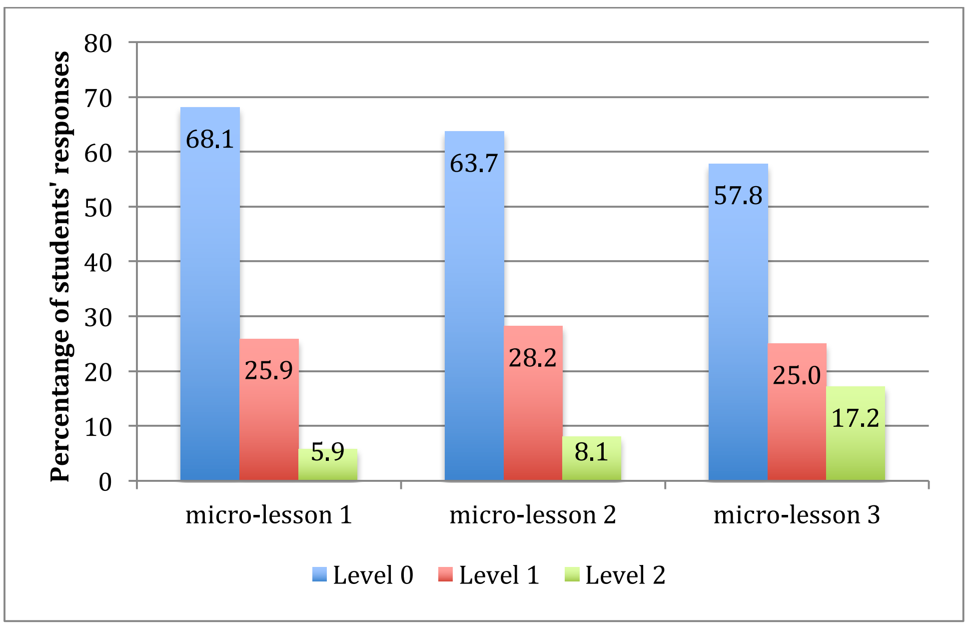

Figure 17. Comparison of the distribution of the use in assessment methods (UAS) for the students in the micro-lesson.

Final Project - Video:

During Fall 2011 students used the last two weeks of the semester to make an in-class presentation of their lesson plans. In the redesigned course, these presentations were replaced with the final project video (FPV), a short video in which students either described or enacted the lesson plan they proposed. Guidelines for the FPV were similar to the micro-lessons, except that FPV was expected to contain more details and be longer than the videos produced for the micro-lessons. However, the students repeated (in terms of level of detail and length of the video) what they had done previously for the micro-lessons. Guidelines for the FPV can be found in Appendix D. The distribution of children's ideas used for the FPV are the same as for the LP (See **Error! Reference source not found.**) since both are elements of the final project.

As for the micro-lessons, the data from the FPV was analyzed at the student level. **Error! Reference source not found.** shows the distribution of students' level of sophistication on the categories of PCK for the FPV. For the KCI category more than half of the students in the course (58.7%) clearly stated which children's idea they were addressing. For the UIS category, the majority of students (58.0%) incorporated children's ideas in their design, but did not propose activities that clearly incorporated those ideas. Finally, for the UAS category the majority of the students' responses (42.7%) did not include an assessment strategy that measured whether the stated children's idea was addressed or not.

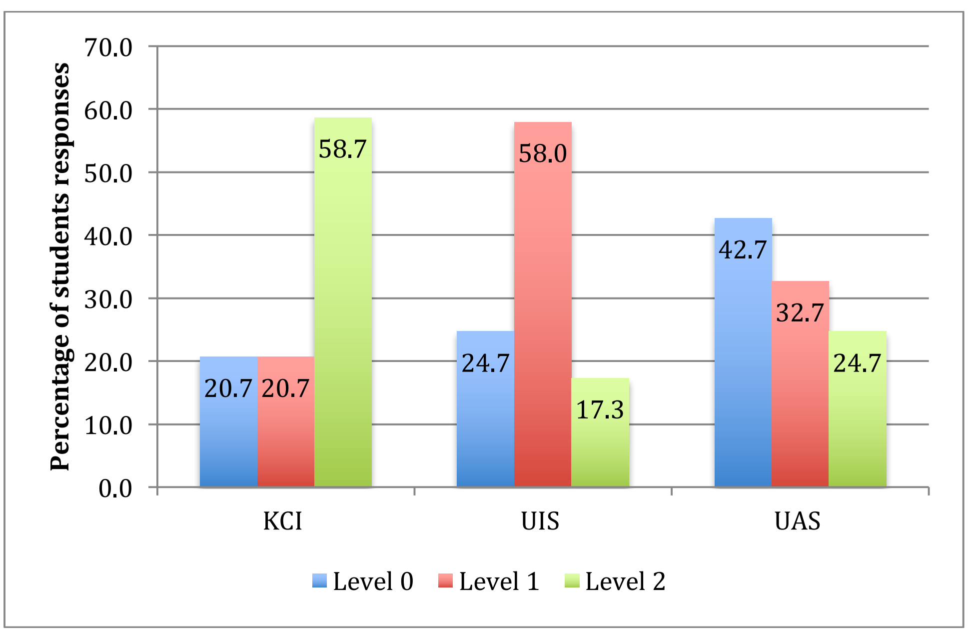

Figure 18. Distribution of KCI, UIS, and UAS for the students in the final project video.

In summary, by the FPV the majority of students had achieved level two for the KCI category. However, they did not develop instructional and assessment strategies that clearly incorporated those ideas. Also by the FPV the students had higher levels of UAS over time; i.e. at the time of the FPV there was a larger percentage of students' responses that were placed in level two compared to all micro-lessons.

Findings

It was expected that the students' level of sophistication of PCK in their micro-teaching would improve as time passed, because students would have had longer exposure to the second cycle of the PLB; i.e. more exposure to children's ideas, discussion about the use of those ideas, as well as feedback on the incorporation of those ideas in their microteaching. To determine the changes across time in the three categories of PCK (KCI, UIS, and UAS), data were collected in the redesigned course from 168 students. All students were required to create a micro-lesson at the end of each conceptual unit, which occurred approximately every four weeks. However, there were students who did not create a micro-lesson. To address the issue of missing data, a pairwise deletion was used; i.e. all the available data are used for the analysis, only the specific missing values were removed from the analysis (Field, 2013). **Error! Reference source not found.** shows the number of students who provided artifacts in each micro-lesson and the final project video.

Table 18.
Number of students in each conceptual unit that created micro-lessons.

	Micro-lesson 1	Micro-lesson 2	Micro-lesson 3	FPV
# of students	135	124	116	150

Fisher's Exact Test was performed to determine whether or not there was a significant improvement in students' level of sophistication of PCK. The data was broken up into pairs of times to determine the changes in students' level of PCK across time. By breaking up the data into three contiguous pairs - micro-lessons one and two (ML1-ML2), micro-lessons two and three (ML2-ML3), and micro-lesson three with the final project video (ML3-FPV) - it was possible to see progression in time. To decrease the probability that one or more Type I errors would occur (finding a non-existing effect) in a family of comparisons, a Bonferroni's correction was used (Keppel and Zedeck, 2002), yielding a level of significance of 0.017 instead of 0.050. Also, due to the fact that the available data does not satisfy the requirements of square contingency tables for McNemar's test, which is normally used for repeated measures with categorical data, only medium and large effects were considered. **Error! Reference source not found.** presents the results of the Fisher's Exact Test for all pairs.

Table 19.
Fisher's Exact Test results for categories of PCK for all pairs of time.

Time (Pairs)	Categories of PCK	χ^2	Degrees of Freedom	Significance	Effect Size
ML1-ML2	KCI	13.095	2	.001	0.223 (L)
	UIS	6.524	2	.038	-
	UAS	0.498	2	.807	-
ML2-ML3	KCI	3.856	2	.141	-
	UIS	0.316	2	.875	-
	UAS	4.851	2	.106	-
ML3 -FPV	KCI	27.815	2	<.001	0.317 (L)
	UIS	0.258	2	.903	-
	UAS	15.749	2	<.001	0.244 (L)

For ML1-ML2, there was a statistically significant difference in students' levels of KCI between micro-lesson one and micro-lesson two with a large effect size. In the case of the UIS and UAS categories, after Bonferroni's correction there were no statistically significant differences. For ML2-ML3, there was no statistically significant difference in students' levels of any of the PCK categories between micro-lessons two and three. Finally, for ML3-FPV, there was a statistically significant difference in students' responses for KCI and UAS with a large effect size but no significant difference for UIS. Students more frequently indicated which children's ideas they were addressing and used that idea in their assessment strategy in the final project video than in micro-lesson three. There was no statistically significant difference for the UIS category in the final project video compared to micro-lesson three. See **Error! Reference source not found.** and **Error! Reference source not found.** for more details.

Distribution of UIS and UAS when controlling for KCI

As it with the analysis of the LP and critiques, the UIS and UAS category were observed as a function of KCI. **Error! Reference source not found.** shows the frequency distributions of students' level of KCI for the micro-lessons and FPV. Students' responses placed in level zero for the KCI category; consequently, were also placed in level zero for the UIS and UAS.

Table 20.
Frequency distribution of micro-lessons and FPV.

	ML1	ML2	ML3	FPV
Level of KCI	Frequency	Frequency	Frequency	Frequency
0	34 (25.2%)	12 (9.7%)	5 (4.3%)	31 (20.7%)
1	51 (37.8%)	45 (36.3%)	53 (45.7%)	31 (20.7%)
2	50 (37.0%)	67 (54.0%)	58 (50.0%)	88 (58.7%)

Error! Reference source not found. shows the percentages of groups' levels of UIS and UAS for the micro-lessons and FPV when controlling for KCI levels 1 and 2. More details on the distributions of UIS and UAS and descriptions for the micro-lessons and FPV can be found in Appendix H. At KCI level one, as students' exposure to the treatment (second cycle of the PLB) increased and they received more feedback on the integration of knowledge of children's ideas into their microteaching, their levels of UIS and UAS improved. At KCI level two, there was a deterioration of students' level of UIS between micro-lesson one and two. However, there was a small improvement in students' level of UIS between micro-lessons two and three, and micro-lesson three and the final project video. Finally, for the UAS category there was an overall improvement in students' levels of sophistication between the micro-lessons and the final project video.

Table 21.
Comparison of the percentages of groups' levels of UIS and UAS for the micro-lessons and FPV when controlling for KCI levels 1 and 2.

KCI Level			ML1 (%)	ML2 (%)	ML3 (%)	FPV (%)
1	UIS Level	0	27.5	8.9	13.2	16.1
		1	52.9	64.4	79.2	58.1
		2	19.6	26.7	7.5	25.8
	UAS Level	0	66.7	64.4	56.6	29.0
		1	27.5	31.1	26.4	41.9
		2	5.9	4.4	17.0	29.0
2	UIS Level	0	0.0	10.4	12.1	1.1
		1	70.0	79.1	60.3	78.4
		2	30.0	10.4	27.6	20.5
	UAS Level	0	48.0	56.7	55.2	27.3
		1	42.0	31.3	25.9	40.9
		2	10.0	11.9	19.0	31.8

To determine if there was a statistically significant difference in the level of UIS and UAS when controlling for KCI, a Fisher's Exact test was used. **Error! Reference source not**

ound. presents the results of the Fisher's Exact Test for UIS and UAS when controlling for KCI. When controlling for KCI at level one, the results for the UIS category indicated that after Bonferroni's correction for the level of significance, there was no statistically significant difference in the distribution of students' levels of sophistication of UIS across time. There was a statistically significant difference in the distribution of students' levels of sophistication of UIS across time controlling for KCI at level two, with a small size effect. There was a statistically significant difference in the distribution of students' levels of sophistication UAS across time, with a large effect size when controlling for KCI at level one and two.

Table 22.
Fisher's exact test results for UIS and UAS as a function of KCI level 1 and 2 for the micro-lessons and FPV.

Level of KCI	Categories of PCK	χ^2	Degrees of Freedom	Significance	Effect Size
1	UIS	14.521	6	.022	-
	UAS	18.821	6	.004	0.229 (L)
2	UIS	21.872	6	.001	-
	UAS	23.797	6	.001	0.213 (M)

In summary, a statistically significant difference in students' levels of UIS while controlling for KCI at level two is observed across all times (ML1-FPV), in particular between the time pairs of ML1-ML2 and ML3-FPV. For students' levels of UAS while controlling for KCI at level one and two a statistically significant difference was found when comparing across all times; i.e. ML1-FPV. However, these differences were diluted; i.e. changes were gradual and no significant differences were observed for the contiguous pairs at KCI level one. Whereas for the UAS category at KCI level two the significant difference was most pronounced for the time pair of ML3-FPV. This suggests that when the children's idea was clearly stated, students more often developed instructional and assessment strategies that would address the children's idea for the FPV.

In general, results from the video analysis indicated that as time progressed, students demonstrated a higher level of sophistication of knowledge of children's ideas (KCI) in their micro-lessons and FPV. This trend was particularly evident between micro-lessons one and two and between micro-lesson three and the final project video. There were no significant changes overall for the UIS category. There was an improvement in students' level of UAS over time, particularly evident between micro-lesson three and final project video. When controlling for KCI, there was an overall improvement across time in the categories of UIS and UAS, particularly at level two of KCI. However, when studying the individual pairs of time, results for the UIS category at KCI level two between micro-lesson one and two indicated that students demonstrated higher levels of sophistication during micro-lesson one.

Chapter 5

Discussion & Conclusions

This chapter summarizes the findings of this study. The findings are presented as they pertain to each research question and the implications and recommendations that were drawn from the research are explored. The final section acknowledges the limitations of this research and identifies ways in which this study can be expanded upon in future work.

Overview of Investigation

This study was grounded on Shulman's (1986) theoretical construct of PCK and was designed to determine the extent to which a redesigned physics course affected elementary education majors' knowledge of children's ideas about science and how those ideas were incorporated into their own micro-teaching, lesson plan, and critiques of their peers' lesson plans. More specifically, the study explored the impact of the pedagogical learning bi-cycle (PLB) as it was implemented on students' knowledge of children's ideas (KCI) and the use of those ideas in instructional strategies (UIS) and assessment strategies (UAS). The PLB comprises two learning cycles. The first cycle focuses on physics content. The second cycle, which represents the intervention in this study, focuses on discussion of children's ideas about the physics concepts discussed in the course and the use of the knowledge of children's ideas for the development of instructional and assessment strategies in students' micro-lessons and lesson plans as well as in their critiques of peers' lesson plans?

To explore the effect of the second cycle of the PLB on students' PCK, two research questions were posed. The first research question investigated whether the intervention produced a difference in students' levels of sophistication of three categories of PCK – KCI, UIS, and UAS - between the baseline course (Fall 2011) and redesigned course (Fall 2014). The second question investigated changes in students' level of sophistication in the three categories of PCK over multiple measurements throughout the course.

Research Question #1:

Research question one asked: How does evidence of incorporation of three categories of PCK – knowledge of children's ideas (KCI), use in instructional strategies (UIS), and use in assessments strategies (UAS) - in lesson design by students enrolled in a redesigned physics course for elementary education majors that explicitly integrates knowledge of children's ideas compare with such evidence provided by students who were enrolled in physics course for elementary education majors that did not explicitly integrate knowledge of children's ideas?
It was expected that students enrolled in the *Concepts of Physics* course that explicitly incorporated children's ideas into the curriculum (Fall 2014) would demonstrate more sophisticated levels of PCK in their lesson plans and critiques than those students enrolled in the *Concepts of Physics* course before the second cycle of the PLB was incorporated (Fall 2011). More specifically, research question one examined the impact of the redesigned physics course on students' PCK by comparing two artifacts – lesson plans (LP) and critiques –created by students in the baseline and the redesigned course. Fisher's Exact Test was used to determine if there was a statistically significant difference in levels of sophistication of PCK between the students in the baseline and the students in the redesigned course.

Lesson Plans

Table 23 presents a summary of the results of Fisher's exact test for research question one. There were no statistically significant differences in groups' levels of KCI, but there were statistically significant differences in groups' levels of UIS and UAS between the baseline and redesigned course. As it was shown in Figure 9, the distribution of knowledge of children's ideas of the lesson plans (LPs) showed that the majority of the groups in both the baseline course (42.3%) and the redesigned course (64.7%) clearly identified which children's idea they would address in their lesson plan. A possible explanation for this could be that citing a children's idea to be addressed in the lesson plan corresponds to level one of Bloom's Taxonomy, knowledge of terminology and facts (Krathwohl, 2002). Students were prompted to indicate a children's idea from the reading materials they were provided and it only required that they remember to do so. However, more than 50% of groups in the redesigned course incorporated in some manner children's ideas into the design of their instructional and assessment strategies, whereas more than 70% of groups in the baseline course did not (Figures 10 and 11). Demonstrating the use of these children's ideas in the design of instructional or assessment strategies involves application, knowledge of facts to execute an action, in this case the design of an instructional and assessment strategy.

The statistically significant differences for the categories of UIS and UAS shown in Table 23 seem to indicate that the intervention, the second cycle of the PLB, included an explicit discussion of children's ideas about physics and how to use the children's ideas about physics concepts to design the lesson activities and assessments. Students in the redesigned course had more exposure to PCK and also received feedback regarding their incorporation of children's ideas in their micro-teaching after each conceptual unit. In fact, the incorporation of the creation of micro-lessons at the end of each conceptual unit was intended to provide scaffolding for the development of the lesson plan. Effect sizes for the categories of UIS and UAS of the LP are large (See Table 23), however the differences in the values indicate how the scores were spread; i.e. the larger the spread the more overlap between the distributions and therefore the smaller the value of the effect.

Table 23.
Summary of Fisher's Exact Test Results for Research Question #1.

Lesson Plans			Critiques	
Significance	Effect Size		Significance	Effect Size
		KCI not controlled for		
.139	-	KCI	< .001	0.659 (L)
<.001	0.512 (L)	UIS	< .001	0.917 (L)
<.001	0.557 (L)	UAS	< .001	0.794 (L)
		KCI level one		
.152	-	UIS	< .001	0.893 (L)
.015	0.845 (L)	UAS	< .001	0.719 (L)
		KCI level two		
.001	0.581 (L)	UIS	< .001	0.869 (L)
.005	0.475 (L)	UAS	< .001	0.740 (L)

In analyzing the differences between levels of UIS and UAS demonstrated in the lesson plans, it is important to note that levels of UIS and UAS are dependent upon the level of KCI demonstrated in these lesson plans. If students do not demonstrate a knowledge of children's ideas, they will not be able to use these ideas in the design of instructional or assessment strategies. Therefore, the levels of UIS and UAS demonstrated in groups' lesson plans when controlling for KCI were analyzed. Findings for the analysis of UIS and UAS when controlling for KCI indicated that the level of sophistication for the UIS as well as the UAS categories of the groups in the redesigned course significantly improved as the level of KCI improved (Table 12).

In particular, when controlling for KCI at level two the groups in the redesigned course demonstrated higher levels of sophistication of the use of children's ideas in instructional and assessments strategies than those in the baseline course. Those difference were statistically significant with large effects (Table 23). This means that the groups in the redesigned course more frequently developed instructional and assessments strategies that incorporated children's ideas than the groups in the baseline course. A factor that influenced these differences is that as data gets stratified and as KCI improves the spread of how the scores are distributed (the degree of kurtosis of the curve) across the levels of UIS and UAS becomes more concentrated (meaning less spread) which decreases the overlap and therefore increases the effect size. This makes sense given that when you are not controlling for KCI you are including all the values of UIS and UAS, however when you control for KCI and in particular as KCI improve then you are discriminating values and in the case of the redesigned course the groups' levels of UIS and UAS improved which means higher concentration of scores in the levels one and two which translates in a more leptokurtic distribution. There could be other factors that influence the differences in effect sizes, such as the fact that in the lesson plans the groups chose the topic they would develop the lesson plan, which means that not all the groups created a lesson plan on the same topic, differences in topic could mean that there were also differences in difficulties developing instructional and assessment strategies for these topics; i.e. students that developed a lesson plan on the heat and light topic may have found it more difficult to design an activity or assessment strategy that would address children's ideas than those groups that chose the force and motion topic.

The statistically significant differences in the results (See Table 23) reflect the fact that exposure to the second cycle of the PLB as well as feedback the students were given on the micro-lessons positively impacted groups' levels of sophistication of UIS and UAS. Even though in both the baseline and redesigned course, groups clearly incorporated children's ideas into their lesson plan the groups in the redesigned course more often use those children's ideas to design their instructional and assessment strategies. The explicit discussion of children's ideas provided students with a better understanding of how to use these ideas when designing a lesson plan and feedback on the incorporation of children's ideas in the designed probably conditioned students to use the children's ideas when they developed their instructional and assessment strategies. Results from UIS and UAS as a function of KCI seemed to support the idea that the groups in the redesigned course had a better understanding of the use of knowledge of children's ideas in lesson design than those in the baseline course.

Critiques

Table 23 summarizes the results from Fisher's exact test, which indicates that all three categories of PCK for the critiques were statistically significantly different. More specifically, results from the analysis of the critiques indicated that students in the redesigned course presented higher level of sophistication in all three categories of PCK than students in the baseline course (Figures 12, 13, and 14). In the case of the KCI category, students in both courses - baseline and redesigned - were given specific instructions while preparing the critiques to use the same criteria to evaluate their peers' lesson plans as the instructor had used to score their own lesson plans. Moreover, the majority of the groups' lesson plans in the baseline course (42.3%) included the children's idea to be addressed (KCI), however the majority of students' critiques (59.8%) in the baseline course failed to indicate whether or not those ideas were clearly stated in their peers' lesson plan (See Figure 12). The results of Fisher's exact test presented in Table 23 seem to suggest that explicit discussion of children's ideas about physics as part of the course as well as the feedback the students received through the instructor's evaluation of their groups' micro-lessons resulted in more students recognizing whether their peers' lesson plans included children's ideas.

The effect size differences are even larger for the categories of UIS and UAS which can be appreciated by the larger effect sizes (See Table 23). This seems to indicate that the explicit discussion of children's ideas as a core of the redesigned course as well as feedback received from the micro-lessons provided students with better understanding of use of children's ideas in their lesson plan, which allowed them to analyze the use of children's ideas in their peers' lesson plans. As with the lesson plan, the differences in effect size values indicated that when the effect sizes are larger the spread of the distributions is smaller. The fact that UIS has a larger effect size than the other categories (KCI and UAS) means that there was less overlap between the two distributions (baseline and redesigned course) - 65% of students were placed in level two for the redesigned course compared to more than 60% students placed in level zero for the baseline course (Figure 12).

Results of the analysis of UIS and UAS while controlling for KCI indicated that there were statistically significant differences between the baseline and redesigned courses (Table 23). As the level of KCI improved, more students in the redesigned course indicated whether their peers incorporated children's ideas in their instructional and assessment strategies. In the case of the critiques the changes in the values of the effect sizes indicated that there was a larger overlap between the distributions. This means that even though the differences between the distributions are still statistically significant and these differences are large the concentration of scores between the levels are not as pronounced. For example, for UIS at KCI level one more than 90% of the students in the baseline course were placed in level zero, compared to 80% of students in the redesigned course placed in level two. While, for UIS at KCI level two 67.9% of students in the baseline course were placed in level zero, compared to 90% of students in the redesigned course were placed in level two (Effect size for UIS at level two of KCI is smaller than effect size for UIS at level one of KCI). This means that as KCI improved students' levels of UIS in the baseline course also improved (a 24.5% decrease in the number of students placed in level zero). However, the statistically significant difference in the distribution of UIS between the courses - baseline and redesigned - indicated that improvements in students' levels of sophistication of UIS in the redesigned course were larger (See Table 23).

The fact that effect size differences for the complete data set were larger for the critiques than for the lesson plans were expected. Because, if students' struggled to achieve mastery in the incorporation of children's ideas in their own lesson plans, most likely they will struggle to achieve mastery in analyzing the incorporation of children's ideas in their peers' lesson plans.

Overall Conclusions for Research Question #1

Results from the analysis of the lesson plans indicated that groups in the redesigned course presented higher levels of sophistication in the categories of UIS and UAS than those in the baseline course (Figures 10 and 11). When controlling for level of KCI, Fisher's exact test results indicated that statistically significant differences for UIS only remains at KCI level two, while UAS showed statistically significant differences at both KCI levels one and two (Table 23). The effect size is largest at KCI level one. Results from the critiques show that students in the redesigned course presented higher levels of sophistication in all three categories of PCK – KCI, UIS, and UAS – than those in the baseline course.

A point to remember when discussing the results of lesson plans and critiques together is that the unit of analysis for these artifacts was different, while for the lesson plans a group unit of analysis was used for the critiques individual unit of analysis was used. It is important to point this out because, as it was mentioned earlier, theory of groups' dynamics indicate that the individuals' responses are greatly impacted by the groups' interactions. This means that the changes in level of sophistication of PCK in the lesson plans are moderated by the groups while in the case of the critiques we are discussing changes at the student level. Therefore, changes at the student level could be larger than at group level. The results for the analysis of both the LP and critiques suggest that the second cycle of the PLB significantly affected students' PCK, specifically for the UIS and UAS categories. Improvement of levels of UIS and UAS as students' levels of KCI improved were verifiable even though the majority of participants in the baseline course incorporated children's ideas in their lesson plans to some degree. This indicates that explicitly incorporating the knowledge of children's ideas about physics and additional feedback on the use of those ideas in class assignments in the redesigned course resulted in higher levels of PCK. As with the lesson plans, comparing the levels of UIS and UAS while controlling for KCI yielded smaller effect sizes for the differences between the baseline and redesigned courses, which could be due smaller sample sizes or other factors that are not been accounted for.

Research Question #2:

Research question two asked: To what extent does the level of sophistication of three categories of PCK – KCI, UIS, and UAS - in students' micro-teaching and final project video change through a semester in the redesigned physics course for elementary education majors? It was expected that the level of sophistication of the integration of children's ideas into the students' micro-lessons would improve with longer exposure to the second cycle of the PLB and feedback on the micro-lessons specific to incorporation of children's ideas in the micro-lessons.

More specifically, research question two explored the impact across multiple measurements through the semester of the redesigned physics course on students' categories of PCK - KCI, UIS, and UAS - by comparing students' micro-lessons (MLs) and final project videos (FPVs) created throughout the semester. Micro-lessons contiguous throughout the semester were compared.

The results presented for the analysis of the MLs and the FPV provide evidence of improvement in students' PCK across multiple measurements through the course, specifically for the KCI and UAS categories (Figures 15 and 17 Figure 18) for distribution of students' levels of KCI and UAS for the micro-lessons and the FPV. In particular, there were significant differences in students' level of KCI across subsequent measurements, particularly between the first and second (ML1-ML2) and third and last (ML3-FPV) measurements with large effect sizes (Table 24). There were no significant differences across measurements in the case of UIS category. However, there was an improvement overall across measurements for the UAS categories, but the differences were only significant between micro-lesson three and the final project video. See Figure 17 and 18 for a distribution of students' level of sophistication of UAS in the micro-lessons and final project videos. Absence of statistically significant improvement in the UAS category levels when comparing the other micro-lessons could be attributed to insufficient mastery of the category of KCI or other factors not being accounted for such as difference in topics used to developed the micro-lessons. Effect size for the KCI category increases over time (See Table 24), which suggests that longer exposure to the second cycle of the PLB, which focused on children's ideas about physics positively impacted students' level of sophistication of KCI. The increase in effect size for the KCI category between the first measurement (ML1-ML2) and third measurement (ML3-FPV) indicates that the difference in the distributions is more pronounce as time progressed (See Table 24).

Table 24.
***Summary of Fisher's Exact Test Results for Research Question #2*[4]**

	ML1-ML2		ML2-ML3		ML3-FPV	
	Significance	Effect Size	Significance	Effect Size	Significance	Effect Size
KCI	.001	0.223 (L)	.141	-	< .001	.317 (L)
UIS	.038	-	.875	-	.903	-
UAS	. 807	-	. 106	-	< .001	.244 (L)

Looking at the results of UIS and UAS together seems to indicate that it is not necessary to improve UIS in order to improve UAS. In order to develop an instructional strategy to address a particular children's idea, the students needed to understand the physics content, the specific children's idea about that content, and different strategies to address children's idea. However, in order to develop an assessment strategy to measure whether a particular children's idea was addressed for this particular study, it was only necessary to know the children's idea and then formulate a question about the particular children's idea to determine whether or not the children's preconceived or incomplete idea had changed after completing the lesson. Therefore, when students clearly stated a children's idea, it might have been easier for them to design the assessment strategy to assess the idea, than to design an instructional strategy to address that idea. UIS and UAS require the same level of Bloom's taxonomy, the application of knowledge is different because for UIS an extra layer of knowledge of strategies to address children's idea was needed in this particular study.

[4] For the analysis of UIS and UAS as a function of KCI, only UAS category at levels one (large effect) and two (medium effect) of KCI were significant.

Comparison of the levels of UIS and UAS when controlling for KCI between different points of measurements showed that although there was no significant difference for UIS at either level one or two of KCI. There were statistically significant differences between different measurements within level one and two of KCI for UAS (Table 22). These differences indicated that UAS improved across measurements as KCI improved. However, the effect sizes when comparing UAS while controlling for KCI are smaller for the differences across times (Table 22). This change in the values of effect size indicates that as KCI improved the differences between the different measurements is decreasing, which reaffirms that as exposure to the PLB increased the students' level of sophistication of UAS improves. When exposure is long enough, there will be no statistically significant differences because students would have reached mastery.

In general, the changes in students' level of sophistication of PCK did not monotonically increase from one measurement to the next (See Figures 15, 16, 17, and 18). This seems to suggest that other factors could have influenced the results, such as effects due to theme. Time (i.e. *when* in the course the micro-lesson was created) and theme (i.e. *what* content the micro-lesson was created) were confounded due to the nature of the course Time and theme were changing together. As we know from literature (Borowski et al., 2012), the PCK construct is dependent on content. It is possible that some topics students might perceive some topics as easier than other topics with regard to incorporation of children's ideas in the micro-lesson. For example, the order of conceptual units in the course was first Force and Motion (F&M), followed by Circuits and Magnets (C&M) and, then Heat and Light (H&L). It is possible that the themes were unequally difficult for students. In particular, the researcher speculates that the topic of H&L could have been considerably more difficult to students to understand than the other two conceptual units. Supporting evidence for this hypothesis is that only six percent of the FPVs addressed a children's idea from H&L. If students found the theme of H&L more difficult it could explain why there were no significant difference between the pair of ML2-ML3.

Another factor is related to how group dynamics might have influenced students' responses. Even though the micro-lessons and FPV were analyzed at the student level, students worked in groups to create them. Individual student scores depended on the overall ability of others in the group and might not reflect how the student would have performed had she completed the assignment alone.

Connections of Results from the Research Questions with Literature

Findings from this analysis seem to agree with previous research suggesting that elements of PCK can be learned. For example, the improvement of students' levels of PCK in the lesson plans were consistent with Beyer and Davis' (2012) findings in which they identified changes in pre-service teachers' knowledge of specific elements of PCK, such as the knowledge of assessment methods, knowledge of science curriculum, and knowledge of instructional strategies from the analysis of pre- and post-tests of participants' evaluation of lesson plans. Findings of this study also support Van Driel and colleagues' (1998) conclusion that even though strong content knowledge and teaching experiences are key factors for the development of teacher's PCK, the knowledge of children's ideas is something that can be introduced in professional development courses that would improve teachers' PCK. In particular, Van Driel and colleagues suggested that teacher training programs targeted to improve teacher's PCK should enable teachers to learn specific topics from a teaching perspective; i.e. learn about how students form their knowledge and how their knowledge evolves in specific topics, as well as allow teachers to practice the use of PCK in teaching situations. Results from the analysis of UIS and UAS as a function of KCI confirmed the research by Borowski et al. (2012) showing that there are correlations between the different categories of PCK that compose what teacher knowledge and that the size of the correlation between the categories of teacher knowledge changes as the levels of teachers' expertise changes.

Results from research question two, with regard to comparisons across time, confirmed the findings of Molina et al. (2011) that pre-service teachers' participation in micro-teaching increased participants' content knowledge and pedagogical content knowledge. However, the current study did not measure whether content knowledge of students changed due to participation in microteaching. The research of Molina et al. (2011) did not discuss the impact of subject matter on improvement of pedagogical content knowledge.

Limitations of the Study

Given that data were collected in a classroom setting, there were limitations presented to the internal validity due to the structure of the course. Among these limitations is the fact that the course had a specific structure; for instance, the organization of the syllabus and the order in which the topics would be taught were already established. Because the course was not an educational research laboratory[5] setting, it was not possible to observe different groups of students learning different topics at the same time. This limitation affected the analysis and claims of the research, because it prevented independent control of the variables of time and theme. It was not possible to clearly attribute differences in PCK between measurements to only

[5] In this case the laboratory setting refers to the fact that the study was not done in an educational research laboratory environment. Therefore, the researchers could not control for the change in time and topic at the same time. It is not referring to the course being a laboratory.

one of the factors. Consequently, claims about the impact of the second cycle of the PLB on students' levels of PCK are limited.

Another limitation of the setting was related to the composition of groups throughout the semester. With the exception of the critiques, the students formed groups to create the different artifacts. The members of the groups as well as the number of the members in each group changed considerably from artifact to artifact. In general, diversity in the formation of groups was encouraged because it supports learning. However, in the case of this research the restructuring of groups presented a limitation. Students' behavior and responses can vary considerably depending on the dynamic of the group, which in turn can affect the measurements of student as well as group levels of PCK.

Regarding the critiques, a possible limitation was that students might have "played nice," focusing on providing positive feedback to their peers regarding other aspects of the lesson rather than the integration of children's ideas in the lesson plan and video. Even though students were told that their critiques would not be shared with their peers and that their grades on the lesson plan and final project video would not depend upon the critiques provided by their peers, it is possible that some students may have been concerned about offending their peers or negatively affecting their peers' grades. This made it difficult to determine whether students' responses reflected an actual assessment of their peers' lesson plan or was treated in a way that would not hurt their peers' grades or feelings.

A limitation regarding the rubric for the critiques was that the artifacts received scores of zero, one, or two just by indicating their peers' incorporation of children's ideas about physics in the lesson plans. These scores did not take into account the degree of detail students provided about their peers' incorporation of children's ideas in the lesson plan; i.e. how carefully they discussed and gave opinions on how children's ideas were used or not in their peers' instructional and assessment strategies. Details in students' implementation of knowledge of children's ideas could have been lost, i.e. students' responses that may have demonstrated higher understanding of knowledge of children's ideas were placed in the same level as other students who may not have the same level of understanding just because the rubric did not account for such information.

Another limitation was related to the participants. Even though the course was created for elementary education majors, approximately 20% of the participants were not elementary education majors. The findings might have been stronger had the sample been composed of all elementary education majors. Those students who were elementary education majors had only completed the *Foundations of Education* course prior to enrolling in the *Concepts of Physics* course. They had no previous training on instructional and assessment strategies. Changes in students' levels of UIS and UAS were limited to students' prior knowledge as well as the instruction provided in the course. Generalizations that can be made regarding the findings are limited to participants who bring similar prior knowledge into the course.

Finally, there was a limitation regarding the instructor. The instructor of the course was the same for the baseline and redesigned course. This presented a limitation because, even though he was a very experienced instructor in physics, he was not as experienced when it came to the teaching of PCK in the course. Therefore, there could have been an increase in his level of PCK in teaching children's ideas about physics between the baseline and the redesigned course. His level of sophistication of PCK may have been more sophisticated when he taught the redesigned course.

Changes in the research design could provide solutions to some of these limitations. A change that could improve the quality of the data would be to refined the instruments by including more point-scales to obtain a cleaner data set; i.e. create a rubric that has a larger scale that would allow for greater discrimination between students' level of sophistication of PCK. One solution could be to add in each question of the rubric level zero for no children's idea present, level one for an implicit mention of children's idea, level two for a mention of children's idea, however a wrong use of a children's idea, level three for clear and correct incorporation of children's idea. In the case of the use in instructional and assessment strategies on top of adding more scale points it would be also useful to add sub-question that would specifically asked whether the children's ideas were correctly incorporated into the design; i.e. whether not only students indicate the idea being addressed but also they are designing appropriate activities and assessments. In the case of the critiques two changes could improve the collection of data for that particular artifact. One solution would be to use double-blind peer review for the lesson plans only in which the elementary education majors would be randomly assigned a lesson plan to evaluate but the lesson plan would not have any identification of the authors. As with the rubric for the lesson plan adding more scale points to each question of the rubric as well as adding an extra layer to each question of the rubric that accounts for the missing information might also improve the data gathered from the critiques. For example, the question of the rubric that asked whether their peers incorporated children's ideas in their instructional strategy could include a sub-question that asked in which way were these were ideas incorporated. Unfortunately, not all limitations could be address in a classroom setting.

Implications of Research & Future Work

In this section, the implications of this study are discussed and recommendations for the implementation of physics courses for elementary education majors are given. The implications of the research are separated into two different categories, for teachers and faculty and policy makers and administratprs. Finally, recommendations for future work are presented.

Implications

This investigation showed that incorporation of explicit discussion of children's ideas about physics in a physics course for elementary education majors positively impacted students' PCK, specifically in the categories of knowledge of children's ideas and use of those ideas in instructional and assessment strategies. The explicit incorporation of children's ideas and discussion of those ideas into the core of the course (Fall 2014) significantly affected students' levels of sophistication of use of children's ideas in the instructional and assessment strategies compared to those of students who were exposed to children's ideas but not such discussions (Fall 2011). For those students in the redesigned course, students' level of PCK sophistication was increased over the semester. Based on these findings some recommendations are presented to teachers, faculty, and educational leadership.

Teachers & Faculty

Previous research (George, 2000; Perrodin, 1966; Simpson and Oliver, 1985) showed that children's interest in science starts deteriorating as they go through the school science curriculum. Among the reasons presented are that many science courses at the elementary level are reduced to learning vocabulary and ideas (Newton & Newton, 2000). This might be due to elementary teachers' discomfort teaching science (Jones & Carter, 2007; Loughran, 2007b).

Many elementary teachers feel they lack content knowledge and pedagogical content knowledge with which to teach science (Harlem, 1997; Jones & Carter, 2007; Loughran, 2007b), so they avoid teaching it or tend to use teacher-centered strategies (Skamp, 1993, Tilger, 1990, Woodbury, 1995). A common solution to these issues has been to introduce more content courses (Morrell & Carroll, 2003; Roth, 1996; Skamp & Muller, 2001), but previous research has found that adding content alone is not enough and does not guarantee better teaching (Mikeska et al., 2009; Morrell and Carrol, 2003; Roth, 1996; Skamp and Muller, 2001). In fact, research by Mikeska and colleagues (2009) showed that there are three main factors with which future elementary teachers struggle: engagement with science, development of instructional strategies to teach science, and understanding of children's ideas about science.

The incorporation of discussion of children's ideas about physics in the redesigned *Concepts of Physics* course directly addressed the last point in the findings of Mikeska et al. (2009) as well as filling the gap that elementary teachers experience regarding deficiency of PCK. During the cycle of the course that discussed children's ideas about physics, the students not only learned to understand those ideas, but they also used that knowledge to design instructional and assessment strategies that would directly address children's preconceived or incomplete ideas. Physics courses for future teachers should provide elementary education majors with opportunities to learn about children's common preconceived ideas and the nature of those preconceived ideas as well as how to design appropriate instructional and assessment strategies to overcome those preconceived ideas.

Leadership in Education

The U.S. has always strived to maintain a lead in science and therefore in STEM education (NSB, 2010; 2012). In order to maintain or regain the lead and to improve the level of science education, it is important to also improve the quality of teacher education, in particular in the area of science. Research has suggested a relationship between teacher knowledge of students' ideas and student learning (Sadler et al., 2013; Strong, 2011). Faculty members in Colleges of Education and Colleges of Natural Sciences who are collectively responsible for of creating courses for the preparation of future elementary education teachers should develop a set of recommendations for the preparation of elementary teachers which includes the learning of content knowledge combined with pedagogical content knowledge. These guidelines should be presented in combination with effective methods to assess pre-service teachers' pedagogical content knowledge.

There have been several initiatives to improve level of science instruction in K-12, the most recent of which is the Next Generation of Science Standards (NRC, 2013). However, as pointed out by Rodriguez (1997, 1998) guidelines are not enough. If elementary education majors do not experience science learning in their content courses consistent with the standards and if the connection between their method courses and content courses is not made explicitly, then we cannot expect the future elementary education teachers to apply those ideas effectively when teaching in their own classrooms. The creation of more courses that connect the content knowledge with pedagogical knowledge should be encouraged and perhaps even required in the education programs for the preparation of future teachers.

In order to accomplish this, more collaborative efforts are needed across colleges that include the College of Natural Sciences, where the content courses are often taught, and Colleges of Education, where the educational methods courses are often taught. Through such collaborative efforts, the blending of content knowledge and pedagogical content knowledge is more likely to occur, leading to the development of courses that are more balanced in content and pedagogical knowledge and that provide the support that research shows elementary education majors need to teach science better. Examples of collaborative efforts, not specifically directed to elementary education majors, can be seen in programs such as the Learning Assistance (LA) model or the U-Teach model. In both models students majoring in STEM fields have the opportunity to become certified as a secondary teacher in STEM fields. The LA model is hosted in a science content department, such as the physics or chemistry department. Undergraduate majors in STEM disciplines are hired as learning assistants to assist instructors teach large enrollment class using student center teaching techniques (Otero, Pollock, & Finkelstein, 2010). Part of the training LAs received is participation in a course offered by the School of Education that complements their teaching experiences (Otero, et al., 2010). During the course, LAs reflect on their teaching practices, evaluate how the content courses in which they participate have changed due to the inclusion of LAs, share experiences across STEM disciplines, and investigate relevant educational literature (Otero, et al., 2010). The LAs test their understanding of content and pedagogy while situated in practice and in the context in which they would be teaching the content (Otero, et al., 2010). The U teach model also works with majors in STEM disciplines in a four-year degree during which students complete a degree in a STEM field and fulfill the requirements for an initial teaching license in secondary science or mathematics. These initiatives are a start, but such type of collaborations should not be limited to secondary education teachers. All education majors would benefit from synergistic initiative that would provide them with opportunities to directly see the connection between the pedagogical practices and content.

Future Work

For future work, it is most important to start with improvements of the research design. For example, a pre-test should be implemented in order to assess participants' initial level of content and pedagogical content knowledge. The pre-test could be a multiple-choice questionnaire given at the beginning of the course that includes content questions about the physics topics that will be discussed as well as questions that address common children's misconceptions about those topics. An example of such a questionnaire is the one created by Sadler et al. (2013). The questionnaire consists of multiple-choice questions about physical science for middle school level. The questionnaire for teachers included the content questions, but also teachers were asked to responds which of the content questions their students more likely get wrong and which one will be the most common wrong answer given by their students. Teachers' responses to those questions provide a measurement of teachers' PCK level. These data would allow for stronger claims about the impact of the explicit discussion of children's ideas about science in participants' levels of PCK.

It would also be interesting to study the interaction between the variables of time and theme on levels of PCK by developing a research design in which the variables of time and time could be disentangled. One possibility is to condcut this study in the context of professional development workshops for newly inducted teachers. In this setting, groups of teachers would participate in a series of workshops addressing an individual conceptual unit of the *Concepts of Physics* course. The conceptual unit addressed in the workshop would be different for each group. For example, at one-point time one group would complete a unit on Force & Motion, while simultaneously the other group would complete a unit on Circuits & Magnets. Then at a later time the topics for the groups would be interchanged. At the end of each workshop the participants would create a micro-lesson. The data collected would allow for comparisons of the participants' level of PCK per theme when controlling for time. With this data it would be possible to determine which variable – time (longer exposure to the PLB) or theme (the topic of conceptual unit) - is a better predictor of elementary education majors' changes in PCK.

It would also be informative to conduct a longitudinal study to compare how elementary education majors in the redesigned course perform in their methods and content courses as well as in their experiences as student teachers when compared to those students who did not participate in the redesigned course. Through the longitudinal study it would be possible to collect information to determine how much transfer of teaching skills, as well as the understanding of the importance of knowledge of children's' ideas, occurs between the redesigned course, other content and teaching methods courses, and in the elementary education majors' own classrooms.

Other concerns in elementary teacher preparation are engagement in science (Mikeska et al., 2009), as well as attitudes and beliefs about science (Jones & Carter, 2007; Loughran, 2007a; Olson & Riordan, 2012). Another area of inquiry in extending this project would be to investigate how the redesigned course influences elementary education majors' engagement in science as well as their motivation and attitudes toward learning and teaching physics. This research would explore the impact of the redesigned physics course on elementary education majors' views of science and physics in particular. It could potentially inform teacher educators and physics departments about how to most effectively modify their own courses to attend to the needs of future elementary education majors.

Closing Thoughts

Grossman and McDonald (2008) suggested that a common language and a global framework are imperative in order for research on teaching to move forward. They also made clear that research on teaching should serve as guidelines for the development of courses for pre-service teachers, but each teacher preparation program should be adapted to the local schools' needs. The framework for teacher preparation should be global enough such that novice teachers could rely on it for support, but the framework should be adaptable because education in every community, district, or geographical area is different. It is important to cater to the schools and students with which future teachers are expected to deal (Grossman & McDonald, 2008). As teacher preparation programs need to be adapted to the demands of the school and the area in which the teachers will be teaching, the use of PCK also needs to be adapted to the subject's needs. Content courses as well as method courses for future elementary teachers should incorporate discussions of children's ideas not in general terms, but in light of the specific topic being discussed.

In this study, a description of the core ideas incorporated in a physics course for future elementary teachers was provided. The principal goal of the redesigned course was to expose students to the elements of PCK that focus on knowledge of children's ideas as well as the use of that knowledge in their instructional and assessment strategies. Additionally, a goal of the redesigned course was to provide students with the opportunities to put that knowledge in practice through development of micro-lessons and lesson plans. Results of this study supported the impact of the second cycle of the PLB on students' growth in PCK. The redesigned course intended for students participating in the *Concepts of Physics* course to see the relevance of the course to their future role as elementary teachers and not feel as if this course was another requirement they had to fulfill in order to obtain their degree by relating the physics content with discussions and experiences that are related to their future career. In that way the physics content does not seem as a requirement that is not going to be useful in their future career, but also a course where they can learn about how children may think about these concepts and also they personally experience how to teach physics through inquiry-based model. As in the words of Mann (1912) “He must go through the notions indicated, not to satisfy his spirit of wonder, but to fulfill to the letter some requirement of school system.” (p. 252).

In the *Concepts of Physics* course for future elementary teachers, each element of the course was carefully crafted to incorporate the characteristics that research has identified as key elements—the knowledge and skills that elementary education majors’ need and that teacher educators are in the best position to provide.

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Appendix A: Concepts of Physics Schedule

Schedule for the baseline course, Fall 2011.

PHYS 106 **CONCEPTS OF PHYSICS** **Fall 2011**

Ref # 13155 ***Schedule***

Schedule is subject to change with prior notice. In case of change, you will be informed by email & revisions will be posted on K-State Online

Day, Date	LECTURE (MWF 10:30-11:20) in Cardwell 102	ACTIVITIES CENTER (Times posted on K-State Online) in Cardwell 216
M, 08/22	Introduction	No Activities Center this week : Please print out **Exploration 01** and **Elaboration 01** and bring them to Lecture for discussion
W, 08/24	Exploration 01 & Start Explanation 01 (Position & Motion)	
F, 08/26	Explanation 01 & Start Elaboration 01 (Position & Motion)	
M, 08/29	Discuss Elaboration 01 & Implications for elementary school	Exploration 02 (Start at 11:30 A.M.)
W, 08/31	Discuss Exploration 02 & Explan. 02 (Interactions & Mom)	Exploration 02 (Due at 9:30 A.M.) Elaboration 02 (Start at 12:30 P.M.)
F, 09/02	Discuss Elaboration 02 (Interactions & Momentum)	Elaboration 02 (Due at 9:30 A.M.)
M, 09/05	LABOR DAY (University Holiday)	
W, 09/07	Discuss Exploration 03 & Explan. 03 (Speed, Slow & Turn)	Exploration 03 (Start at Tuesday 8:30 AM, Due 9:30 A.M. Wednesday)
F, 09/09	Discuss Elaboration 03 (Describing Forces)	Elaboration 03 Due at 9:30 A.M.
M, 09/12	Discuss Elaboration 03 & Implications for elementary school	Exploration 04 (Start at 11:30 A.M.)
W, 09/14	Discuss Exploration 04 & Explan. 04 (Interactions & Forces)	Exploration 04 (Due at 9:30 A.M.) Elaboration 04 (Start at 12:30 P.M.)
F, 09/16	**TEST 01** (Covers everything until Monday, 09/12)	Elaboration 04 (Due at 9:30 A.M.)
M, 09/19	Discuss Elaboration 05 & Implications for elementary school	Exploration 05 (Start at 11:30 A.M.)
W, 09/21	Discuss Exploration 05 & Explanation 05 (Energy)	Exploration 05 (Due at 9:30 A.M.) Elaboration 05 (Start at 12:30 P.M.)
F, 09/23	Discuss Elaboration 05 (Kinetic & Potential Energy)	Elaboration 05 (Due at 9:30 A.M.)
M, 09/26	Discuss Elaboration 05 & Implications for elementary school	Exploration 06 (Start at 11:30 A.M.)
W, 09/28	Discuss Exploration 06 & Explan. 06 (Many forms of Energy)	Exploration 06 (Due at 9:30 A.M.) Elaboration 06 (Start at 12:30 P.M.)
F, 10/30	Discuss Elaboration 06 (Many forms of Energy)	Elaboration 06 (Due at 9:30 A.M.)
M, 10/03	Discuss Elaboration 06 & Implications for elementary school	Exploration 07 (Start at 11:30 A.M.)
W, 10/05	Discuss Exploration 07 & Explanation 07 (Heat Energy)	Exploration 07 (Due at 9:30 A.M.) Elaboration 07 (Start at 12:30 P.M.)
F, 10/07	**TEST 02** (Covers everything from 09/14 through 10/03)	Elaboration 07 (Due at 9:30 A.M.)
M, 10/10	Discuss Elaboration 07 & Implications for elementary school	Exploration 08 (Start at 11:30 A.M.)
W, 10/12	Discuss Exploration 08 & Explanation 08 (Electricity)	Exploration 08 (Due at 9:30 A.M.) Elaboration 08 (Start at 12:30 P.M.)
F, 10/14	Discuss Elaboration 08 (Electricity)	Elaboration 08 (Due at 9:30 A.M.)
M, 10/17	Discuss Elaboration 08 & Implications for elementary school	Exploration 09 (Start at 11:30 A.M.)
W, 10/19	Discuss Exploration 09 & Explan. 09 (Combining Resistance)	Exploration 09 (Due at 9:30 A.M.) Elaboration 09 (Start at 12:30 P.M.)
F, 10/21	Discuss Elaboration 09 (Series & Parallel Circuits)	Elaboration 09 (Due at 9:30 A.M.)
M, 10/24	Discuss Elaboration 09 & Implications for elementary school	Exploration 10 (Start at 11:30 A.M.)
W, 10/26	Discuss Exploration 10 & Explanation 10 (Magnetism)	Exploration 10 (Due at 9:30 A.M.) Elaboration 10 (Start at 12:30 P.M.)
F, 10/28	**TEST 03** (Covers everything from 10/05 through 10/24)	Elaboration 10(Due at 9:30 A.M.)
M, 10/31	Discuss Elaboration 10 & Implications for elementary school	Exploration 11 (Start at 11:30 A.M.)

W, 11/02	Discuss Exploration 11 & Explanation 11 (Vibration & Waves)	Exploration 11 (Due at 9:30 A.M.) Elaboration 11 (Start at 12:30 P.M.)
F, 11/04	Discuss Elaboration 11 (Combining Waves)	Elaboration 11 (Due at 9:30 A.M.)
M, 11/07	Discuss Elaboration 11 & Implications for elementary school	Exploration 12 (Start at 11:30 A.M.)
W, 11/09	Discuss Exploration 12 & Explanation 12 (Interference)	Exploration 12 (Due at 9:30 A.M.) Elaboration 12 (Start at 12:30 P.M.)
F, 11/11	Discuss Elaboration 12 (Beats & Diffraction)	Elaboration 12 (Due at 9:30 A.M.)
M, 11/14	Discuss Elaboration 12 & Implications for elementary school	Exploration 13 (Start at 11:30 A.M.)
W, 11/16	Discuss Exploration 13 & Explanation 13 (TBA)	Exploration 13 (Due at 9:30 A.M.) Elaboration 13 (Start at 12:30 P.M.)
F, 11/18	**TEST 04** (Covers everything from 10/26 through 11/15)	Elaboration 13 (Due at 9:30 A.M.)
M, 11/21	THANKSGIVING BREAK	
W, 11/23		
F, 11/25		
M, 11/28	Discuss Elaboration 13 & Implications for elementary school	Activity Center is open at regular times for you to browse through your activities materials and plan your project
W, 11/30	Student presentations of mini-lessons	
F, 12/02		
M, 12/05		
W, 12/07		
F, 12/09		

Schedule for the redesigned course, Fall 2014.

PHYS 106 — **CONCEPTS OF PHYSICS** — **FALL 2014**

Ref # 12793 — ***COURSE SCHEDULE* (REVISED NOV 20, 2014)***

DAY	DATE	LECTURE (Cardwell Room CW 103)	ACTIVITY CENTER (CW 224) or OUT OF CLASS	TOPIC
Mon.	8/25	___	Activity Center CLOSED during the 1st week of Class	
Tue.	8/26	**L00**: Introduction & Expectations for the Course		
Wed.	8/27	___		
Thu.	8/28	**L01**: Position & Motion (Begin)		Position & Motion
Fri.	8/29	___		
Mon.	9/1	LABOR DAY HOLIDAY		
Tue.	9/2	**L02**: Position & Motion (End)	___	Velocity & Position
Wed.	9/3	___	Start Exploration 1A-Part 1	Momentum & Forces
Thu.	9/4	**L03**: Forces & Motion (Explanation 1A-1)	Exploration 1A-Part 1 (Due @ 1:30PM)	Momentum & Forces
Fri.	9/5	___	Start Elaboration 1A-Part 1	Momentum & Forces
Mon.	9/8	___	Continue Elaboration 1A-Part 1	Momentum & Forces
Tue.	9/9	**L04**: Forces & Motion (Discuss Elaboration 1A-1)	Elaboration 1A-Part 1 (Due @ 1:30 PM)	Momentum & Forces
Wed.	9/10	___	Start Exploration 1A-Part2	Forces & Energy
Thu.	9/11	**L05**: Forces & Motion (Explanation 1A-2)	Exploration 1A-Part2 (Due @ 1:30PM)	Forces & Energy
Fri.	9/12	___	Start Elaboration 1A-Part 2	Forces & Energy
Mon.	9/15	___	Continue Elaboration 1A-Part 2	Forces & Energy
Tue.	9/16	**L06**: Forces & Motion (Discuss Elaboration 1A-2)	Elaboration 1A-Part 2 (Due @ 1:30 PM)	Forces & Energy
Wed.	9/17	___	Start Exploration 1B	Kids' Ideas of Force & Motion
Thu.	9/18	**L07**: Forces & Motion (Explanation 1B)	Exploration 1B (Due @ 1:30 PM)	Kids' Ideas of Force & Motion
Fri.	9/19	___	Start Elaboration 1B	Kids' Ideas of Force & Motion
Mon.	9/22	___	Continue Elaboration 1B	Kids' Ideas of Force & Motion
Tue.	9/23	**L08**: Forces & Motion (Discuss Elaboration 1B)	Elaboration 1B (Due @ 1:30 PM)	Kids' Ideas of Force & Motion
Wed.	9/24	___	Start Elaboration 1C-Part 1	Force & Motion Design Micro Lesson
Thu.	9/25	**L09**: Forces & Motion (Conclude Elaboration 1C)	Continue Elaboration 1C-Part 1	Force & Motion Design Micro Lesson
Fri.	9/26	___	Elab. 1C-1 (Due 1:30 PM) Start Elab 1C-2	Force & Motion Critique Micro Lesson
Mon.	9/29	Review Session for TEST 1 (7:00-8:00 PM)	Continue Elaboration 1C-2	Force & Motion Critique Micro Lesson
Tue.	9/30	**TEST 1 : Postion, Velocity, Forces & Motion**	Continue Elaboration 1C-2	**All Topics Completed Until Now**
Wed.	10/1	___	Start Expl 2A-1 Continue Elab 1C-2	Charges & Circuits
Thu.	10/2	**L10**: Electricity & Magnetism (Explanation 1A-1)	Expl 2A-1 (Due 1:30PM) Continue Elab 1C-2	Charges & Circuits
Fri.	10/3	___	Start Elab 2A-1 Elab. 1C-2 (Due 1:30 PM)	Charges & Circuits
Mon.	10/6	___	Continue Elaboration 2A-Part 1	Charges & Circuits
Tue.	10/7	**L11**: Electricity & Magnetism (Discuss Elaboration 2A-1)	Elaboration 2A-Part 1 (Due @ 1:30 PM)	Charges & Circuits
Wed.	10/8	___	Start Exploration 2A-Part2	Magnetism & Electromagnetism
Thu.	10/9	**L12**: Electricity & Magnetism (Explanation 2A-2)**	Continue Exploration 2A-Part2***	Magnetism & Electromagnetism
Fri.	10/10	___	Expl.2A-2 (due 1:30 PM) Start Elab. 2A-Part 2	Magnetism & Electromagnetism
Mon.	10/13	___	Continue Elaboration 2A-Part 2	Magnetism & Electromagnetism
Tue.	10/14	**L13**: Electricity & Magnetism (Discuss Elaboration 2A-2)	Elaboration 2A-Part 2 (Due @ 1:30 PM)	Magnetism & Electromagnetism
Wed.	10/15	___	Start Exploration 2B	Kids' Ideas of Electricity & Magnetism
Thu.	10/16	**L14**: Electricity & Magnetism (Explanation 2B)	Exploration 2B (Due @ 1:30 PM)	Kids' Ideas of Electricity & Magnetism
Fri.	10/17	___	Start Elaboration 2B	Kids' Ideas of Electricity & Magnetism
Mon.	10/20	___	Continue Elaboration 2B	Kids' Ideas of Electricity & Magnetism
Tue.	10/21	**L15**: Electricity & Magnetism (Discuss Elaboration 2B)	Elaboration 2B (Due @ 1:30 PM)	Kids' Ideas of Electricity & Magnetism

Wed.	10/22	___	Start Elaboration 2C-Part 1		Electric & Magnets Design Micro Lesson
Thu.	10/23	**L16**: Electricity & Magnetism (Conclude Elaboration 2C)	Continue Elaboration 1C-Part 1		Electric & Magnets Design Micro Lesson
Fri.	10/24	___	Elab. 2C-1 (Due 1:30 PM)	Start Elab 2C-2	Electric & Magnets Critique Micro Less.
Mon.	10/27	Review Session for TEST 2 (7:00-8:00 PM)	Continue Elaboration 2C-2		Electric & Magnets Critique Micro Less.
Tue.	10/28	**TEST 2 : Electricity & Magnetism**	Continue Elaboration 2C-2		**Entire 'Electricity & Magnetism' Unit**
Wed.	10/29	___	Start Expl 3A-1	Continue Elab 2C-2	Heat & Heat Transfer
Thu.	10/30	**L17**: Electricity & Magnetism (Explanation 1A-1)	Expl 3A-1 (Due 1:30PM)	Continue Elab 2C-2	Heat & Heat Transfer
Fri.	10/31	___	Start Elab 2A-1	Elab. 2C-2 (Due 1:30 PM)	Heat & Heat Transfer
Mon.	11/3	___	Continue Elaboration 3A-Part1		Heat & Heat Transfer
Tue.	11/4	**L18**: Heat & Light (Discuss Elaboration 3A-1)	Elaboration 3A-Part 1 (Due @ 1:30 PM)		Heat & Heat Transfer
Wed.	11/5	___	Start Exploration 3A-Part2		Light
Thu.	11/6	**L19**: Heat & Light (Explanation 3A-2)	Exploration 3A-Part2 (Due @ 1:30PM)		Light
Fri.	11/7	___	Start Elaboration 3A-Part 2		Light
Mon.	11/10	___	Continue Elaboration 3A-Part2		Light
Tue.	11/11	**L20**: Heat & Light (Discuss Elaboration 3A-2)	Elaboration 3A-Part 2 (Due @ 1:30 PM)		Light
Wed.	11/12	___	Start Exploration 3B		Kids' Ideas of Heat & Light
Thu.	11/13	**L21**: Heat & Light (Explanation 3B)	Exploration 3B (Due @ 1:30 PM)		Kids' Ideas of Heat & Light
Fri.	11/14	___	Start Elaboration 3B		Kids' Ideas of Heat & Light
Mon.	11/17	___	Continue Elaboration 3B		Kids' Ideas of Heat & Light
Tue.	11/18	**L22**: Heat & Light (Discuss Elaboration 3B)	Elaboration 3B (Due @ 1:30 PM)		Kids' Ideas of Heat & Light
Wed.	11/19	___	Start Elaboration 3C-Part 1		Heat & Light Design Micro Lesson
Thu.	11/20	**L23**: Heat & Light (Discuss Elaboration 3C)	Continue Elaboration 3C-Part 1		Heat & Light Design Micro Lesson
Fri.	11/21	___	Elab. 3C-1 (Due @ 1:30 PM)	Start Elab 3C-2	Heat & Light Critique Micro Lesson
			THANKSGIVING BREAK		
Mon.	12/1	Review Session for TEST 3 (7:00-8:00 PM)	Continue Elaboration 3C-2		Heat & Light Critique Micro Lesson
Tue.	12/2	**TEST 3 : Heat & Light**	Continue Elaboration 3C-2		**Entire 'Heat & Light' Unit**
Wed.	12/3	___	Start Lesson Plan	Continue Elab 3C-2	
Thu.	12/4	**L24**: Prepare Lesson Proposal in Groups	Continue Lesson Plan	Continue Elab 2C-2	
Fri.	12/5	___	Lesson Plan (Due 5:00PM)	Elab. 3C-2 (Due 1:30 PM)	
Mon.	12/8	___	Start Preparing Overview Presentation Video		
Tue.	12/9	**L25**: Prepare Lesson Video in Groups	Overview Video (Due 5:00 PM)	Start Critiques	
Wed.	12/10	___	Continue Critiques		
Thu.	12/11	**L26**: Discuss Critiques & Improvements of Lessons	Submit Critique (12:00 PM)	Read Your Critique	
Fri.	12/12	___	___		
Mon.	12/15	___	___		
Tue.	12/16	___	___		
Wed.	12/17	Review Session for FINAL EXAM (7:00-8:00 PM)	___		
Thu.	12/18	**FINAL EXAM (9:40 - 11:30 AM)**	___		**COMPREHENSIVE**
Fri.	12/19	___	___		Course Grades Posted

***Instructor may modify the above schedule with prior notice to students. Changes will be posted on K-State Online & Announced in Lecture**

** Lecture L12 on 10/09 is online due to the **Education Symposium**. Class Participation points for Lecture L12 will be average of Lectures L11 and L13.

*** The due date/time for Exploration 2A-Part 2 is Friday, October 10th, 1:30 P.M., due to the Education Symposium on October 9th.

Appendix B: Comparison of Samples

In this appendix demographic information between baseline and redesigned course is presented. Also additional demographic information collected only for the redesigned course. For the comparison between both groups results of a statistical analysis are given to confirm there was no difference among the groups.

Demographic information for baseline and redesigned courses.

	Fall 2011	Fall 2014
# of Participants	110	168
Gender	Female 90.0% Male 10.0%	Female 92.9% Male 7.1%
Year in School	Freshmen 27.4% Sophomores 43.5% Juniors 19.0% Seniors 10.1%	Freshmen 3.7% Sophomores 67.0% Juniors 23.9% Seniors 5.5%
Majors in College	Elementary Education 76% Other Education 6% Art, Business, Health 18%	Elementary Education 80% Other Education 10% Art, Business, Health 10%

Comparisons Between Baseline & Redesigned Course

Gender

A chi-squared analysis was used to determine if there was a statically significant difference the in the distribution of gender between the baseline and redesigned course. The two assumptions that need to be met in order to run a chi-square test of independence are that the sample size has more than 5 samples per cell, which is clearly met in this case. There were 110 students in the baseline course, 11 of which are male and 99 are female, while there were 168 students in the redesigned course, 12 of which were male and 152 were female. The second assumption relates to independence of observations. The students being compared are from two different semesters, three years apart, none of the students in the baseline course were part of the redesigned course. Therefore, the assumptions were met. Table 25 shows the results of the chi-square test. Results of the chi-square indicated that there is no statistically significant difference in the distribution of gender between the two courses; i.e. the distribution of genders in the baseline and redesigned course are the same.

Table 25.
Chi-square test for gender distribution.

χ^2	Degrees of Freedom	p-value
0.71	1	.400

Year in School

A One-way ANOVA was run to test whether there was a statistically significant difference in the distribution of the year in school participants were when they took the *Concepts of Physics* course. Information about the year in school participants were when they enrolled in the course was collected. The sample consisted of 110 students in the baseline and 168 students in the redesigned course. A one-way ANOVA was run to test whether there was a statistically significant difference between the populations of both groups. Prior to run the ANOVA some assumptions need to be tested to validate the results of the test. Those assumptions are: (1) dependent variables must be continuous; (2) Independent variables should be two or more categorical independent groups; (3) Independence of observation; (4) Normality; and (5) Homogeneity of variance.

The dependent variable in this case is year in school, which goes from freshman to senior. The independent variable is Fall in which the course was taken. Results for the skewness and kurtosis indicated that the assumptions for normality were met, Levene test for homogeneity of variance was not significant, which indicates that variance for the groups are equal. Therefore, the assumptions were met. Analysis of variances showed there was no significant difference in the distribution of year in school for the participants. This means there is no significant difference in the distribution of year in school of the participants between the baseline and redesigned course. Table 26 shows the results of the ANOVA test as well as the distribution of students' year in school for both courses, baseline and redesigned.

Table 26.
Analysis of variance for Year in School.

F	Degrees of Freedom	p-value
0.01	6	.999

Major

The dependent variable in this case is program students were enrolled when they took the course of Concepts of Physics. The independent variable is Fall in which the course was taken. The distribution of majors' students that were enrolled in was not normally distributed. Even though the distribution was not normal, ANOVA test is robust enough to stand violation of normality. Results indicated Levene's test was not significant, which indicates that variance for the groups are equal.

Table 27 presents the results of the analysis of variance test. ANOVA results indicated there was no significant difference in the distribution of the major students were enrolled in when they took the Concepts of Physics course. This means there is no statistically significant difference in the distribution of majors' students were enrolled in when they took the course between the baseline and redesigned course.

Table 27.
Analysis of variance for Major students declared when they enrolled in the CoP course.

F(1,18)	Degrees of Freedom	p-value
0.144	18	.709

Appendix C: IRB Letter

KANSAS STATE UNIVERSITY | University Research Compliance Office

TO: N. Sanjay Rebello
Physics
116 Cardwell

Proposal Number: 6110

FROM: Rick Scheidt, Chair
Committee on Research Involving Human Subjects

1 Feb 12

DATE: February 1, 2012

RE: Proposal Entitled, "Infusing Pedagogical Content Knowledge into a Pyshics Course for Future Elementary Teachers"

The Committee on Research Involving Human Subjects / Institutional Review Board (IRB) for Kansas State University has reviewed the proposal identified above and has determined that it is EXEMPT from further IRB review. This exemption applies only to the proposal - as written – and currently on file with the IRB. Any change potentially affecting human subjects must be approved by the IRB prior to implementation and may disqualify the proposal from exemption.

Based upon information provided to the IRB, this activity is exempt under the criteria set forth in the Federal Policy for the Protection of Human Subjects, **45 CFR §46.101, paragraph b, category: 1, subsection: ii.**

Certain research is exempt from the requirements of HHS/OHRP regulations. A determination that research is exempt does not imply that investigators have no ethical responsibilities to subjects in such research; it means only that the regulatory requirements related to IRB review, informed consent, and assurance of compliance do not apply to the research.

Any unanticipated problems involving risk to subjects or to others must be reported immediately to the Chair of the Committee on Research Involving Human Subjects, the University Research Compliance Office, and if the subjects are KSU students, to the Director of the Student Health Center.

Appendix D: Final Project Guidelines

Fall 2011

PHYS106 CONCEPTS OF PHYSICS FALL 2011

PROJECT & PRESENTATION GUIDELINES

Sign Up Deadline: 11:59 P.M., Monday, November 07

Proposal Due Deadline: 11:59 P.M., Thursday, November 17

What is this assignment about?

The assignment is an opportunity for you to think about transferring what you have learned in this class to teaching in an elementary school.

You and your group will create a 50 minute lesson for elementary kids addressing a topic covered in class. You and your group will first submit a proposal that is no more than three pages long, describing the lesson. Your proposal should address the criteria described below. Then you and your group will present a segment of the 50 minute lesson as explained below.

In addition to preparing and presenting a lesson with your group, you will also critique at least one presentation made by others in detail. All lesson plans will be posted online. You will individually be assigned one. Be sure to read the lesson plan in advance and then pay close attention when that group presents their work in class. You will then have to write a critique of the proposal and the presentation that is no more than one page long.

How do I form and work with my group?

Form a group of between three to five people that you can work with. Remember – no fewer than three and no more than five people per group. When you create your group, you must make sure that…

- They are people you are comfortable working with.
- You can mutually agree on what project you will do and what segment of it to present
- You decide to share the work and not rely on one or two people to do everything.
- Although you share responsibility, you trust that everyone in the group will know everything about the project and can take the place of anyone else in the group.

If for any reason you have trouble forming a group as described above, please let me know as soon as possible.

What do I do with my group?

At your first group meeting you should decide:

- When you will make your presentation and sign up for it soon. (This is top priority. Decide this first so that one person in your group can sign up for the presentation)
- What topic you will do for the proposal.
- Who will do what – You can assign tasks but each person should read and approve the final proposal. Each person should know enough about the proposal so that you can describe it to anyone.
- What segment of it will you present and when will you do it (You can decide this even after you have submitted this proposal)

At future group meetings you should plan to:

- Discuss the lesson and plan the learning experiences for the children. (Note: The Activities Center in Cardwell 216 will be kept open and all of the equipment that you have used so far will be available for you to play).
- Practice your final presentation: It is important that you are all well coordinated as a group and play your respective roles effectively. Therefore, you are strongly recommended to practice the presentation at least once as a group.

What should my group and I put in the three-page proposal?

The three-page proposal (11 point font, 0.5 inch margins) should contain the following information:

- Full names (Last name, First name) of everyone in the group.
- What elementary grade level the lesson is targeted at.
- The students' learning goals for the lesson. Be sure to choose something that is doable in a 50 minute class. Remember you are dealing with elementary kids, so your goals should be very focused.
- The National and State Science Standards addressed by the lesson.
- How this lesson addresses any relevant readings on children's ideas of science that have been posted on the K-State Online website of this course.
- How you will assess whether students have met the goals.
- What materials you will need: This includes the hands-on activities, computer programs and written worksheets that you will have students use. You are allowed to use any material for the hands-on activities that we have used in class or you can get your own inexpensive materials.
- A clear timeline of how the 50 minutes will be spent: E.g. First 10 minutes do this, next five minutes do that, etc.
- References of any sources that you have used. It is okay to borrow lesson plans from any source, but if you do so it is not okay to pretend that you came up with it yourself. If you borrowed it, please indicate accurately in your proposal where you found the information.

Your proposal, along with those of all other groups in the class will be posted online. So, make sure it looks good!

How do my group and I prepare for the presentation?

Go through your overall proposal and decide as a group what segment of it you would like to present either in front of class or to the students in the school. Try to select an activity that is most central to the entire lesson and one that would be most interesting for the audience to watch and learn about.

What else will I be required to do?

In addition to preparing and presenting a lesson with your group, you should be present for all presentations made in class. If you miss one of the six days in class when these presentations are being given, you will lose attendance points, just like you would if you missed a lecture.

You will be assigned a specific proposal and presentation to critique. Be sure to download the proposal of the assigned presentation in advance and pay close attention when that group presents their work in class. You will write a critique of the proposal and the presentation that is no more than one page long. When you critique the proposal and the presentation, please use the same criteria described below that I will use to grade these assignments.

Your critique is not a group activity and must be done individually. You and your group members may be assigned different presentations to critique, so this part of the project is not done collaboratively.

How will my work on this assignment be graded?

The criteria for each component of this project are described below.

Proposal (worth total of 50 points)

You and your group will be graded on the proposal and presentation as a whole which means you will all receive the same number of points. The criteria are:

- Feasibility of learning goals for a 50-minute class and the age-group of the kids (6 points)
- Alignment of assessments with the learning goals (8 points)
- Alignment of the lesson plan and the goals (6 points)
- Appropriateness of the materials used (6 points)
- Alignment of lesson with National Standards (6 points) and State Standards (4 points)
- Alignment of lesson with readings on children's ideas of science posted on K-State Online (6 points)
- Overall clarity of the proposal (8 points)

Presentation (worth total of 30 points)

You and your group will be graded on the proposal and presentation as a whole which means you will all receive the same number of points. The criteria are:

- Alignment of the presentation with the lesson plan in proposal (6 points)
- Active engagement of learners and audience during the presentation (16 points)
- Overall clarity of the presentation (8 points)

Critique (worth total of 20 points)

You will be graded individually for your one-page critique of another group's proposal and presentation. Your group members may be asked to critique a different proposal/presentation, so you will be graded independently on this aspect of the project. The criteria are:

- Critique of the proposal been as per each of the criteria described above. (10 points)
- Critique of the presentation as per each of the criteria described above. (10 points)

PHYS106 | CONCEPTS OF PHYSICS PROJECT GUIDELINES | FALL 2014

What is this assignment about?

The assignment is an opportunity for you to think about transferring what you have learned in this class to teaching in an elementary school.

You and your group will create a 50 minute lesson for elementary kids addressing a topic covered in class. You and your group will first submit a lesson plan that is no more than three pages long, describing the lesson. Your lesson plan should address the criteria described below. Then you and your group will present a 5-minute long overview of the lesson and upload a video of it on YouTube.

In addition to preparing the lesson plan and overview video, you will also critique at least one lesson plan and video made by others in detail. All lesson plans and videos will be posted online. You will individually be assigned one to critique. Be sure to read the lesson plan in advance and then view the YouTube video in detail. You will then have to write a one-page critique of the lesson and the overview.

How do I form and work with my group?

Form a group of between **<u>two to five</u>** <u>people</u> that you can work with. Remember – no fewer than two and no more than five people per group. When you create your group, you must make sure that…

- They are people you are comfortable working with.
- You can mutually agree on the lesson topic you will do and what you will present
- You decide to share the work and not rely on one or two people to do everything.
- Although you share responsibility, you trust that everyone in the group will know everything about the project and can take the place of anyone else in the group.

If for any reason you have trouble forming a group as described above, please let me know.

What do I do with my group?

At your first group meeting you should decide:

- What topic you will do for the proposal. You can choose from a list of the following topics. Chose the topic that was MOST difficult for ***you*** to understand, and explain ***why*** it was difficult and why a kid might find it challenging.
  - **Force & Motion**
  - **Electricity & Magnetism**
  - **Heat & Light**
- Who will do what – You can assign tasks but each person should read and approve the final lesson plan. Each person should know enough about the lesson plan so that you can describe it to anyone.
- What segment of it will you present in the overview and when will you do it (You can decide this even after you have submitted this lesson plan)

What should my group and I put in the three-page lesson plan?

The three-page lesson plan (11 point font, 0.5 inch margins) should contain the following information:

- Full names (Last name, First name) of everyone in the group.
- What elementary grade level the lesson is targeted at.
- The students' learning goals for the lesson. Be sure to choose something that is doable in a 50 minute class. Remember you are dealing with elementary kids, so your goals should be very focused.
- How this lesson addresses any relevant readings on children's ideas of science that have been learned in this class. Explain why this topic may be difficult to the elementary kids.
- How you will assess whether students have met the goals.
- What materials you will need: This includes the hands-on activities, computer programs and written worksheets that you will have students use. You are allowed to use any material for the hands-on activities that we have used in class or you can get your own inexpensive materials.
- A clear timeline of how the 50 minutes will be spent: E.g. First 10 minutes do this, next five minutes do that, etc.
- A clear distinction between the three phases of the 3E Cycle: Exploration, Explanation, Elaboration.
- References of any sources that you have used. It is okay to borrow lesson plans from any source, but if you do so it is not okay to pretend that you came up with it yourself. **If you borrowed it, please indicate accurately in your proposal where you found the information**.

Your lesson plan, along with those of all other groups in the class will be posted online. So, make sure it looks good!

How do my group and I prepare for the overview video?

Go through your overall proposal and decide as a group what segment of it you would like to present either in front of class or to the students in the school. Provide an overview of the activity. You are strongly encouraged to use demonstrations.

When and how do my group and I submit the overview video?

Your overview should be in a video **no less than 5 minutes long and no more than 7 minutes long**, which you will upload on YouTube using the instructions you have used previously. Upload video onto YouTube. Follow written instructions in 'ACTIVITIES' folder on K-State Online. You can also find these instructions at:

http://lifehacker.com/5804501/how-to-upload-videos-to-youtube-for-beginners

DEADLINE for Overview Video Submission: 5:00 P.M. on TUESDAY, DECEMBER 09

What else will I be required to do?

You will be assigned a specific lesson plan and overview video (associated with the lesson plan) to critique. Be sure to download the lesson plan and pay close attention to the video. You will write a one-page critique of the lesson plan and video. When you critique the lesson plan and overview video, please use the same criteria described below that I will use to grade these assignments.

Your critique is not a group activity and must be done individually. You and your group members may be assigned different presentations to critique, so this part of the project is not done collaboratively.

When and how do I submit the critique?

Your critique should be in a Word file no more than one (1) page long, Arial, 11 point font, 0.5 inch margins.

There will be a drop box in the **PROJECT** folder on K-State Online titled **CRITIQUE** for you to upload the one-page critique.

How will my work on this assignment be graded?

The criteria for each component of this project are described below.

Lesson Plan (worth total of 50 points)

You and your group will be graded on the lesson plan as a whole which means you will all receive the same number of points. The criteria are:

- Feasibility of learning goals for a 50-minute class and the age-group of the kids (6 points)
- Alignment of assessments with the learning goals (6 points)
- Alignment of the lesson plan and the goals (6 points)
- Appropriateness of the materials used (6 points)
- Alignment of lesson with children's ideas of science (10 points)
- A clear distinction of the phases of the 3E learning cycle (10 points)
- Overall clarity of the proposal (6 points)

Overview Presentation (worth total of 30 points)

You and your group will be graded on overview presentation as a whole which means you will all receive the same number of points. The criteria are:

- Alignment of the presentation with the lesson plan (6 points)
- Active engagement of learners and audience during the presentation (16 points)
- Overall clarity of the presentation (8 points)

Critique (worth total of 20 points)

You will be graded individually for your one-page critique of another group's proposal and presentation. Your group members may be asked to critique a different proposal/presentation, so you will be graded independently on this aspect of the project. The criteria are:

- Critique of the proposal been as per each of the criteria described above. (10 points)
- Critique of the presentation as per each of the criteria described above. (10 points)

Appendix E: Examples of Lesson plan & Critique

Lesson Plan

Magnetism & Electricity

Lesson Plan Level: 4th Grade

Student Learning Objectives:

- The students will demonstrate knowledge of magnetism by discussing the properties of magnets
- The students will demonstrate analysis of the properties of magnets by classifying objects as magnetic or non-magnetic
- The students demonstrate evaluation of magnetic properties by predicting and verifying experimental outcomes

Relation to Readings over kids ideas of magnetism:

This lesson addresses the misconceptions students may have about magnets. These misconceptions include:

- Magnets attract all metals
- All silver colored objects are attracted to magnets

Assessment:

The assessment for this lesson will consist of the following rubric.

file:///Users/rebekahanliker/Downloads/MyRubric.xls-4.html

Materials:

- 6 small bar magnets
- 1 box of paper clips
- Ziplock bags filled with a variety of materials for the students to test magnetism characteristics (paper, wood, cloth, etc.)
- Pencils, string, and small circular magnet
- Paper, pencils, white board, and dry erase markers
- Compasses

Group Size: 3-4 students

Timeline:

1. Divide Students into groups of three to four students (5 min.)
2. Hand out materials (5 min.)
3. Give instructions (5 min.)
4. Make predictions (5 min.)
5. Perform experiment (10 min.)
6. Lecture (5 min.)
7. Make new predictions (5 min.)
8. Perform experiment (5 min.)
9. Write explanation (5 min.)

Exploration Activity:

Magnetism Fishing: We will pass out “fishing poles” made of pencil, string, and a magnet to each group. We will also distribute to each group a ziplock bag filled with various items (paper, metal, wood, cloth, etc.) Students will gather paper, pencil, white board and marker.

First, students will predict as a group what items will be picked up with their fishing pole and what won’t. Students will record their group predictions on paper. Next, each group will use their fishing pole and ziplock bags to take turns trying to attract/pick up items out of the bag using their magnet fishing pole. Once the group is done, they will write their observations of which object was or was not attracted to the magnetic fishing pole. They will record these observations on their white boards and then a representative from each group to share their predictions and their findings and similarities of the items that they were able to pick up with the magnetic fishing pole.

Explanation:

For our explanation phase the teacher would explain and review how magnets are only attracted to metal objects. In order to help them understand we would have a course discussion where we review and discuss the result of their experiments and talk about why cloth, wood, and other things are not attracted to the magnet. In order to get the discussion going the teacher would ask questions such as:

- What objects were attracted to the magnet? What objects were not?
- Why do you think those objects were not attracted to the magnet?

Elaboration:

For the elaboration phase of the lesson, students will once again do the Magnetism Fishing experiment. Students will again make predictions as to what they believe is and is not going to be attracted to the magnet. They will then test their predictions and record the data they collect on their white boards. Once they have completed the experiment, students will write an explanation as to why or why not their predictions were correct.

Source of lesson plan: https://www.srpnet.com/education/pdfx/magnetism.pdf

Critique

Physics 106
Critique
December 11th, 2014
Video 21

The video that I'm critiquing did their video over insulation and what are good insulators. They also implement what insulator will be best for keeping an object warm. Overall they did a good job at creating an idea that elementary kids commonly have misconceptions about.

Feasibility of learning goals for a 50- minute course and age group

After reviewing their lesson plan they are targeting the 3rd grade level, which I feel that this lesson plan may be for more of an advanced grade level, possibly 5th graders. With their goal being that students understand properties of insulators, characteristics that accompany the transfer of an ice (solid) state to a water (liquid) state, they relate that very well to their whole lesson plan.

Alignment of assessments with the learning goals

I feel that they could name more specific assessment goals instead of just restating their learning goals. The alignment of how the student will portray if they learned the material or not is a little bit unclear still in their lesson plan. Within the explanation of how they will understand if goals were met or not they include how students will try different objects, which could've been included in the learning goal.

Alignment of the lesson plan and the goals

The alignment with the exploration portion helps students figure what works as an insulator and what doesn't work. The explanation was more toward, what is a good conductor when comparing insulators to metal. This is where the confusion plays a key role because you're trying to help 3rd graders understand insulation and the part of trying the different insulators matches up with this, but talking about metals and latent heat is a bit off topic for this specific grade level and lesson. The learning goals are very clear and lesson plan mostly follows along with it except the explanation cycle.

Appropriateness of the materials used

All the materials listed are very age appropriate for 3rd graders, as long as the worksheets fit their proper age as well. These materials are also very accessible and cheap in most school settings, so this does make for a very sufficient lesson plan.

Alignment of lesson with children's ideas of science

The alignment with the lesson and children's idea of science are very confusing because they talk about two different concepts. The whole lesson plan is focused on students understanding good and bad insulators and the children's idea section talks about insulation and temperature. This will be very hard to help kids realize the misconception if you're including temperature in their ideas and only measuring the water in the actual lesson plan. This just needs to be more clarified.

Clear Distinction of the phases of the 3E learning cycle

The lesson plan does include a clear breakdown the 3E learning cycle phases and what will take place in each of the cycles. The exploration is the strongest part of the 3E learning cycle, because it gives a full clarification of what the students will do through the experiment. The explanation is a little unclear and could be difficult for 3rd graders to understand because it's very complex. It would've been helpful to have some student interaction in the explanation phase. The elaboration phase has some very good points like asking questions to the students, but could use some more points in this section. They could elaborate on how they would do these experiments again and help to explain this to students and ask them their ideas of how they see things after doing the experiment.

Overall clarity of the proposal

Overall the clarity of the proposal is pretty clear, but has some unclear parts. Just for future reference to make sure the goals match the lesson exactly and will be helpful to the students. Also to make sure the lesson is age appropriate to whatever the grade level will be. Finally, this proposal could've used some more detail in the 3E learning cycles, but were headed in the right direction, just need to be developed further.

Presentation- Alignment of the presentation with lesson plan

The actual video presentation itself was very good, but left out some parts of the lesson plan. The introduction of the video explained kid's misconceptions on the chosen topic, which was explained thoroughly. The introduction lacked information after this because there was no explanation with the learning goals, grade level, or how they will assess if the students have learned the material. The materials needed for the project was explained very thoroughly as well as the 3E learning cycle. Those components followed the lesson plan very closely.

Active engagement of learners and audience during the presentation

Overall there was a lack of learners and audience in the presentation, due to the fact that the presenters were just covering the informational items of the lesson plan, instead of actually actively doing the lesson plan. It was very hard to imagine the experiment without any prior knowledge of the lesson plan from the video alone. The presenters had a very good, clear explanation of what they were presenting, but this may be very difficult for a 3rd grader to follow along with. It was very hard to engage in the video since this video was only an informational explanation of the lesson plan, leaving some parts out.

Overall clarity of the presentation

The presentation of the video was very clear to understand and everything was explained thoroughly. If you're comparing the presentation to the lesson plan then the clarity is blurry because there are components missing in the video that were in the lesson plan. Overall, they did a good job presenting the idea as a whole, but could definitely use some developing in the middle sections that are missing from the video that were in the lesson plan.

Appendix F: List of children's ideas

Table 28 and Table 29 present the complete list of children's ideas presented in the course for micro-lessons two and three with a short explanation of what those ideas mean, as well as the scientific idea. Figures 19 and 20 show the distribution of children's ideas for the micro-lessons two and three.

Table 28.
List of Children's ideas presented in the course for micro-lesson two (Circuits and Magnets).

Children's Idea	Explanation of Children's Idea	Scientific Idea
Unipolar Model (Driver, 1985, p. 36)	Children believe that only one end of the battery needs to be connected to the light bulb in order for the current to start flowing and the light bulb to glow.	Both poles of the battery need to be connected to opposite ends of the filament in order to close the current loop and make the light bulb glow.
Clashing current model (Driver, 1985, p. 36)	Children believe that current leaves both ends of the battery and clash at the light bulb to create light.	The current flows from one end of the battery across the filament and into the other end of the battery.
Attenuation model (Driver, 1985, p. 36)	Children think that when light bulbs are connected in series, the current is consumed in each light bulb. This means that light bulbs downstream would be dimmer.	In a series circuit, in which light bulbs are connected one after the other, the current that runs through each light bulb is the same. If the light bulbs are identical, they will be equally bright.
Magnets attract all metals (Stephans, 1994).	Children believe that all metal objects will be attracted to magnets.	Only ferromagnetic metals are attracted to magnets.
All silver objects are attracted by magnets (Stephans, 1994).	Children believe that all objects that shine or are silver colored will be attracted to magnets.	Only ferromagnetic materials are attracted to magnets. These materials can be dull or shiny.
Strength of a magnet is determined by its size (Stephans, 1994).	Children believe that the bigger the magnet is, the stronger it will be.	Strength is a property of a magnet that depends on the type of material from which the magnet is made, not the size of the magnet.

Children's Idea	Explanation of Children's Idea	Scientific Idea
The effect of a magnet passes through paper but not through thicker materials like wood (Stephans, 1994).	Self-explanatory.	The effect of a magnet depends on its strength and the materials being attracted to it. The effect of a strong magnet on a ferromagnetic object can pass through thicker materials like wood.
Magnetic fields are only created by magnets (Stephans, 1994).	Self-explanatory.	Electromagnets also create magnetic fields. The Earth, other planets, and stars also create magnetic fields.
Magnetic fields are two-dimensional (Stephans, 1994).	Self-explanatory.	Magnetic fields are three-dimensional.
Magnetic field lines only exist outside of the magnet (Stephans, 1994).	Some children believe that because we cannot see the inside of a magnet, there is no magnetic field inside.	The atoms inside the ferromagnetic materials align to form the magnetic field inside and outside of the object. Magnetic fields are continuous.

The most common children's ideas used by groups during micro-lesson two were: a) All metals are attracted to magnets (27.4%); b) All silver objects are attracted to magnets (24.2%), c) Unipolar model (16.1%), and d) Clashing currents (12.9%). All the other ideas were addressed by less than five percent of the groups. All the children's ideas about circuit and magnets presented in Table 28 – which contains the complete list of children's ideas discussed in the *Concepts of Physics* course about Circuits and Magnets - were addressed by at least one student. From Figure 19, it can be seen that for micro-lesson two the percentage of groups' responses that were placed in the None category, which represents the level zero of the KCI category (3.2%) is reduced by almost twenty percent points compared to micro-lesson one (22.4%). Figure 19 shows the distribution of children's ideas used by students in the Circuits and Magnets micro-lessons.

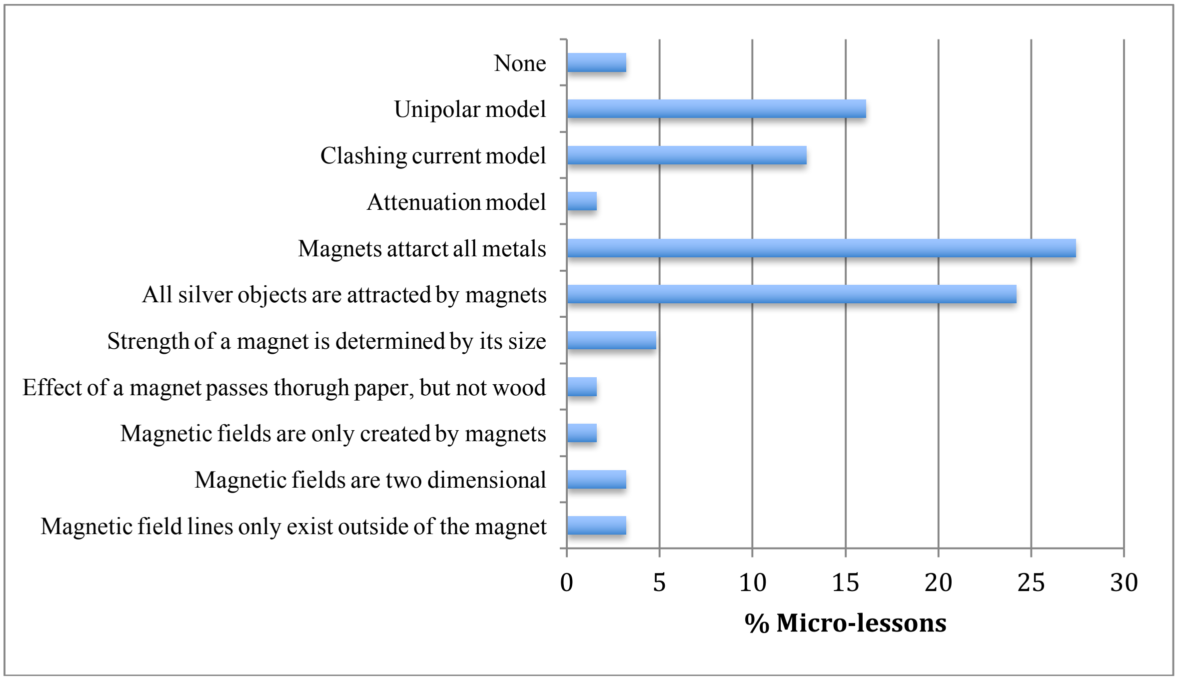
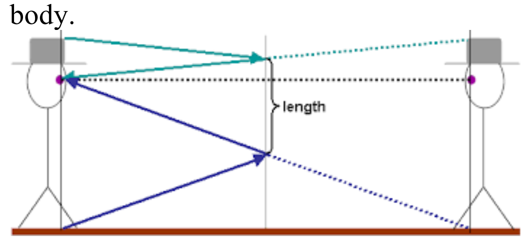


Figure 19. Distribution of children's ideas used by students in micro-lesson two (Circuits and Magnets).

Table 29 contains the list of children's ideas presented in micro-lesson three (Heat and Light), examples for the children's ideas, and the scientific idea. Figure 20 shows the frequency distribution of children's ideas used by groups in micro-lesson three (Heat and Light).

Table 29.
List of children's ideas presented in the course for micro-lesson three (Heat and Light).

Children's Idea	Explanation of Children's Idea	Scientific Idea
Light: The source idea (Driver, 1985)	When children are asked where the light is, they tend to point at its source, such as a flashlight or a light bulb.	Light is a wave, which originates at a source and travels in straight lines through a medium such as air.
Light: The effect idea (Driver, 1985)	When asked where the light is, children point at the effect, such as the light spot produced by a flashlight.	Light also exist in the space between the source and its effect.
A mirror reflects light in all directions (Driver, 1985).	The idea comes from children's belief that light is everywhere. When light bounces back from shiny objects, the light will reflect in all directions.	Light travels in straight lines. Mirrors only reflect light with the same angle as the incident light.

Children's Idea	Explanation of Children's Idea	Scientific Idea
The size of a mirror determines how much we can see of ourselves (Driver, 1985).	Children believe that a body-sized mirror is necessary in order to see their whole body reflected on it.	Plane mirrors reflect light with the same angle as the incident light. The light beam that starts at the top of the head and travels in a direction parallel to the floor goes straight to the mirror. The mirror reflects light straight back in a line parallel to the floor. The light beam that comes from the feet will hit the mirror in the middle. The mirror reflects the light and bounce back with the same angle. Therefore, the mirror only needs to be about half the size of the body. 
The intrinsic illumination idea - we see objects because light falls on them (Driver, 1985).	Children believe that when light falls on to the object, the object becomes illuminated, has its own glow, and therefore we can see the object.	We perceive the light that bounces off the object, and then the brain processes the information, allowing us to see the object.
The vision idea (Driver, 1985, p. 25)	Children believe that we are able to see because the eyes have active roles, meaning that the eyes process the image instead of the brain.	Eyes are only light receptors.
Heat is what is done to the object, such as heating or cooling (Driver, 1985).	Some children identify heat with a sort of material that has the ability to make objects hotter or cooler.	Heat is the amount of energy transferred from an object that is at a higher temperature to an object at a lower temperature.
Heat is the property of an object, such as being hot or cold (Driver, 1985)	In this case the word heat is being confused with the temperature of an object.	Heat is the amount of thermal energy transferred in a given process. It is not a property intrinsic to the object.
The bigger the object is, then the cooler/hotter it will be (Driver, 1985).	Consistent with the idea that temperature is the amount of heat an object has, children believe that the temperature of an object depends on its size.	Temperature is a measurement of the average kinetic energy of the particles that make up the object.

Children's Idea	Explanation of Children's Idea	Scientific Idea
Ice changes temperature; therefore, the bigger the ice the colder it is (Driver, 1985).	This idea is related to the previous idea in which children believe that the bigger the ice cube is, the colder it will be. As the ice cube becomes smaller, it will become warmer.	Ice is the solid state of water, which depending on altitude and pressure, has a temperature of zero degrees Celsius independent of its size. The temperature of the ice will remain at zero degrees Celsius until all the ice has melted.

Figure 20 show that the most common children's ideas used for micro-lesson three were: a) Mirror reflects light in all directions (33.9%) and b) The size of the object affects the amount of heat it can absorb (8.9%). The other children's ideas were used less than eight percent by groups. No group addressed the children's idea "heat is the property of an object, such as being hot or cold". Figure 20 shows that for micro-lesson three, about eighteen percent of students' responses were placed in the None category, which represents a 15% points increase in comparison to micro-lesson two.

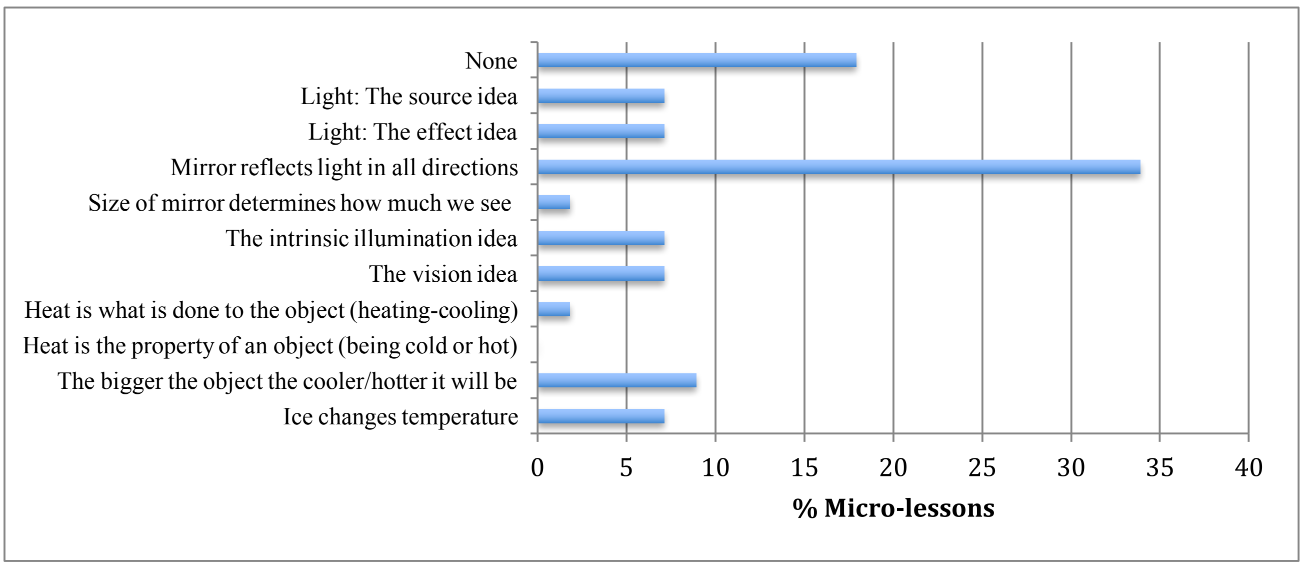


Figure 20. Distribution of children's ideas used by students in micro-lesson three (Heat and Light).

Table 30.
Distribution of children's ideas used by students during the micro-lessons.

Force & Motion Children Idea	%	Circuits & Magnets Children Idea	%	Heat & Light Children Idea	%
None	22.4	None	3.2	None	17.9
Force is transfer	4.1	Clashing currents model	12.9	Light as a source	7.1
Force runs out	18.4	Unipolar model	16.1	Light as an effect	7.1
Force has to do with living things	2	Current is consumed in each light bulb	1.6	Mirror reflects in all directions	33.9
Constant motion -> Constant Force	2	All metals are attracted to magnets	27.4	We see objects because light falls on them	7.1
Amount of motion = Amount of force	14.3	All silver objects are attracted to magnets	24.2	Eyes play an active role in seeing	7.1
If an object is not moving there is no force	4.1	Strength of a magnet is determined by its size	4.8	Heat is what is done to the object (heating-cooling)	1.8
If an object is moving there is a force in the direction of motion	6.1	Effect of a magnet passes through paper, but not wood	1.6	Heat is property of an object (being cold or hot)	0
Heavy objects fall faster	26.5	Magnetic fields are only created by magnets	1.6	The size of the object affects the amount of heat it absorbs	8.9
-	-	Magnetic fields are 2D	3.2	Ice changes temperature	7.1
-	-	Magnetic field lines exist only outside magnets	3.2	The size of the mirror determines how much we can see of ourselves	1.8

Table 31.
Distribution of Children's ideas used by the groups in the lesson plan[6].

Children's idea	F2011 (%)	F2014 (%)
Force runs out	11.1	10.9
Forces are to do with living things	11.1	4.7
Constant motion requires constant force	8.3	10.9
Amount of motion is proportional to the amount of force	8.3	3.1
If an object is not moving, there is no force acting on it	0.0	6.3
If an object is moving, then there is a force acting on it in the direction of motion	0.0	1.6
Unipolar and clashing current models	2.8	6.3
Attenuation model	0.0	1.6
Magnets attract all metals	11.1	12.5
All silver objects are attracted by magnets	11.1	9.4
Strength of magnet is determined by its size	8.3	7.8
Effect of a magnet passes through paper but not wood or thicker materials	8.3	1.6
Magnetic fields are only created by magnets	5.6	6.3
Magnetic fields are two dimensional	0.0	1.6
Light: The source idea	0.0	1.6
Mirror reflects light in all directions	0.0	1.6
Heat is what is done to the object (heating-cooling)	5.6	3.1
Heat is the property of an object (being cold or hot)	5.6	1.6
Sounds are waves*	2.8	0.0
All objects heat or cool at the same rate*	0.0	1.6
Magic mirrors (inverting images)*	0.0	1.6
Confuse kinetic energy and potential energy*	0.0	1.6
If there is no motion, there is no energy*	0.0	3.1

[6] The ideas marked with an asterisk were invented ideas by the students

Appendix G: Description of Categories of PCK

Table 32.
Description and example of the different levels of knowledge of children ideas for the micro-lessons, FPV, and lesson plans.

Level	Description	Example(s)	Explanation
0	There is no evidence of acknowledgement of the use of children's ideas in the design of micro-lesson.	"For our lesson plan we chose to do our project for force and motion. We would start with an exploration." The completed lesson plan does not indicate which children's idea the students addressed.	Students either focus on goals/objective to create their micro-lesson or start the lesson describing the activities, but there is no indication of which children's ideas they are addressing. In the context of role-playing a teacher-student interaction, the student who acts as the teacher does not ask the children about what they think.
1	There is some indication of the use of children's ideas in the design of the micro-lesson. Children's ideas are implicitly present (it can be inferred by what students are saying which children's idea they are addressing, but the children's idea is not said literally as it was presented in the course).	• "We will be exploring the ideas of temperature and heat by exploring how different objects act as insulators. This will challenge students to understand how temperature can be retained and released differently through different objects." • "Children might confuse potential energy with kinetic energy. Children might believe you need to know speed to determine kinetic energy. Children may not factor friction and gravity into experiments."	• By clearly indicating a section called children's ideas it can be inferred that the students were thinking about children's ideas when they created the lesson plan. But from the students' statement it is not clear which children's idea about heat they were addressing. • Students are indicating that children struggle with those concepts. The misconception they indicate is an invented idea[1], but the idea is not clearly articulated. Stating that children have difficulty to understand a concept or the mathematical definition of the concept does not mean that it is a misconception.

Level	Description	Example(s)	Explanation
2	It is clearly stated and identifiable which children's ideas were used in the design of the micro-lesson (children's ideas were presented as they were given in the course.).	• "This lesson addresses children's incorrect idea that moving objects stop because the force runs out." • "Many students believe that when an object is moving, there is a force acting on it in the direction of motion."	In both of these cases students are clearly indicating which idea they are addressing in their lesson plan. The ideas are consistent with two of the ideas provided for the course.

Table 33.
***Description and examples of each of the levels of use in instructional strategies for the micro-lessons, FPV, and LP*.**

Level	Description	Example(s)	Explanation
0	1) There is no evidence of acknowledgement of the use of children's ideas in the design of micro-lesson. 2) The activities proposed are not related to the children's idea being addressed.	Students are addressing the idea that "constant motion requires constant force." Students' timeline of the activities[7]: "10 minutes: Prediction of what will happen when inclination is changed for the ramp. They will predict why they think the car stopped and how the speed was affected by the inclination of the ramp. 10 minutes: To show the cars on the ramp with the different inclinations. Put time on a chart so they can see the fastest car and distance. 20 minutes: Discuss why the cars stopped and how the speeds of the cars differed because of the inclination. We can show by using the dot diagram (snapshots)."	• If the KCI level is zero, then the KIS level would be zero. • This activity does not address the idea proposed. Children will observe that the higher the ramp, the farther the car would go, but the car will eventually stop. The fact that the car stops confirms children's idea that for a car to keep moving there needs to be a force constantly applied to the car. The correct approach should have been help children understand that it is the force acting on the car in opposite direction of the movement that causes the car to stop.

[7] This is an excerpt of the students' lesson plan.

1	There is some indication of the use of children's ideas in the design of the micro-lesson activities.	The lesson plan is addressing the children's idea that "non-moving objects do not have energy." The strategies proposed by the students to address this idea were: "Have the students define energy and transferring energy and collaborate with the course. Then they will do the basketball and tennis ball experiment so that they can physically see what it looks like when energy is transferred…as as [sic] a course and come up with a definition that we all agree on. Now, in pairs the students will elaborate on the ideas of kinetic, potential, and transferred energy. They will do the marble and ruler experiment first and then as a course we will go outside and do the slide experiment."	This is an idea the students proposed. Even though the activities proposed in the lesson plan discuss some ideas about energy it is unclear how those activities would address the children's idea proposed, since it does not seem the students specifically talk about energy in a static situation.

2	It is clear how the activities described address the proposed children's idea.	Students are addressing children's ideas on heat: "Heat is what is done to the object, such as heating or cooling." The activities presented were: "Step 1- [T]he kids will [w]rite out what they are seeing in the lava lamp on their group of desks and how they think it works…Call on three to five students to share their observations of the lava lamp. Step 2 - Pour water into a beaker and have the kids feel the outside of it to see if it is hot or cold. Then place it onto the electric heating pad until it begins to boil. Add food coloring to the boiling water so that the kids can see the circular motion of the liquid. Step 4- Pour the liquid into a mug so that the students can feel the cup. They will feel their hand begin to heat up. Step 5- [H]ave the students go over to the desk lamp and place their hand close to the light bulb in the lamp.	Having children write about and discuss their observations starts conversations about whether or not their ideas were confirmed by their observations. The discussion is then complemented by a different activity, one that shows that hotter objects give away some of their heat to a colder object next to it, reaffirming the correct idea that heat is the transfer of thermal energy rather than what is done to an object.

Table 34.
Description and examples of different levels of use in assessment strategies for the micro-lessons, FPV, and LP.

Level	Description	Example(s)	Explanation
0	1) There is no evidence of acknowledgement of the use of children's ideas in the design of micro-lesson. 2) The assessment strategies proposed are not related to the children's idea being addressed.	The children's idea discussed was *source and effect and light as an entity*. The proposed assessment strategy: "Ask that students stand in front of a mirror and students move back and forth, students will see that the same amount of their body is visible. This shows children the idea of reflection. [sic]"	The proposed assessment strategy is an instructional strategy. The teacher is conducting an activity where the students can experience what happens when they look at themselves in the mirror.
1	There is some indication of the use of an assessment strategy to determine whether a children's idea was addressed or not.	The children's idea addressed is: "non-moving objects do not have energy." The proposed assessment strategy was: "Pass out an exit ticket to each student. They must write one thing that they learned during the lesson, as well as one question they still have."	Even though it is a formative assessment strategy, it does not necessarily provide the specific information the teacher needs to know in order to determine if the children's idea was addressed or not. Some children may write about the particular idea, but others may just talk about different points that they liked or disliked about the lesson.
2	It is clear how the assessment strategy measured whether or not the proposed children's idea was addressed.	The children's idea addressed was that: when an object is in motion there is force acting on the object in the same direction as the motion. The assessment strategy proposed: "To make sure that the students understand the forces we will ask them to draw their own picture/diagram of the forces acting on the ball. The students will hold up their pictures of the forces acting on the ball allowing us to quickly see if they understand the forces. When all of the students have clearly demonstrated that they know the different forces affecting the soccer ball, we will move onto the elaboration."	It is very clear that the assessment strategy is designed to address the children's idea. Asking children to draw the forces acting on the object with arrows to indicate directions allows the teacher to determine if children understood that there are other forces acting on the object and not necessarily in the direction of motion.

Table 35.
Descriptions and examples of the different levels of knowledge of children's ideas for the critiques.

Level	Description	Example	Explanation
0	There is no indication in the critique that students thought about their peers' use (or not) of children's ideas.	"When watching this presentation I think that I really enjoyed the energy of one of the group members. The others weren't as lively as the others. As for the content of the project, it was very informative and met all of the criteria. The only thing is that I wish that it were presented better. Overall, I think that the group did a great job, and that it was a great choice for a presentation."	That extract represents the extent of the critique presented by the student about his or hers peers' lesson plan. There was no mention of the use or not of children's ideas.
1	There is some indication that they thought about whether or not their peers used children's ideas in their design.	"They really thought from the students' point of view and thought about possible things the students would think. It is good to think that way because then you know what to ask the students and what kinds of things to explain to them."	The student is pointing out that their peers included children's point of view, which can be inferred to mean children's ideas. But it is not level two because it is open to interpretation whether the students are really talking about the incomplete or incorrect children's ideas being addressed, or if it is referring to other things, such as the idea that children confuse the concepts of kinetic energy with potential energy.
2	The student clearly indicates whether or not her peers used children's ideas in their design.	"The group did not address children's ideas of science. They talk about what their goal is to teach the kids that day"	The student clearly indicates that the lesson plan she evaluated it is not indicating which children's idea they were addressing.

Table 36.
Descriptions and examples of the different levels of use in instructional strategies for the critiques.

Level	Description	Example	Explanation
0	There is no evidence that the student indicated whether or not her peers used children's ideas in the design of their activities.	"I really liked their experiment, because it is extremely hands on, which is perfect for kindergarteners. It was as simple as dropping a tennis ball down a ramp to hit a water bottle."	The student is focusing on other aspects of the activity and not whether their peers used a children's idea to guide the design of the activity.
1	There is some indication that the student thought about whether or not her peers used children's ideas in their design.	"The lesson lines up perfectly with the children's ideas of science. [T]hey discuss where the source of the light is and where it goes, how it is reflected, and how we are able to see it."	In this case the student is acknowledging that her peers considered children's ideas in their design. But they do not discuss how the children's ideas were used to design the activities.
2	The student clearly indicates whether or not her peers used children's ideas in their design.	"The alignment with the lesson and children's idea of science is very confusing because they talk about two different concepts. The whole lesson plan focused on students understanding good and bad insulators and the children's idea section talks about insulation temperature."	In this case the student is clearly acknowledging that their peers used children's ideas in their design. She discusses how even though the children's ideas are present, the organization of the instructional strategies does not fully align with those ideas her peers intended to address.

Table 37.
Descriptions and example of the different levels of use in assessment strategies for the critiques.

Level	Description	Example	Explanation
0	No mention of students' peers use of children's ideas in their assessment strategies. Most of the time the level zero is given to cases where the student focuses on her peers' organization of the proposal or how engaging the presentation/video was, rather than focusing on the content of the lesson per se.	"The proposal is well thought out and is very easy to read. I particularly enjoyed the layout of the experiment in how the teacher would explain to his or her students what magnets are and how they work. Then right after the explanation the students break off into groups and get to test the magnets on certain things in order to grasp the concept of a magnet."	The example represents the extent of the critique presented by the student. There is no indication of the student commenting on assessment strategies or children's ideas.
1	The student indicates whether or not her peers aligned the children's idea with the assessment method proposed, but she does not indicate whether it was properly aligned or not. Another case of level one is that the student mentions the assessment, but she does not indicate if it aligns with children's ideas.	"Lesson plan clearly states the assessments with the activities by the leading questions".	The student is stating that there is an assessment that is aligned with the activities. But it is unclear whether or not the assessment and activities are aligned to the children's ideas (unclear if the leading questions are the children's ideas).
2	The students identify whether or not her peers aligned the assessment method with children's ideas and commented on how effectively the assessment and children's ideas were aligned.	"For the assessment; I am not sure that it truly allows them to get the learning of children's ideas. Providing a graph does not show that the children have grasped the concepts."	The student clearly acknowledges that the assessment strategy her peers proposed in their lesson plan is not appropriate for assessing whether or not the children's idea was adequately addressed.

Appendix H: Distribution of UIS and UAS as a function of KCI

Lesson Plans

Figure 21 and 22 show the distribution of levels of sophistication of UIS and UAS in the groups' lesson plans (LP) when controlling for KCI – level one. For the UIS category, in general when a children's idea was present although not clearly stated, the groups' lesson plans in the baseline course demonstrated higher levels of sophistication in their designs of instructional strategies, than those in the redesigned course. For the UAS category, in general when a children's idea was present but not clearly stated, the groups in the redesigned course demonstrated higher levels of sophistication in their design of an assessment strategy that incorporated children's ideas than those in the baseline course.

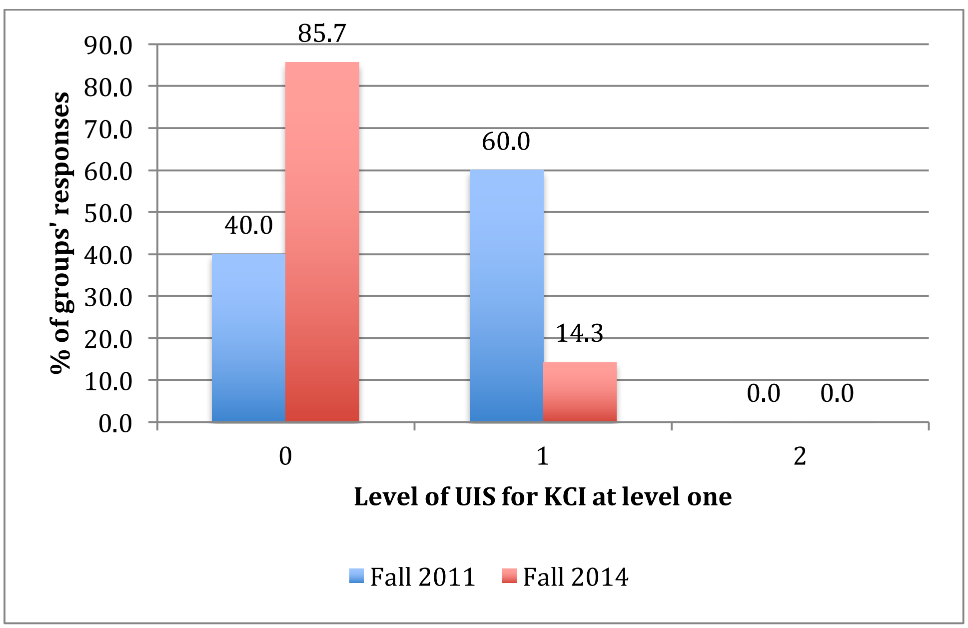


Figure 21. Distribution of the levels of UIS as a function of KCI for the LP (KCI = 1).

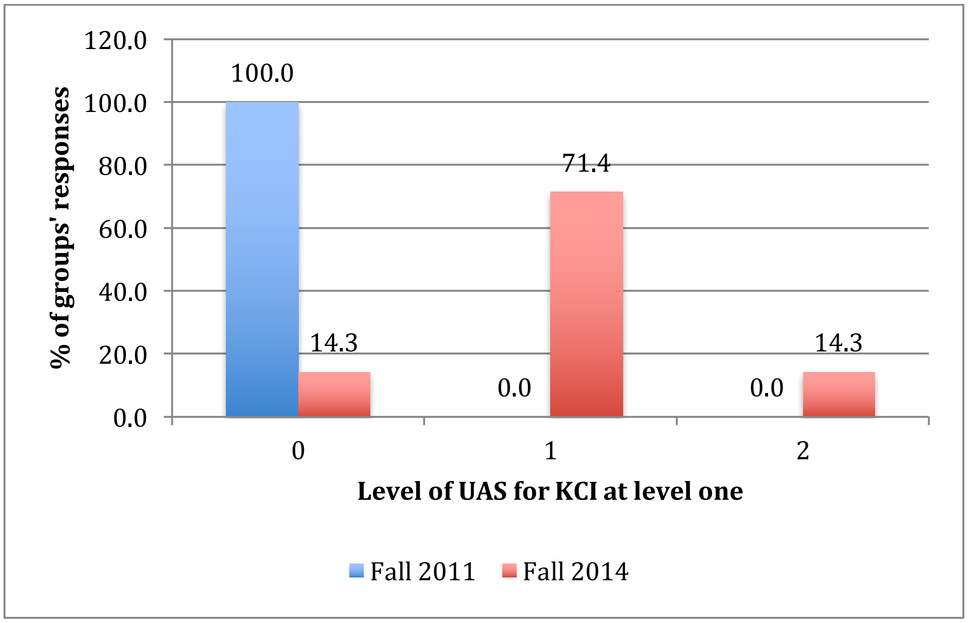


Figure 22. Distribution of the levels of UAS as a function of KCI for the LP (KCI = 1).

Figure 23 and 24 show the distribution of levels of sophistication of UIS and UAS for the baseline and redesigned course represented in the groups' lesson plans (LP) when controlling for KCI – level two. For the UIS category, groups in the redesigned course more often designed instructional strategies that incorporated children's ideas, when those ideas were clearly stated. For the UAS category when KCI is at level two, groups in the redesigned course more often designed assessment strategies that incorporated children's ideas than those in the baseline course, when those ideas were clearly stated.

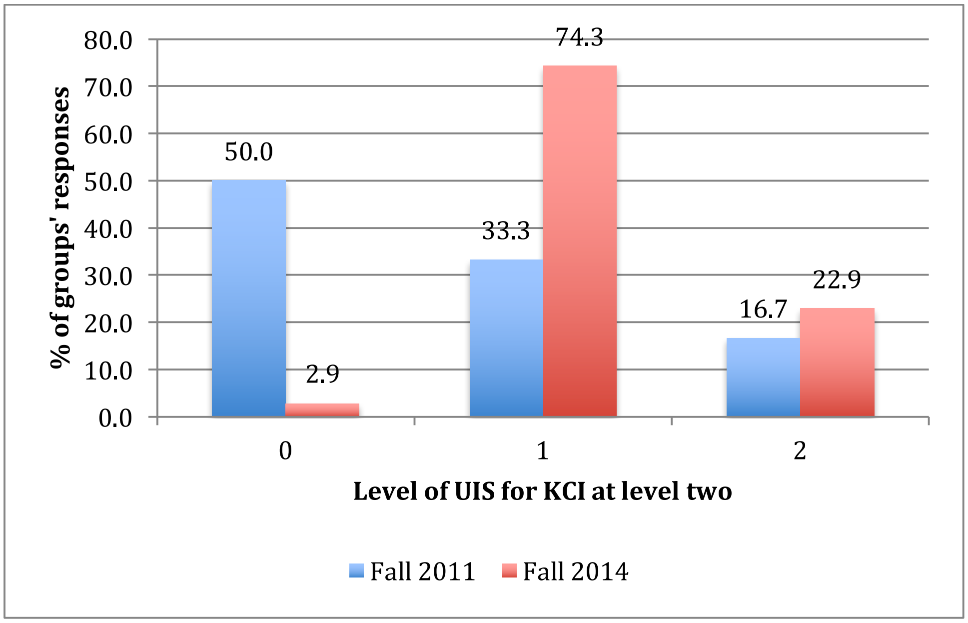


Figure 23. Distribution of the levels of UIS as a function of KCI for the LP (KCI = 2).

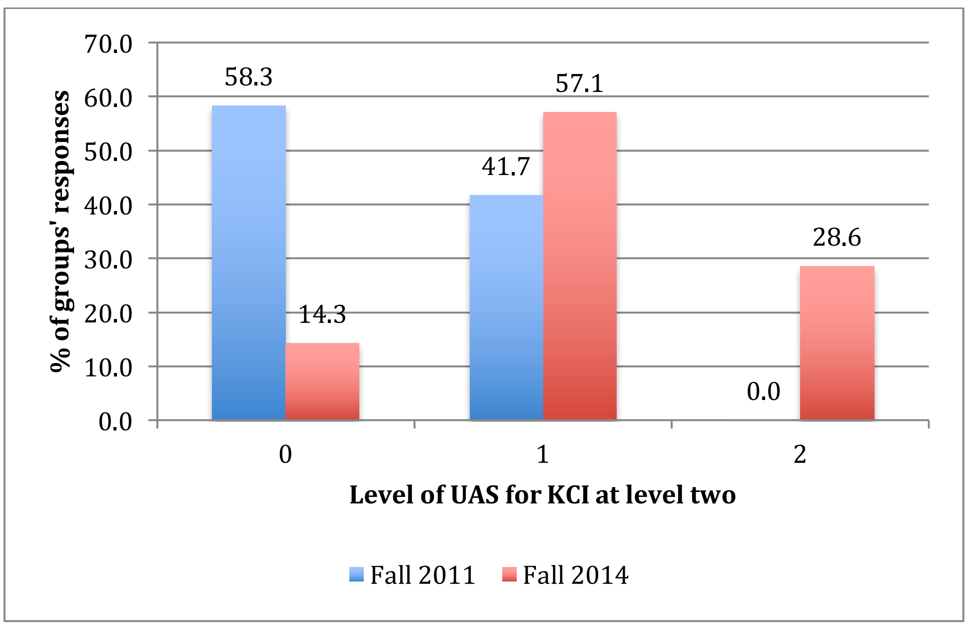


Figure 24. Distribution of the levels of UAS as a function of KCI for the LP (KCI = 2).

Critiques

Figure 25 and 26 show the distribution of students' levels of sophistication of UIS and UAS in students' critiques when controlling for KCI – level one. For the UIS category, when a children's idea was stated in some manner in the lesson plan, students in the redesigned course more often discussed whether or not the instructional strategy proposed in the LP incorporated the children's idea stated than the students in the baseline course. For the UAS category, when a children's idea was stated in some manner in the lesson plan, students in the redesigned course more often than students in the baseline course discussed whether or not the assessment strategy proposed in the LP incorporated the children's idea stated.

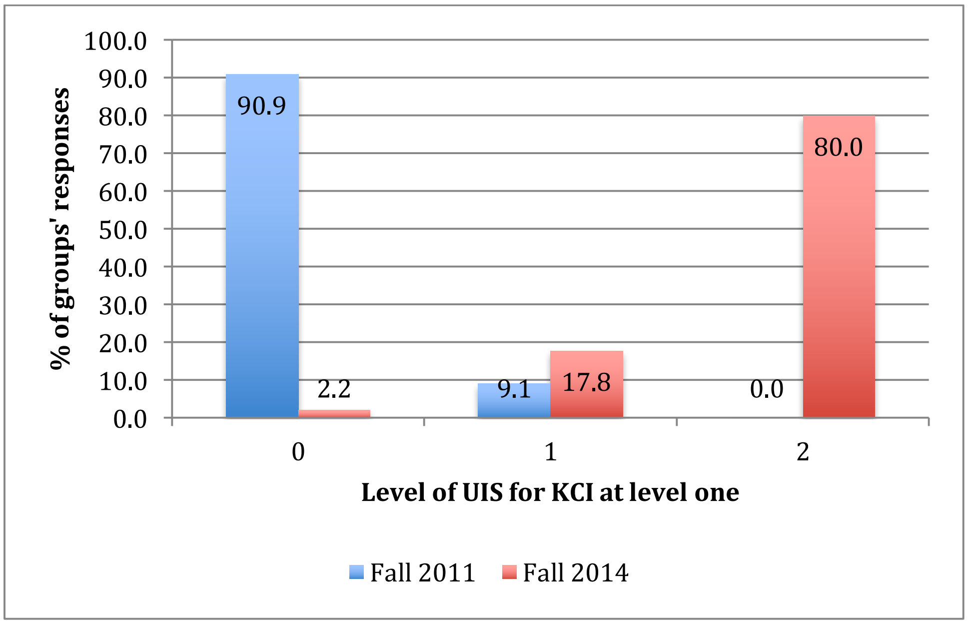


Figure 25. Distribution of the levels of UIS as a function of KCI for the Critiques (KCI = 1).

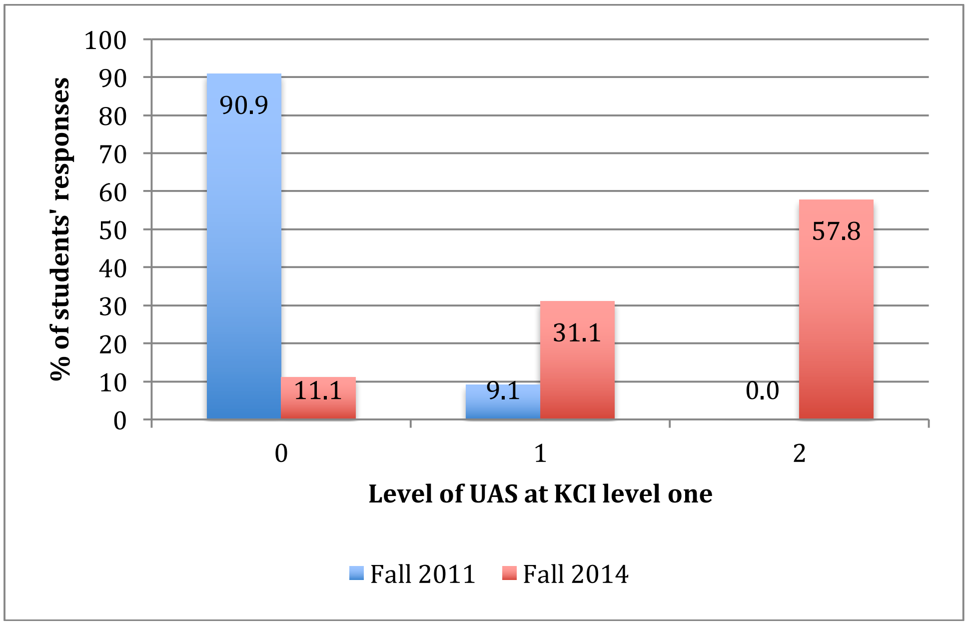


Figure 26. Distribution of the levels of UAS as a function of KCI for the Critiques (KCI = 1).

Figure 27 and 28 show the distribution of students' levels of sophistication of UIS and UAS in the students' critiques when controlling for KCI – level two. For the UIS category, when a children's idea was clearly stated in the lesson plan, students in the redesigned course more often discussed whether or not the instructional strategy proposed in the LP incorporated children's idea than students in the baseline. For the UAS category, when a children's idea was clearly stated in the lesson plan, students in the redesigned course more often discussed whether or not the assessment strategy proposed in the LP incorporated the children's idea than students in the baseline.

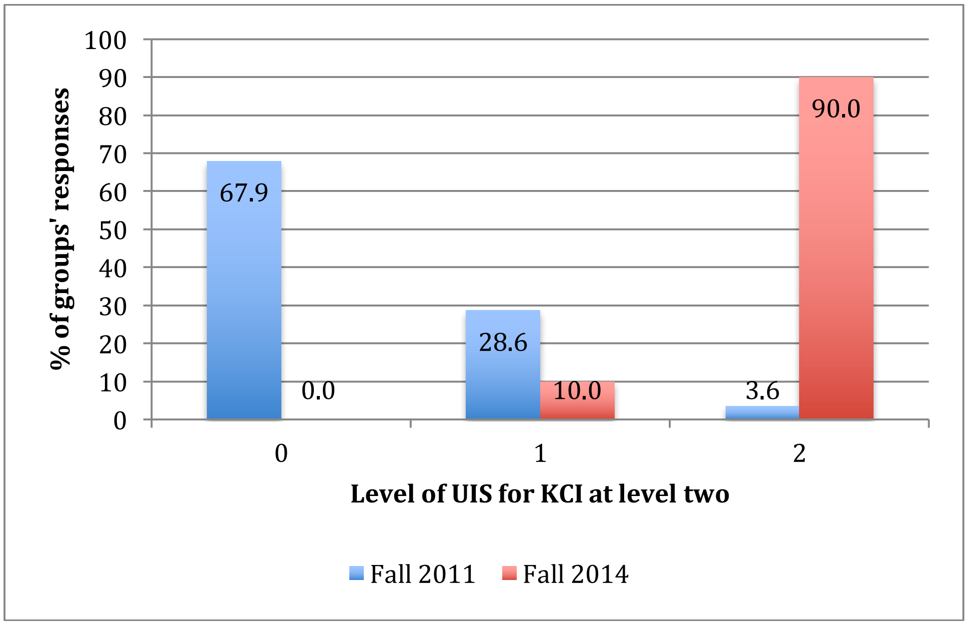


Figure 27. Distribution of the levels of UIS as a function of KCI for the Critiques (KCI = 2).

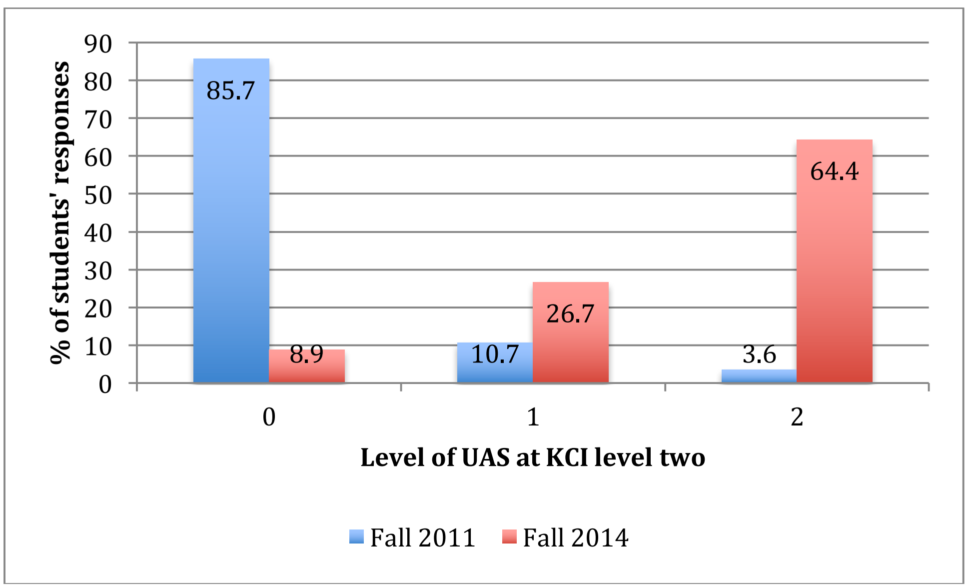


Figure 28. Distribution of the levels of UAS as a function of KCI for the Critiques (KCI = 2).

Micro-Lessons

Figure 29 and 30 show the distribution of students' levels of sophistication of UIS and UAS when controlling for KCI – at level one. Results showed that for the UIS category students' responses across time were more often placed in level one, while for the UAS category students' responses were more often placed in level zero. Although an improvement across time was observed. As students' exposure to the treatment (second cycle of the PLB) increased and they received more feedback on the integration of knowledge of children's ideas into their microteaching, their levels of UIS and UAS improved when a children's idea was present but not clearly stated.

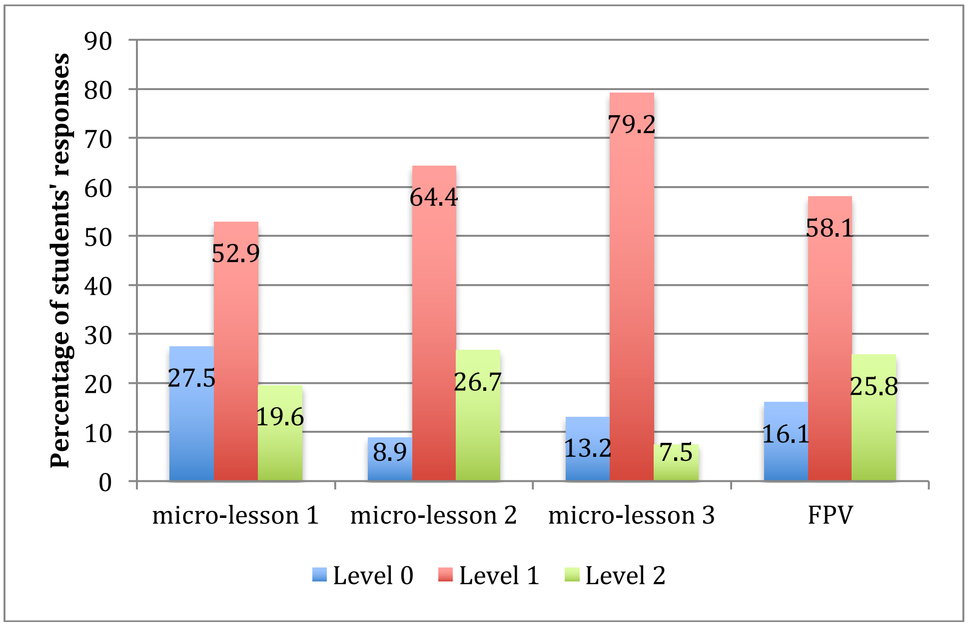


Figure 29. Distribution of the levels of UIS as a function of KCI for the micro-lessons and FPV (KCI = 1).

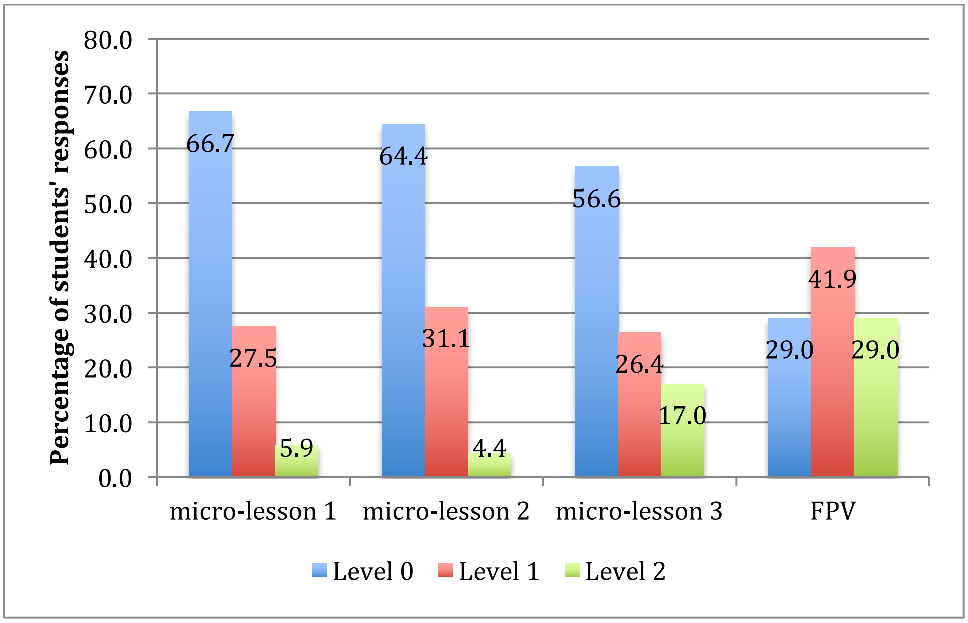


Figure 30. Distribution of the levels of UAS as a function of KCI for the micro-lessons and FPV (KCI = 1).

Figures 31 and 32 show the distribution of students' levels of sophistication of UIS and UAS when controlling for KCI – at level two. Results showed that for the UIS category students' responses across time were more often placed in level one, while for the UAS category students' responses were more often placed in level zero. Although an improvement across time was observed. As students' exposure to the treatment (second cycle of the PLB) increased and they received more feedback on the integration of knowledge of children's ideas into their microteaching, their levels of UIS and UAS improved when a children's idea were clearly stated.

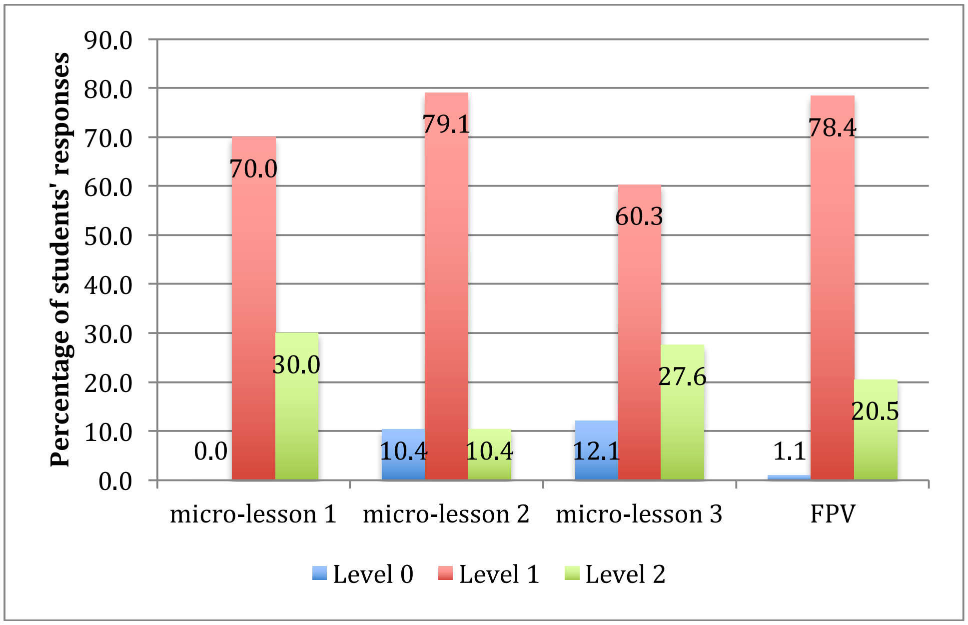


Figure 31. Distribution of the levels of UIS as a function of KCI for the micro-lessons and FPV (KCI = 2).

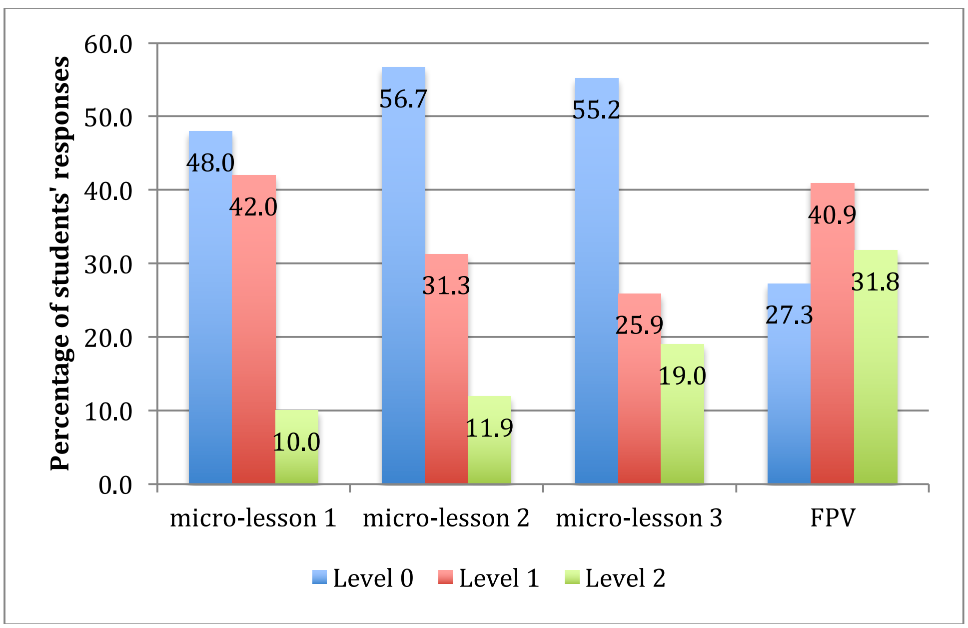


Figure 32. Distribution of the levels of UAS as a function of KCI for the micro-lessons and FPV (KCI = 2).