INFUSING PEDAGOGICAL CONTENT KNOWLEDGE INTO A PHYSICS COURSE FOR FUTURE ELEMENTARY TEACHERS

PROJECT DESCRIPTION

> "*Pre-service elementary teachers should be familiar with current research findings on the teaching/learning process and be able to apply these findings in the classroom. They must also understand that, as reflective practitioners, they have a responsibility to study, use and identify a variety of developmentally appropriate activities that demonstrate different approaches to knowledge construction and application.*"

The proposed project answers the above call put forth in the position paper by the Association of Childhood Education International (ACEI, 1997). We reform an existing course for future elementary teachers – *Concepts of Physics* – to integrate pedagogical content knowledge and metacognitive reflection with the learning of physics concepts. We thus facilitate future elementary teachers to see the relevance of the physics they are learning to their chosen profession. Our efforts address the recommendations of the National Science Teaching Standards (NRC, 1996) and are consistent with decades of research on the preparation of future science teachers.

This project is based on the theoretical construct of Shulman's (1986) *pedagogical content knowledge* (*PCK*) . We develop and implement an instructional model – *pedagogical learning bicycle* (*PLB*) – an adaptation of the currently used 3E (Explore-Explain-Elaborate) learning cycle proposed by Karplus (1974). The latter is currently used in *Concepts of Physics* in an activity-based learning environment to construct an understanding of physics concepts. We extend the 3E learning cycle into a bicycle consisting of two intertwined 3E cycles. The first cycle facilitates learning physics concepts. The second cycle, which builds on the first, facilitates metacognitive reflection (MR), development of pedagogical content knowledge (PCK) and its application to teaching in an elementary science classroom.

Although this project focuses on a particular course at a single university, it can potentially serve as a model for other science content courses for future teachers at other institutions.

GOALS & OBJECTIVES

The overarching goal of this project is to infuse pedagogical knowledge (PCK) and metacognitive reflection (MR) into a physics course for future elementary teachers. To achieve this goal we:

- develop, implement and test units based on the *pedagogical learning bicycle* (*PLB*) in the *Concepts of Physics* course. Specifically, the PLB units provide opportunities for learners to …
    - reflect on their own learning and the learning of elementary school children,
    - become knowledgeable about research on children's ideas of science,
    - develop and critique strategies based on their knowledge of children's learning of science,
- expand the emphasis of the course to include reflection of the pedagogy and its transferability to teaching situations in an elementary school setting.
- develop and adapt strategies to assess students' conceptual learning, attitudes toward science and beliefs about learning and teaching science before and after they have completed the course.
- utilize the services of future elementary teachers who have previously taken *Concepts of Physics* and elementary science methods courses to serve as teaching assistants in the modified course.
- disseminate the results of the project to physics educators elsewhere, with a view to establishing the project as a model that can be emulated to reform similar courses at other institutions.

NEED AND SIGNIFICANCE OF THE PROJECT

This project addresses an important need in the science content preparation of elementary teachers: to foster a connection between learning of science content and reflective teaching practice.

Nearly four decades ago, Lortie (1975) first pointed out the significance of the "apprenticeship of observation" that underscored the impact of teachers' experiences as students in shaping their views about teaching. Other researchers extended this concept to include teachers' beliefs about teacher effectiveness and student interactions (Clark, 1988; Nespor, 1987; Wilson, 1990), as well as their beliefs about new teaching practices (Hollingsworth, 1989; Richardson, 1991). Research (DeBoer, 1991; Donnelan, 1982) has shown that most elementary teachers feel they lack adequate knowledge to teach science. While they may have learned about inquiry-based teaching in science methods courses, their science content courses are taught more traditionally (Hurd, 1983; Stake & Easley, 1978; Tamir, 1983). Therefore, most pre-service teachers believe that inquiry-based science teaching is not possible in a real science classroom.

Science content classes taken by pre-service elementary teachers in most universities across the U.S. are taught in a traditional didactic style. In the last 25 years or so there have been several attempts toward creating curricula that incorporate inquiry-based teaching in physics classes. One of the most widely known curricula is *Physics by Inquiry* (McDermott, 1996) – a set of laboratory materials that emphasize conceptual development and scientific reasoning skills. Students work in collaborative groups with simple equipment and use the results of their inquiry to construct mental models. Another more recent effort is the *Physics for Elementary Teachers* curriculum developed by Goldberg and others (Goldberg, Robinson, & Otero, 2006). The physics content is organized into seven cycles that revolve around the unifying theme of interactions of energy or forces. In addition to enabling future elementary teachers to learn physics content and the nature of science, the curriculum also has specific lessons on helping these future teachers reflect on their own learning through a process of metacognition. Additionally, these future elementary teachers also learn about how their future students, i.e. elementary school children, think and learn about scientific phenomena and engage in the process of inquiry. They also reflect on how their own learning is connected to the learning of these children. Recent research has shown that students' engagement in activities related to learning about learning in which undergraduate students discuss videos of elementary school children learning a science concept can improve the undergraduate students' attitudes about science and beliefs about the nature of science (Harlow, Swanson, Dwyer, & Biachini, 2010).

The *Concepts of Physics* (Zollman, 1990) course at Kansas State University uses activity-based collaborative learning with hands-on experiments with a focus on conceptual understanding. When pre-service teachers take this course they tend to focus solely on the content of the course and do not spend time on metacognitive self-reflection or on thinking about how the pedagogy that was used in the class may be adapted to a future elementary classroom. These issues are supposed to be addressed in a later science methods class. When students take this methods class, about two or three semesters later, they often do not see how the pedagogy and methods learned in this class can be integrated with the science content learned in *Concepts of Physics*. Thus, even when students take science content classes that actively model constructivist pedagogy, they find it difficult to see the value of these classes in their preparation as future elementary teachers (Hurd, 1983). Therefore there is a need for an intervention that more clearly demonstrates the value of *Concepts of Physics* to pre-service elementary teachers' future professional roles. The project is an attempt to create a model that addresses this need.

An important question that must be addressed is – **Why not adopt/adapt existing curricula such as *Physics by Inquiry* (PbI) or *Physics for Elementary Teachers* (PET)?** The reason is that both of these curricula are based on models that work best with smaller class sizes of about 30 students at a time. The *Concepts of Physics* class has an enrollment of 110 students with one instructor and is taught in a lecture-based format. Given this situation and the current financial climate, it is unlikely that a wholesale transformation to a model similar to PbI or PET, both of which require a larger faculty to student ratio, is sustainable at Kansas State University. Therefore the next best solution is to create an instructional model that does not require a large increase in the faculty to student ratio and yet affords several of the benefits of PbI or PET. Furthermore, the instructional model created by this project can potentially be adapted to any large enrollment science course for pre-service elementary teachers at another institution with similar financial constraints and low faculty to student ratios.

RESEARCH BASE & ITS RELEVANCE TO THE PROJECT

Below we present a brief overview of the two areas in research literature relevant to the project.

Knowledge of Pre-Service Elementary Teachers

The traditional model of pre-service elementary science education dates back to the early 1900s and consists primarily of three strands: general education (liberal arts courses), content knowledge (subject-matter courses) and professional knowledge (pedagogy) (Cremin, 1978). Teacher education programs have remained remarkably unchanged over the past several decades (Clark, & Marker, G., 1975; Feiman-Nemser, 1990; Howey, 1983; Gabel, 1994).

In the last three decades researchers have expanded the definition of content (or subject-matter) knowledge in several ways in the context of teacher education. Generally they believe that content knowledge should no longer be strictly defined as knowledge of the subject matter e.g. physics laws and principles. Rather, they argue that content knowledge should include aspects that are also relevant to teaching and learning of the subject matter. For instance, McDiarmid and others (1989) include "flexible matter understanding" – the ability to make connections with the outside world – as an important aspect of content knowledge for teachers. Gregory and McTure (1992) have developed a more interdisciplinary model for content knowledge that they use to teach science to pre-service teachers. Fensham (1992) provides other examples of similar viewpoints.

Shulman (1986) has offered a viewpoint that is most relevant to this project. He has proposed the inclusion of two other kinds of knowledge within the framework of content knowledge: *pedagogical content knowledge* (PCK) and *curricular content knowledge* (CCK). PCK refers specifically to the pedagogy specific to the discipline. CCK refers to setting instructional objectives and designing curriculum in a particular subject area. Shulman (1986) points out that CCK can help teachers integrate a subject vertically through various grade levels and understand it in a context larger than day-to-day teaching. Several curriculum development initiatives such as Project 2061 – Science for All Americans (Rutherford & Ahlgren, 1990) and NSTA's Scope Sequence and Coordination Project have utilized CCK as a guiding construct.

The construct of PCK is particularly relevant to this project because it serves as a bridge between a subject-matter knowledge and pedagogy. PCK includes knowledge about how students learn the discipline, the primary misconceptions and strategies that facilitate students learning of the content. All of these issues, Shulman argues, are not solely pedagogical in nature. Rather they are intrinsically tied to the subject matter. Thus pedagogy and subject matter are inseparable.

Stengel (1992) points out that the construct of PCK was used in Project 30 – a Carnegie Foundation initiative to reform teacher education – that involves faculty from the College of Education as well as subject-matter faculty from departments in the College of Arts and Sciences. More recently Barnet and Hodson (2001) have used this framework to examine teaching views and practices as gleaned from interviews with exemplary science teachers about the ways in which they constructed lessons. He concludes that PCK lends a metacognitive framework that could form the basis for rethinking subject-matter courses taken by pre-service science teachers.

In summary, PCK transcends learning about the discipline. It also includes learning about the pedagogy of a discipline. The inseparability of pedagogy from the subject matter of the discipline is central to our project. The project aims at infusing pedagogy into a physics-content course; therefore *pedagogical content knowledge* is the theoretical framework for the project.

Learning Cycle Revisited – A Metacognitive Learning Cycle

The learning cycle model of instruction developed by Karplus (1974) and others is based on the Piagetian model of intellectual development (Inhelder & Piaget, 1958). Many aspects of the learning cycle such as the three phases of instruction have not changed. The *exploration* phase is based on the ideas of assimilation and disequilibria. In this phase students experience a discrepant event that is specifically designed to create cognitive dissonance by challenging their preconceptions. This experience motivates the students to be more acceptable of alternative conceptions that they construct in the *concept introduction* (or concept construction) phase, which is based on the principle of accommodation i.e.

modifying existing knowledge structures to incorporate new knowledge. Finally, they apply the mental model(s) that they create in this phase to a different situation in the *application* phase that follows.

Several researchers have noted the benefits of the learning cycle. Scharmann (1992) found the learning cycle a useful strategy to address students' misconceptions and promote conceptual change. Marek and Methven (1991) found it to be useful for practicing elementary teachers, whose students developed superior reasoning abilities compared to those who taught using traditional techniques. More recently, Settlage (2000) has successfully used the learning cycle to improve self-efficacy of pre-service teachers.

Over the past two decades, a vast body of research (Baird et al., 1991; Beeth, 1998; Hennessey, 1991, 1993) has shown that true conceptual development also requires students to reflect metacognitively about their learning experiences. This research has led other researchers to consider modifications to the original learning cycle to include opportunities for metacognitive reflection. Good (1989) and Lavoie (1992) added a prediction step in each phase of the learning cycle and found that students became more aware of their misconceptions when they were asked to articulate their predictions. Barman (1997) added an *assessment* phase in which students would explore their misconceptions before the *exploration*, which he called the *investigative* phase.

More recently Blank (2000) has built on Barman's idea to create what she calls the *metacognitive learning cycle*. (MLC) The MLC is the four-phase cycle proposed by Barman (1997), along with a built-in *status check* in each phase (except the *exploration*). The status check involves applying the conditions of Hewson's conceptual change model (Hewson & Hewson, 1988; Hewson & Thorley, 1989; Posner, Strike, Hewson, & Gertzog, 1982) to examine the status of each of the three characteristics (intelligibility, plausibility and fruitfulness) of the science ideas constructed by the learner.

Blank (2000) implemented the MLC model by having students perform a status check of their ideas by asking themselves a series of questions developed by Hennessey (1991, 1993). Students perform this status check first in the *assessment* phase where they explore their preconceptions and later in the *concept introduction* and *concept application* phases as they first develop and later apply their conceptual reasoning. Blank required each of her students to maintain a concept journal where they would record the conditions of their ideas by applying the status check and then revisiting their ideas in a later phase. Blank compared student learning of a group of students using the MLC with that of a control group that used the unmodified learning cycle. She also compared the quality of student dialog between the two groups. Blank found no significant learning gains on content knowledge assessment measures administered directly after instruction, but she found significant differences when the same assessment was delayed. Thus, students who had used the MLC did not necessarily learn more, but rather their deeply rooted knowledge structures were altered as a result of the metacognitive reflection, and therefore they retained what they had learned longer. Blank also found significant differences in the quality of discourse in the two groups. Discussions among students who used the MLC were reported to be "particularly engaging and thoughtful" (Blank, 2000).

The MLC forms an integral part of the theoretical framework of *pedagogical content knowledge* (PCK) on which the proposed modification is based. The MLC is a viable instructional model by which PCK can be learned. The proposed course modification which includes the *pedagogical learning bicycle* (PLB) adapts the metacognitive feature of the MLC.

***CONCEPTS OF PHYSICS*: THE EXISTING COURSE**

Zollman (1990) first developed the *Concepts of Physics* course at Kansas State University to use inquiry and discovery-based learning for future elementary teachers. The course covers most topics in introductory physics – motion (kinematics), force (Newton's Laws), momentum, energy (various forms of energy), heat (forms of heat transfer), thermodynamics, simple circuits (batteries and bulbs) and magnetism. Typically future elementary teachers feel inadequately prepared to teach these concepts because they perceive science to be a collection of a large number of facts that have to be memorized. To address this issue, the course focuses on the process of scientific reasoning rather than on factual knowledge.

The course was funded through a local course improvement program grant from NSF (Grant # SER 79-00507) and first ran in 1978. Most commonly, other courses of this type (Arons, 1976; Fuller, 1980) were taught with small class sizes of 20-30 students with hands-on materials and several interactive engagements. This class, however, typically has an enrollment of about 110 students; therefore it was necessary to design a different kind of course to meet these needs.

The Piagetian (Inhelder & Piaget, 1958 and 1969) model of intellectual development forms the theoretical basis for the course. It consists of 15 weeklong activity-based units. Each unit addresses a particular physics conceptual area (e.g. heat, kinematics, etc.) and is centered on a series of about eight to 10 short hands-on activities that students perform throughout the week in an Activities Center (Zollman, 1974). Lectures meet three times a week on a Monday-Wednesday-Friday schedule while the Activities Center is open to students about 30 hours a week. A teaching assistant facilitates students as they complete hands-on activities, working at their own pace often in small collaborative groups.

The learning cycle model of instruction (Karplus, 1974) is the pedagogical structure of the course. It consists of three different phases of instruction. In the *exploration* phase, which runs from Monday to Wednesday morning, students perform a set of exploration activities in the Activities Center. These activities have a general goal and some instructions, but students are not expected to answer all the questions correctly. Also they are not explicitly told what to do and how to do it. Rather they have to use their prior experience and intuition to explore the physical concept using the equipment available and record their observations on a worksheet. Often students are asked to make predictions based on their understanding. In this phase, students are not penalized for incorrect answers or predictions as long as they have satisfactorily performed the activity and explored the concept as intended. The purpose of the *exploration* is to give all students in the class a shared set of experiences that they later understand based on the concepts that they learn in the next phase.

The *concept introduction* phase is during the Wednesday class lecture. The instructor begins by asking students to describe their experiences by posing questions on a clicker system. To guide the students to an understanding of the model or theory that can explain their observations the *concept introduction* includes expository statements by the instructor explaining students' observations in the *exploration*. The lecture prepares students to apply these concepts in different contexts.

In the *concept application* phase students transfer their learning from the *concept introduction* to new contexts. They return to the Activities Center to make predictions about the outcome of certain situations presented to them. They test their predictions using the equipment. Often the activities they perform in this phase involve specific measurements and a few simple calculations. The focus is on helping students develop skills to transfer their conceptual understanding to new situations.

Students return to the lecture on Friday and again on Monday. The class discussion on Friday centers on the *concept application* activities. Monday's class is also used for the same purpose. Often the class is also used to raise issues that may have arisen in the previous week's learning cycle which could not be addressed based on present knowledge. Thus, Monday's lecture can effectively set the stage for the week's *exploration* activity. No new content knowledge is covered on Monday because that would defeat the purpose of the *exploration* activities that follow.

The Office of Planning and Assessment at Kansas State University conducted an independent evaluation of course when it was first created. They compared student learning in *Concepts of Physics* (treatment) with student learning in a course taught by the same instructor using traditional methods (control). A comparison between student performance on identical final exams taken by the control and treatment courses was used to assess student learning. Questions on the final exam were classified by topic and the type of knowledge needed to answer the question (calculation, conceptual and recall). With the student's GPA used as a covariate in the analysis, the treatment course fared better than the control course in all topical categories. Statistically significant differences were found on questions pertaining to force and energy. Similarly, the treatment course fared better in conceptual and calculation questions. *Concepts of Physics* was clearly a success in enhancing students' conceptual learning.

The instructor described the level of classroom interaction in this course to be greater compared to the traditional large lecture course (Zollman, 1990). Students had all worked on the activities and were interested in trying to understand them; therefore they asked questions during the lecture. Some students complained about the relative lack of direction in the *exploration* activities early in the semester, but later realized their value after completing a few learning cycles. Since its development the course has been taught by Drs. Zollman (Co-P.I.), Rebello (P.I.) and other faculty members in the Physics Department. Overall, faculty members teaching this course have reported similar positive teaching experiences.

WHY MODIFY *CONCEPTS OF PHYSICS*?

As demonstrated by the evaluation above, *Concepts of Physics* met its stated goal of improving students' conceptual understanding of physics vis-à-vis a traditional course. However, there is room for improvement. As described above, one of the common student complaints is the lack of appreciation of the value of unguided explorations. Students who have taken science in high school are often used to cookbook lab experiments telling them exactly what to do and even what to expect. They do not see the value of more open-ended experiments. This problem is of particular concern because it indicates that future elementary teachers do not see this class as being relevant to their professional roles as teachers. These findings are consistent with research (Morrisey, 1981; Shrigley, 1974; Sunal, 1982) which has shown that most pre-service elementary teachers' attitudes about science may not be directly linked to their attitudes about the teaching of science. Further, research has shown that positive attitudes may not necessarily translate into positive science teaching behaviors (White & Tisher, 1986).

In the current system, a few semesters after completing *Concepts of Physics* the pre-service teachers take an elementary science methods class in the College of Education. This class is supposed to serve as a bridge between the inquiry-based science learning that students experience in *Concepts of Physics* and effective classroom practice of future elementary science teachers. However, research has also shown that student learning is highly situated and that knowledge is essentially compartmentalized (Bransford, Brown, & Cocking, 1999). Students typically find it difficult to integrate concepts across topics in the same course let alone across different semesters and courses. Therefore it is important to create experiences within the context of the science content course that addresses issues pertinent to the teaching of the subject matter. These experiences must be designed in the framework of PCK – the notion that pedagogical knowledge is subject matter and student dependent (Shulman, 1986).

Finally, research has also shown that students are more motivated to devote time and effort to learning if they perceive a future value of what they are learning (White, 1959) or if their knowledge is of value to others (McCombs, 1996; Pintrich & Schunk, 1996). Therefore by addressing pedagogical issues in the context of a subject-matter course, students are more easily able to see how the knowledge acquired in this content course can be useful for them in their future professional roles as teachers.

CONCEPTS OF PHYSICS: PROPOSED MODIFICATION

The modification proposed in this project does <u>*not*</u> involve a complete overhaul of *Concepts of Physics*. The intent of the modifications is to enable the future elementary teachers taking this course to see the connection between their experiences in this course and their future roles in an elementary classroom.

Main Elements

The main elements of the modified *Concepts of Physics* course are as follows:

- Expand the course goals to focus not only on constructing content knowledge (CK) but also constructing pedagogical content knowledge (PCK).
- Include activities in which future elementary teachers:
  - observe and discuss videos of children learning science and seek patterns in how children create and express their ideas about their everyday experiences;

  - read and reflect on research literature on children's ideas of science, what difficulties they face and how they learn science; and
  - apply their understanding of physics content, children's ideas of science and age-appropriate pedagogical strategies to develop and critique lesson plans targeted at facilitating children in an elementary classroom learn physical science.
- Utilize formative and summative assessments of student learning that assess both their conceptual knowledge of physics as well as their pedagogical content knowledge.

Physics Content

To support these goals within a four-credit course, we reduce the physics content coverage and use the time to facilitate student learning about pedagogy. This change is unavoidable, given the finite time available. Rather than cover a large number of topics divided into 15 weeklong learning cycles, we focus on half as many topics. We are guided by the Kansas Curricular Standards for Science (http://www.ksde.org/Default.aspx?tabid=144) as we make our choice about the topics that should be covered. The table below shows the Standards for grades K-7 (elementary and early middle school) and the corresponding units we plan to cover in *Concepts of Physics*. Clearly the units in the course cover the material at a greater depth than the coverage in a Grade K-7 classroom. In order to be able to teach this science content, teachers must clearly understand the material at a greater depth than their future elementary school students.

	KS Science Standard (Physical Science)	**Instructional units in *Concepts of Physics***
Grades K-4	• Properties of objects • Position & motion of objects; forces • Sound • Electricity & magnetism	➢ Properties of matter (mass, volume, phase) ➢ Motion (displacement, velocity, acceleration) ➢ Forces (Newton's Laws) ➢ Energy (forms and transfer of energy) ➢ Sound (vibrations and waves) ➢ Electricity (simple circuits) ➢ Magnetism (attraction and repulsion)
Grades 5-7	• Measuring, describing properties of matter • Changes in properties of matter • Motions & forces • Transfer of energy	

Development of PCK

The seven units in *Concepts of Physics* shown in the table above form the core content of the course. Students' development of PCK is facilitated through activities that fall into three major categories.

Metacognitive Reflection

After constructing an understanding of the concepts, the first step toward developing PCK is engaging in the process of metacognitive reflection (MR) about the way in which one's own understanding was constructed. To be able to understand how their future students might construct their understanding, these future elementary teachers must first learn to reflect on how they themselves constructed their understandings.

Future elementary teachers engage in MR about the nature of what they have learned and explore their own epistemological learning. Below we describe a set of guiding questions that facilitate MR. We have also indicated how these questions relate to Hewson's model of conceptual development (Hewson & Hewson, 1988) and Barman's (1997) ideas of metacognitive assessment.

- What mental resources, past experiences or knowledge did you draw on while trying to understand the topics or concepts? [Metacognitive assessment of past knowledge and experiences]
- What conceptual difficulties, if any, did you or your partners experience while attempting to understand the topic? How can these difficulties be avoided by future students? [Metacognitive assessment of the learning process]

- What strategic difficulties (e.g. operational difficulties with the experimental setup or instructions) did you experience while performing the experiments in the Activities Center and what modifications can you suggest? [Metacognitive assessment of the learning tools and strategies]
- How does the topic or concept relate to your real life experiences or to topics that you may have studied in other classes? [Hewson's status of "plausibility" of the idea]
- You are provided a hypothetical situation in which your partner is having difficulty understanding a particular concept. How would you enable your partner to overcome this difficulty? Suggest a simple activity or direct your partner to a learning resource that your partner may find helpful in overcoming her/his difficulties? [Hewson's status of "intelligibility" of the idea]
- If you were asked to teach this topic to a group of elementary school children, which of the activities that you used may be adapted for this purpose? What adaptations might be necessary? [Hewson's status of "fruitfulness" of the idea] This final question is probed in greater depth later on as described below.

At times, we alert the future elementary teachers to resources in physics education research literature on the web or in the library and ask them to relate the reflections of their learning experiences to published research results about students' difficulties, misconceptions and mental models.

Constructing understanding of how children reason about physical phenomena

Having reflected on their own learning through MR, the future elementary teachers proceed to develop an understanding of how children in elementary school learn physical science. In this process they rely primarily on two resources:

- Videos of children learning and talking about physical phenomena: The PET curriculum utilizes videos of children learning science to facilitate future elementary teachers to build their understandings of how children begin to reason about their everyday experiences in the physical world. For instance, one such video shows children on a playground kicking a soccer ball. The teacher asks them to describe what happens (the soccer ball rolls a certain distance and slows down to a stop) and then explain in their own words what happens. Viewing such a video provides future elementary teachers in *Concepts of Physics* an opportunity to reflect on the ideas and physical intuition that kids of that age might bring to bear as they explain physical phenomena. It also provides a context for future elementary teachers to discuss the ideas – both scientifically correct and incorrect – that the children bring to the classroom and how appropriate learning experiences ought to be designed to build on and perhaps refine these naïve intuitions. Videos of children learning science are obtained with permission from publishers of PET and from other sources.
- Readings from the literature on children's ideas of science: There is a vast body of research literature on how children think about various physical phenomena. One such well known work is the book by Driver and co-workers titled *Children's Ideas in Science*. (Driver, Guesne, & Tiberghien, 1985) More recent research is published in research journals such as IJSE and JRST and pedagogical strategies are published in practitioner journals such as Science & Children and The Physics Teacher.

Developing strategies for facilitating children's learning in physical science

After learning the physics content and constructing an understanding of how children at the elementary school level might reason about physical phenomena, the next set of activities enable the future elementary teachers in *Concepts of Physics* to develop strategies to facilitate children's learning of physical science. The future elementary teachers are given a specific goal: **Develop a lesson plan to enable children in a grade 'N'** (where N is between 2 and 7) **learn 'X'** (where X is a particular physical science concept, e.g. Newton's law of inertia).

To scaffold the progress of future elementary teachers toward this goal, they have to integrate all that they had learned previously: Their own understanding of the content and how they learned it as well as how children of a particular age think about phenomena related to that concept. To scaffold this process of integration, future elementary teachers are urged to address the following questions:

- What do the Kansas and National Standards mandate about learning this particular concept at this grade level? Future elementary teachers refer to specific benchmarks of understandings that are deemed appropriate for children at this grade level for this specific content topic.
- What intuitions can we expect children at this grade level to have about the physical phenomena associated with this concept? Future elementary teachers reflect on what they had learned from viewing the videos of children as well as readings of research literature on children's ideas.
- What existing strategies have been used to help children learn this concept, and in what way can they be adapted and improved based on our understandings of children's ideas? Future elementary teachers research lesson plans that have been developed by others (e.g. those found on the Web) and discuss how they can be adapted for their particular hypothetical class. Specifically, they critique and modify what they find through the lens of their own understanding of the content, appropriateness of the State and National standards and knowledge about children's ideas of these physical phenomena.

The questions above guide students through the process of development of a mock lesson plan for facilitating children's learning of a specific physical science concept. The future elementary teachers work in groups of up to four to prepare their lesson plan and post it online for sharing with the rest of the class. They also critique the lesson plans presented by at least two other groups that are randomly assigned to them. A criteria-based rubric for critiquing lesson plans are provided to the students for critiquing each other's plans. This rubric is based heavily on whether both CK and PCK are addressed in the creation of the plan.

In addition to creating a lesson plan and critiquing plans of other groups, students also have to present their plan to the rest of the class. A random group of students is selected at the end of each two-week unit to present their lesson plan (more details in the next section). We also partner with a local elementary school that has an active afterschool science club in which the future elementary teachers can implement their plans. The PI (Rebello) has worked with a local elementary school in 2006 to set up an afterschool science club. Part of the afterschool science club involved lessons presented by future elementary teachers. These lessons were created as part of a class project in *Concepts of Physics*. We explore the possibility of reviving that partnership with the elementary school for this project.

Model of Instruction – The *Pedagogical Learning Bicycle* (PLB)

Each of the seven content units and the associated PCK described above are learned through an integrated model that we call the *Pedagogical Learning Bicycle* (PLB), which takes two weeks of class time. The PLB consists of two interconnected 3E learning cycles with a metacognitive reflection (MR) bridge.

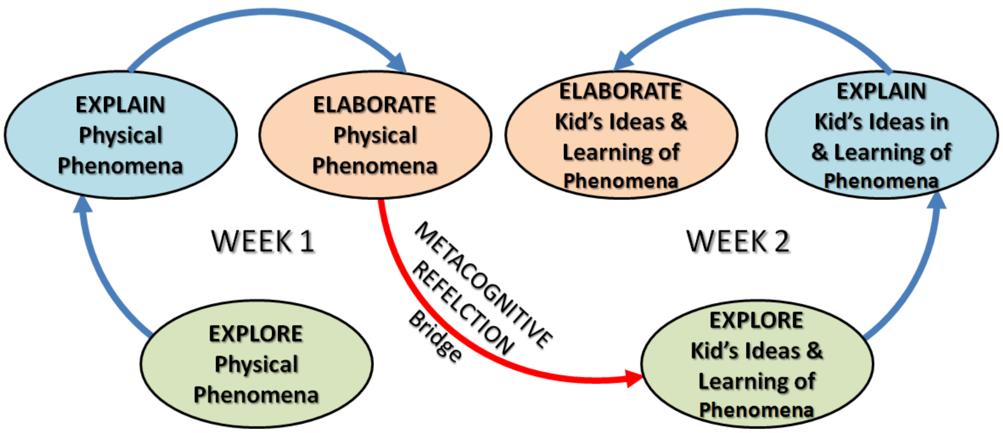
- ***Constructing Conceptual Content Knowledge* (CCK) *of the Physical Phenomena***: The first week of the PLB is identical to the existing *Concepts of Physics* course. It uses a 3E learning cycle to facilitate students to construct their understanding of the relevant physical science content.
  - Week 1: *Exploring physical phenomena* (Activities Center from Monday to Wednesday AM) Students work in groups of three to four to perform activities to explore physical phenomena. They are provided a list of guiding questions and some guidelines on using the equipment but no explicit instructions. Students are not expected to answer the questions or predict physical phenomena correctly. Rather, they use their prior experience and intuition to explore and record the physical phenomena using the equipment available. This provides all students in the class with a shared set of experiences that they later understand based on the concepts they learn in the next phase.
  - Week 1: *Explaining physical phenomena* (lecture on Wednesday) The instructor begins by asking students to describe their experiences in the *Exploration* by posing questions on a clicker system. Using strategies such as peer instruction (Mazur, 1997) the instructor guides the students to an understanding of the model or theory that can explain their previous observations in the *exploration*. The lecture prepares students to apply these concepts in different contexts.
  - Week 1: *Elaborating physical phenomena* (Activities Center from Wednesday to Friday AM and lecture on Friday) Students work in groups to apply their conceptual understandings to make and

test predictions about the outcome of certain situations. Often they perform specific measurements and simple calculations. The focus is on helping students develop skills to transfer their conceptual understanding to new situations. The Friday lecture helps students resolve issues that remain unresolved after they completed the *elaboration* activities in the Activities Center.

- ***Metacognitve Reflection (MR) Bridge*** (Homework over the weekend and lecture on Monday): After students have completed the 3E learning cycle that focused on learning the physical science concepts they address a list of guiding questions online that facilitate them to reflect on their own learning. As described previously, the questions are consistent with Hewson's model of conceptual development (Hewson, 1988; Hewson & Thorley, 1989) and Barman's (1997) ideas of metacognitive assessment. The Monday lecture in the second week is dedicated to helping students share their reflections. The instructor reviews the online responses provided by students to the MR guiding questions prior to the class. Based on these responses, the instructor asks students to share their responses to some commonly expressed reflections. The goal of the MR activities is to serve as a bridge between CK and PCK. Only when students have reflected on their own learning and those of their peers can they even begin to think about the learning of their future students.
- ***Constructing Pedagogical Content Knowledge* (PCK)**: The second week of the PLB is dedicated to learning about children's intuitive ideas about the physical phenomena. The goal is to integrate this knowledge with their own CK and MR to design age-appropriate developmental experiences for elementary school children aimed at facilitating their learning of the relevant physical science concepts. Similar to the week 1 activities, week 2 also uses a 3E learning cycle to facilitate students to construct their PCK.
    - Week 2: *Exploring children's understanding & learning of science* (Activities Center – Monday to Wednesday AM) The goal of this phase is for future elementary teachers to be exposed to the ways in which children talk about everyday physical phenomena and the ideas and intuitions that they bring to bear upon the learning of science. Students work in groups to view and discuss videos of children talking about physical phenomena both inside and outside of a science classroom. They are asked to respond to a set of guiding questions that ask them to describe what they see as well as hypothesize about the underlying mental models that children might be using. We borrow, with permission, videos from the PET curriculum and also explore other sources for such videos.
    - Week 2: *Explaining children's understanding & learning of science* (lecture on Wednesday) The goal of this phase is for future elementary teachers to become familiar with research literature on children's understanding of physical science and to learn to look at classroom situations such as those they have seen in the video through the lens of research on children's understandings of science. The instructor begins by asking students to describe their reactions to the videos of children. Then the instructor provides students a brief overview of the research literature on the topic and asks students to reflect on their observations from children's videos in light of the research literature overview just presented.
    - Week 2: *Elaborating Children's Understanding & Learning of Science* (Activities Center from Wednesday – Friday, homework over the weekend, and lectures on Friday and Monday) The goal of this phase is for the future elementary teachers to first tie together their understandings of the physical science concepts (i.e. their CK), reflections on the ways in which they themselves learn (i.e. their MR), as well as their understanding of children's ideas and learning of science (i.e. their PCK). To facilitate future elementary teachers to integrate these understandings, they are provided with a specific goal: **Develop a lesson plan to enable children in a grade 'N'** (where N is between 2 and 7) **learn 'X'** (where X is a particular physical science concept e.g. Newton's law of inertia). They are expected to research the internet for existing teaching strategies, but also critique and adapt these strategies to specifically address children's ideas and physical intuitions that they have learned about through watching videos and reading the research literature on the subject. After posting their plan on the course website, they are asked to critique plans posted by at least two other groups. During the lecture on Friday, the instructor provides responses to

specific questions and suggestions that students might have about their ongoing lesson plans, which are due on Saturday night to allow for students to critique each other's plans on Sunday. Finally, during the lecture on Monday, pre-selected groups of students present their lesson plans to the entire class.

The *Pedagogical Learning Bicycle* (PLB) model of instruction is shown below. Each week uses a 3E learning cycle, with the first week focusing on construction of CK and the second week focusing on PCK. The MR bridge facilitates a transition from learning the science concepts to learning how these concepts might be taught in an elementary science classroom.



Learning Assessments

The assessments of learning must match the course goals. In addition to the assessments of physical science CK the assessments would also provide the instructor and students feedback about their PCK. The following assessments are used in the modified course.

Formative assessments are used to assess future teacher's knowledge as it develops. These include guiding questions that help focus their observations in the *exploration* and *elaboration* phases, clicker questions in the *explanation* phase in both weeks of the PLB. Additionally, responses to the online MR guiding questions provide insights into the ways in which future teachers are developing their understanding in this course.

Summative assessments are used at the end of each unit. These include the lesson plans that each group of students are expected to create collaboratively, To establish individual accountability, all students in a group are expected to create their own lesson plan, but any one of the plans in graded and the grade is applied to each person in the entire group. Additionally, individual critiques of each other's lessons plans provided by the students are also graded to assess their understanding of CK and PCK. Additionally, assessments such as tests and a final exam include questions related to both PCK and CK.

Teaching Assistants

The Activities Center is operational for about 30 hours each week. This provides ample opportunity for all 110 students in the class to drop by in small groups at their own convenience to complete the *exploration* and *elaboration* activities, each taking at most one hour of their time. The Activities Center is managed by a teaching assistant (TA) at all times. In all three TAs each work for 10 hours each to manage the Activities Center.

The TAs for this course are selected from among future elementary teachers who have taken the class previously and have since completed the elementary science methods classes. Future elementary teachers in this category, who are concentrating in science teaching, typically need to complete three credits worth of Independent Study in the sciences. Three such future elementary teachers are selected each semester. To earn their Independent Study course credits, they serve as TAs for the course. They are trained to use strategies to facilitate student learning without directly answering their questions, rather helping them figure out the answers to their questions by themselves.

PROJECT EVALUATION

Dr. Jacqueline D. Spears, Professor in the College of Education and Director of Science Education at KSU guides the evaluation. Dr. Spears advises the team in developing a diverse set of assessment tools that are appropriate for various facets of understanding. These assessments guide the modification of the instructional materials after each implementation. The formative and summative aspects of the evaluation are discussed separately below.

Formative Evaluation – Does the Project Implementation Work Here?

The formative evaluation of the project addresses three sets of issues as the project develops.

- The first set of issues pertains to the goals of the project – facilitating future elementary teachers to develop their skills of metacognitive reflection (MR) and pedagogical content knowledge (PCK).
    - To what extent are the guiding questions provided to the future elementary teachers in the online homework activities able to facilitate the MR of their learning of the content?
    - To what extent does the scaffolding provided to the students enable them to develop viable lesson plans that demonstrate that they have acquired the expected PCK?

  The assessments of student learning within the course provide the data to answer these questions. Additionally, the evaluator conducts interviews with 10 randomly selected students in the course.
- The second set of issues pertains to changes in students' attitudes and beliefs toward science due to the changes made in the project
    - What views do these pre-service teachers have about science as they enter the course and how do they change as they progress through the course? The Views About Sciences Survey – VASS (Halloun, 1997) is used.
    - What epistemological beliefs about learning science do these pre-service teachers have as they enter the course and how do they change as they progress through the course? The Epistemological Beliefs Assessment for Physical Science – EBAPS (Elby, 2001) is used.
- The third issue pertains to the management and operation of the project. What are the nature and quality of interactions that occur between members of the project staff from different disciplines as they collaboratively plan and implement the project? To answer this question, the evaluator conducts interviews with each member of the project staff as well as sits in on project meetings.

Summative Evaluation – Can the Project Implementation Work Elsewhere?

This project is not merely a local course enhancement. Rather one of the main goals of the project is to create a model of curriculum reform that can be applied elsewhere. The summative evaluation focuses more broadly on assessing the project as an instructional model that can be used to infuse MR and PCK in science-content courses taken by pre-service elementary education majors. The summative evaluation seeks to answer the following broad questions:

- Are there any special features about our students or other aspects of the course that may have assisted this process in addition to the activities and instructional materials used in this course? If so, what are they and what would be the impact of implementing the project with other students or in courses that do not share these features?
- What barriers, if any, exist to the kinds of collaboration between education faculty, science-content faculty and in-service teachers that is required of this type of endeavor? Did our project overcome these barriers and how may these lessons be applied elsewhere?
- How do we sustain the collaboration and efforts spawned by this project beyond the grant period? What mechanisms are needed to apply the ideas of this project toward systemic change initiatives pertaining to the education of pre-service elementary teachers?

The tools for summative evaluation largely constitute interviews with people who were involved in the project or who may be affected by it or similar initiatives elsewhere: science-methods faculty in the College of Education and science-content faculty involved in teaching or developing courses taken by elementary teachers and administrators. The evaluator attempts to ascertain the level of support among these groups of individuals for similar endeavors elsewhere.

DISSEMINATION

The project is disseminated through several channels. 1) Talks and posters at conferences such as AAPT, NSTA, NARST and AETS. 2) Journal articles highlighting specific issues pertaining to our project such as results of the implementations on student learning and attitudes. 3) An interactive Web site describes the project, the underlying educational philosophy and the impressions of students and in-service teachers participating in the project. 4) Outreach to science education faculty and science-content faculty who are in direct contact with pre-service teachers. We believe that this client group might be worth exploring because of their influence over the teaching practices of new teachers.

PROJECT OBJECTIVES & MEASURABLE OUTCOMES

Below we summarize the project objectives and the expected measurable outcomes.

Project Objectives	Expected Measurable Outcomes
Infuse MR in the *Concepts of Physics* course for future elementary teachers.	Students are able to clearly articulate (i) the resources, experiences that they bring to bear and difficulties they encounter in learning science and (ii) strategies that they or their peers might use to learn science.
Infuse PCK in the *Concepts of Physics* course for future elementary teachers.	Students are able to *create* and *critique* age-appropriate l*esson plans* that are (i) are based on the science content they learned in this class, (ii) are consistent with State and National Standards and (iii) demonstrate an awareness of children's ideas of physical science and the ways they learn science.
Improve future elementary teachers' views about science and epistemological beliefs about learning and teaching science.	Students demonstrate (i) pre/post improvement of at least one standard deviation on VASS and EBAPS and (ii) statistically significantly larger number of future elementary teachers graduating choose to concentrate in science.

PROJECT MANAGEMENT

Timeline

The *Concepts of Physics* course is offered only in the fall semester. So, the first implementation is in fall 2012. A start date of January 1, 2012 is requested to allow for a six-month planning period. The 36 month duration of the project allows for three implementations, so that we can make revisions in the each implementation based on evaluation of the previous implementation. The timeline is below.

Project Activities	Spring 2012	Sum 2012	Fall 2012	Spring 2013	Sum 2013	Fall 2013	Spring 2014	Sum 2014	Fall 2014
Start project planning	X								
Develop materials for 1st implementation	X	X							
1st implementation: Collect data			X						
Analyze data from 1st implementation			X	X					
Present 1st implementation results				X	X				
Revisions for 2nd implementation				X	X				
2nd implementation: Collect data						X			
Analyze data from 2nd implementation						X	X		
Present 2nd implementation results							X	X	
Revisions for 3rd implementation							X	X	
3rd implementation: Collect data									X
Analyze data from 3rd implementation									X
Prepare Final Report									X

Project Staff

Dr. N. Sanjay Rebello (P.I.), Associate Professor of Physics, has 12 years experience in curriculum development and physics education research. He has worked on several projects involved in creating instructional materials that include hands-on activities, text and award-winning educational software that targeted high school and introductory non-science undergraduates. His research interests have focused on teaching and learning of physics at the introductory undergraduate level including the development of a software response system to facilitate peer interaction in *Concepts of Physics*. Dr. Rebello has overall responsibility for the management of the project. His responsibilities include collaborating with the co-PIs in the overall administration of the project including (i) developing the instructional interventions, (ii) implementing the instructional material interventions in the classrooms and (iii) supervising the graduate student and project assistant in all aspects of their work.

Dr. Kimberly Staples (Co-P.I.), Associate Professor of Education, currently teaches the elementary methods of science course and supervises clinical experiences for elementary/middle school pre-service teachers. Dr. Staples assists the PI in all aspects of the project. Her expertise with future elementary teachers is especially beneficial in the design of pedagogical interventions including activities that help students see the relevance of the course content in their future roles as elementary science teachers. She also provides expertise in helping the PI relate the subject matter and activities in this course to the Elementary Science Methods course in the College of Education that she teaches for future elementary science teachers.

Dr. Dean Zollman (Co-P.I.), Distinguished Professor of Physics and University Teaching Scholar, has four decades experience in curriculum development and physics education research. He has won numerous national awards and international acclaim for his pioneering work in this field. He was also the developer of the original *Concepts of Physics* course. In addition to his overall mastery of the field of physics education research, Dr. Zollman's expertise from having created and taught the course over several decades is especially beneficial in deciding how to modify the existing course structure.

Dr. Jacqueline D. Spears (Internal Evaluator), Professor of Education and Director of the Science Education Center at KSU, assists the project team in the formative and summative evaluation of the grant including data collection, analysis and creation of annual and final project reports for NSF.

Dr. Spears has extensive experience in project evaluation. She has worked with the Elementary Education and Geology departments to track the effect of modifications in a Geology class taken by Elementary Education majors and with the Women in Science and Engineering Program to develop and assess a new course on *Women in Science*. She has also worked with rural schools in south central Washington and northern Arizona in integrating school reforms to address ethnic diversity. Dr. Spears' diverse experience is invaluable as the formative evaluator for the project. She was also involved in the initial development of *Concepts of Physics* with Dr. Zollman.

Project Assistant plays an integral role in the project in several ways including (i) proofreading written materials created for the project, (ii) transcribing and coding interview data, (iii) organizing data and assisting in the statistical analysis of these data, (iv) managing resources on the web for dissemination of the project results; (v) organizing travel to conferences and (vi) taking full responsibility for monitoring the budget of the project, ordering supplies, and providing general support for the project.

Graduate Assistant: who is completing a doctoral program in physics education research with Dr. Rebello, is employed 50% of the time to work on this project as a graduate research assistant. This individual assists the project team with (i) developing and designing the materials for use in the classroom, (ii) collecting data on the effectiveness of the materials and (iii) creating publishable papers and presenting talks to disseminate the project. The masters thesis or doctoral dissertation of this student focuses on the assessment of student MR and PCK in the project.

RESULTS FROM PRIOR NSF SUPPORT

REC 0816207 $999,955 09/01/2008 – 08/31/2011 P.I. Rebello

Investigating trajectories of learning & transfer of problem solving expertise from mathematics to physics to engineering

Main Findings: This project is a step in creating a knowledge base on the evolution of students' problem solving skills as they progress from mathematics to physics to engineering courses in the undergraduate curriculum. Our results indicate that in all three disciplines students are able to master procedural knowledge. However, they do not necessarily develop a deep conceptual understanding. This issue pervades all three disciplines. In mathematics, the students have difficulty gaining conceptual understanding beyond the action and process levels of a mathematical concept. In other words, students, even after three semester of calculus do not develop an 'object' or 'schema' level understanding of mathematical concepts as per the APOS framework (Dubinsky & Harel, 1992). Students may pass the courses by mastering the procedures without mastering the concepts of mathematics and learning how to transfer them to different situations (Bennett, Moore, & Nguyen, 2011). In physics, students can 'crunch through' the math, but they have difficulty with the physical interpretations of mathematical notations and operations. In particular, we see improvement in students' understandings of integral as an area underneath a curve, however few students display an understanding of integral as a process of accumulation (Nguyen & Rebello, 2011a; Nguyen & Rebello, 2011b). Similarly, students also struggle with the use of graphs in physics sense making (Gire, Nguyen, & Rebello, 2011). Finally, when students move into engineering they appear to have a misdirected understanding of 'area under the curve,' properties of functions, time shifts and other concepts that they appear to have had a clear understanding of in their mathematics class (Chen, Warren, Nguyen, Rebello, & Bennett, 2011).

One key issue is that students seem to be much more adept at applying graphical information to accumulation problems posed during mathematical interviews than they are during physics or engineering interviews. In particular, we have found problems that are mathematically identical where students can do the problem in the context of mathematics but are unable to solve the same problem when posed in the context of physics or engineering. The issue however, is not that students have difficulty recalling concepts. Our interviews indicate that they can recall the mathematical concepts quite easily. The issue is deeper – they have difficulty activating the right conceptual resources within the contexts of the physics or engineering problem. In other words, they appear to have learned the math concepts insofar as applying them to problems in a math course, but later when they transition to a physics or engineering course, they need considerable scaffolding to do so.

In addition to investigating students' difficulties with problem solving and transfer in these three courses, we have also investigated the use of instructional strategies to address students' difficulties with activating the mathematical concept in the context of physics and engineering. In the focus group interviews in physics we have created several collections of problems and hints that show some preliminary success in helping students solve problems in multiple representations. Each collection combines abstract mathematical scaffolding, student evaluation of different lines of reasoning and student creation of complex problems. Using a treatment group, control group and pre-post quasi-experimental design we have shown robust improvements in students skills of transferring mathematical concepts to physics problems (Nguyen, Gire, & Rebello, 2010). We have also developed online learning modules in engineering to help students with their conceptual difficulties. We found significant correlations between module scores, grades on written examinations and performance in previous mathematics courses have demonstrated variable clarity, but qualitative assessments of the technology-facilitated environment point to a clear increase in student learning and engagement (Chen & Warren, 2011).

Research Output & Human Capacity Development: Overall, the project has advanced the state of knowledge of conceptual difficulties that students face as they attempt to transfer their knowledge of mathematics to problem solving in physics and engineering. The project has led to 15 peer reviewed publications and 20 talks at conferences. Two graduate students are completing Ph.D.s in Mathematics Education and Physics Education based on their work completed on this project.