Reform in Entry-Level Undergraduate Science Coursework: Impacts on Pre- and In-Service K-6 Teachers in a National Sample

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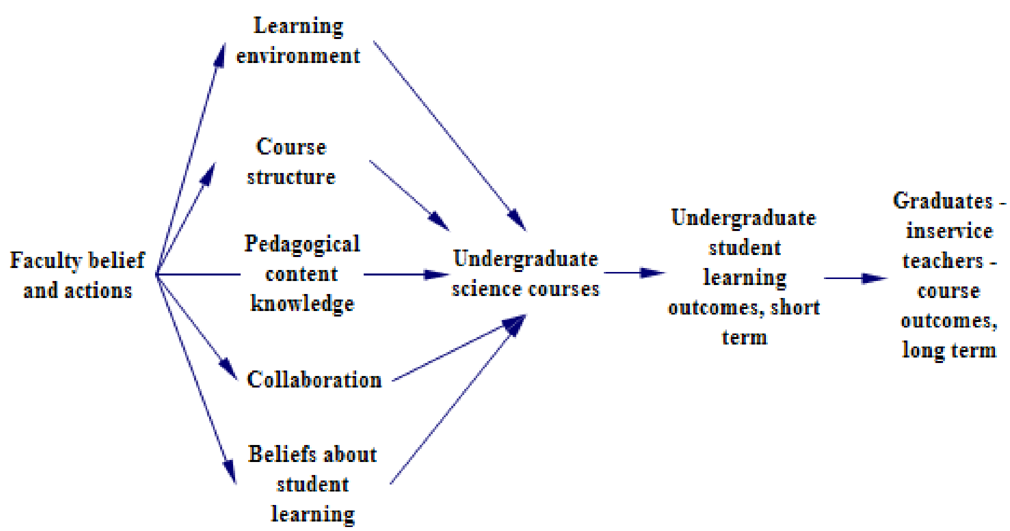
Abstract

The multi-year NSF supported-National Study of Education in Undergraduate Science is a project on critical needs in teaching undergraduate science to diverse majors with an emphasis on preparation and long-term development of pre-service K-6 teachers of science. The impact of undergraduate standards-based, reformed entry-level science courses as compared to traditional coursework is the focus. Reformed science courses were analyzed in a professional development impact design model with a national sample of 19 reformed and comparison undergraduate science courses from a national population of 103 diverse institutions stratified by institutional type. Quantitative and qualitative data were analyzed using comparative and relational studies of the impact design model. Conclusions relate to: evidence and effects of short-term impacts on all undergraduates and long-term effects on matriculated in-service teachers in science teaching, identification of characteristics of reform courses producing significant impacts, and identification of faculty characteristics. Results are reported from a review and synthesis of the research literature, national survey of 103 reformed undergraduate science courses, focus group interviews, individual interviews, teaching observations, and multiple instruments.

Reform in Entry-Level Undergraduate Science Coursework: Impacts on Pre- and In-Service K-6 Teachers in a National Sample

Higher education faculty are under pressure to create effective science teaching to address recommendations found in national reports over the past 30 years. The National Study of Education in Undergraduate Science (NSEUS) project focuses on an examination of critical undergraduate science course characteristics and variations in teaching science content to undergraduates with diverse majors. The NSEUS study is administered by a consortium of universities: the University of Alabama, Kansas State University, and San Diego State University. The goal of the on-going national multiyear study is to investigate the impact of undergraduate course reform on student short-term learning outcomes for all majors while focusing on the long term outcomes of a specific group, pre-service, undergraduate, inservice elementary teachers of science. The long term study focus represents the quality of the developmental pipeline of effective STEM teachers of science.

The research model for this study links beliefs, perceptions, experiences, and actions to the professional knowledge of the course instructor. Such professional knowledge includes pedagogical content knowledge with abilities in planning, implementing, and conducting an undergraduate science course. . Undergraduate students experience the instructor's demonstration of pedagogical content knowledge and beliefs about student learning as exemplified in the courses' learning environment, content structure, and organization. Undergraduate students use these experiences to construct their perspectives of the overall character and nature of the learning structure and teaching actions in the course. As a result of these cumulative experiences, in a general sense, long-term learning outcomes of students can be predicted. Such long-term learning outcomes include perceptions, beliefs, and achievement. These long-term outcomes can evolve from short-term predispositions established during a course, for example, the perception of what constitutes science learning and the nature of science. The research model suggests that pre-service teacher candidates' predispositions, perceptual understandings, and science pedagogical content knowledge as demonstrated in their own in-service teaching of science, will show such long-term outcomes. See Figure 1.



The data and findings in this current research report focus on faculty teaching entry level undergraduate science courses and their graduated students who are now in-service teachers involved with teaching science in elementary school classrooms. The current study addresses four National Science Education Standards (National Research Council [NRC], 1996, pp 28ff and Siebert, & McIntosh, 2001) assumptions; what students learn is greatly influenced by how they are taught, the actions of teachers are deeply influenced by their perceptions of science as an enterprise and as a subject to be taught and learned, student understanding is actively constructed through individual and social processes, and actions of teachers are deeply influenced by their understanding of and relationships with students.

Science teaching requires specialized knowledge that is refined by teachers over time and through extensive experience (Loughran, Gunstone, Berry, Milroy, & Mulhall, 2000). We should expect to see differences among faculty instructors of science in our undergraduate science classrooms based on differences in their knowledge of teaching and its application to actual classrooms with students. Shulman (1987) stated that teacher development of specialized teaching knowledge is even more critical in inquiry-based classrooms. For those undergraduate science courses involved in reforms set in interpreting the guidelines of the National Science Education Standards (p. 7), the knowledge of teaching science, as opposed to a person's knowledge of science, has a great impact on and is particularly important to, the teaching and learning of science by students (Mason, 1999; Gess-Newsome, 1999; Magnusson et al., 1999; Morine-Dershimer, & Kent, 1999; Shulman, 1987).

Effective science teaching is a complex process requiring special knowledge and skills. Lee Shulman (1986) proposed that the study of teachers' cognitive understanding of science content and the connection between this understanding and the instruction provided for students are critical factors in science teaching. The idea of pedagogical content knowledge (PCK) was first used by Shulman to describe the transformation of subject-matter knowledge into forms accessible to the students being taught. Pedagogical content knowledge was envisioned by Shulman as going beyond knowledge of science as a subject or discipline to the dimension of subject matter knowledge useful for teaching. It includes knowledge of the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations: in a word, the ways of representing and formulating the subject that make it comprehensible to others (Shulman, 1986, pp.9). Pedagogical content knowledge also includes an understanding of what makes the learning of specific topics easy or difficult: the conceptions and pre-conceptions students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons (Shulman, 1986, p.9). If those pre-conceptions are misconceptions, which they so often are, then teachers need knowledge of the most effective strategies that are most likely capable of reorganizing the understanding of learners while ensuring meaningful learning**.**

Julie Gess-Newsome (1999) concluded that pedagogical content knowledge is the synthesis of all knowledge needed in order to be an effective science teacher. She described PCK as the only form of knowledge that impacts teaching practice. Pedagogical content knowledge was described by Van Driel, Verloop, and DeVos (1998) as referring to" teachers' interpretations and transformations of subject-matter knowledge in the context of facilitating student learning" (p. 673). Others concluded that PCK was a form of teacher knowledge distinct from other domains (Carlsen, 1999; Magnusson, Krajcik, & Borko, 1999). It was further described as a transformation of different types of knowledge for teaching that include science subject-matter knowledge (Magnusson et al.). Pedagogical content knowledge, thus, includes knowledge of how certain subject concepts, problems, and issues are organized, represented and adapted to diverse abilities of learners and then presented to students. Teachers without knowledge of science or general pedagogical knowledge, typically do poorly in science classrooms and thus have low PCK (Clermont, Borko, & Krajcik, 1994). Because pedagogical content knowledge is both an internal and external construct, it is comprised of "what a teacher knows, what a teacher does, and the reasons for the teacher's actions" in a specific subject area (Baxter & Lederman, 1999, p. 158).

Science pedagogical content knowledge has been explored in a limited number of research studies. Several are summarized here. DeJong, Van Driel, and Verloop (2005) studied the science pedagogical content knowledge of pre-service chemistry teachers as they experienced a postgraduate teacher education program. The results of this qualitative study using discussions and written reports showed that an extensive, one year, training course on teaching chemistry topics, which used particle models for matter, successfully contributed to the development of PCK of the pre-service teachers (DeJong et al., 2005). An earlier study with chemical equilibrium with in-service teachers demonstrated similar results (Van Driel, Verloop, & deVos, 1998).

Elementary education majors from a large university were investigated by Lowery (2002) to examine how pre-service teachers develop pedagogical content knowledge. This qualitative study, based on multiple sources of evidence, showed that confidence in teaching and positive attitudes in teaching science occurred, increasing the pre-service teachers' pedagogical content knowledge increased.

Research on PCK examining the sources, the nature, and the development of various science teaching orientations was conducted by Friedrichsen and Dana (2003, 2005). They used a card-sorting task focusing on clarification of an individual's knowledge and beliefs about teaching and learning science. The set of cards described an instructional strategy, a planning technique, a laboratory activity, or an assessment strategy used in high school biology teaching. This card-sorting task and comments made by the teachers during the sorting process were used with pre-service and practicing teachers at the elementary, middle, and secondary levels. The card sort was found to be a useful tool in identifying teachers' purposes and goals for teaching science. The researchers found that experienced teachers responded differently to the card sort than did pre-service teachers, providing insight into their science pedagogical content knowledge.

Research on experienced and novice physical science/chemistry teachers' pedagogical content knowledge of demonstration teaching was conducted by Clermont et al. (1994). Self-reported "confidence" and "weekly use" in conducting chemical demonstrations in their classrooms were the two criteria used to identify the novice teacher. Videotaped interviews about two basic topics in chemistry were used to determine the extent of the teachers' pedagogical content knowledge. The novice teachers had underdeveloped pedagogical content knowledge in several areas related to the chemical demonstrations. Novices also proposed pedagogically unsound and erroneous demonstrations with less chemistry content. Novice teachers were not as aware of student misconceptions about the demonstration equipment, and rarely discussed sources of student misunderstanding stemming from the demonstrations. Novice teachers differed in the approach taken to promote inquiry-based science learning and did not require students to support their hypotheses. Novices also rarely discussed inaccuracies in students' information. This study showed that PCK could be measured and that there are cognitive differences between teachers with regard to their science PCK.

The lesson preparation method was used in another study to investigate pre-service teachers' pedagogical content knowledge Van Der Valk & Broekman, 1999). Teachers were asked to design an introductory lesson on either temperature and heat for physics or combustion for chemistry for a specific age and level class. An interview instrument was used to investigate five areas of PCK: pupils' prior knowledge, pupil problems, strategies, relevant representations, and student activities. It was concluded that the lesson preparation method, which was mainly verbal, not only displayed the pre-service teachers existing PCK, but also advanced its development.

A two-step instrument to study PCK, Content Representation (CoRe) and Pedagogical and Professional experience Repertoires (PaP-eRs), was developed by Loughran et al. (2000). The instrument was used to describe and determine high school teachers' science pedagogical content knowledge related to specific science concept areas. The researchers concluded that discrimination of levels of PCK could be determined between teachers. Others have used the CoRe and PaP-eRs to examine and report the impact of PCK on science teacher actions in classrooms (Mulhall et al., 2003; Ogletree, 2008).

Building on the existing research base, the National Study of Education in Undergraduate Science (NSEUS) investigated the science pedagogical content knowledge (PCK) of undergraduate faculty who taught undergraduate science courses and of in-service elementary teachers of science who after completing these undergraduate science courses as part of their program, graduated from the institution. These institutions, and one or more of their science courses, were involved in the NASA Opportunities for Visionary Academics (NASA/NOVA) faculty professional development program initiated in 1996. The multifaceted NASA/NOVA program was designed to foster reform in higher education through development and modification of entry-level, undergraduate science courses. A total of 103 institutions were strongly involved in the program over an 11 year period.

Reforms in entry-level undergraduate science courses impact students in higher education. Today's pre-service elementary teacher candidates participate in entry-level science courses as part of their programs. These candidates, in turn, will teach science to their elementary school students, affecting large numbers of children's science education over time. This study addresses the overall problem, "*How do undergraduate entry-level science courses, differing in level of reform, affect student learning outcomes?*" Since significant professional development efforts are underway to enable higher education faculty to reform undergraduate courses, it is important to investigate important variables related to the problem. The study reported here examined a subset of the NSEUS sample, posing the central research question, "*How does the science pedagogical content knowledge of undergraduate science faculty relate to their classroom teaching and to the science pedagogical content knowledge of their students who, upon graduating, are now in-service elementary teachers?*"

Procedure

The research design for this naturalistic study of a subset of the sample was quantitative using qualitative and quantitative data to identify characteristics and relationships in the science pedagogical content knowledge of undergraduate faculty and in-service elementary teachers. The study's population included faculty from a diverse national group of institutions that had undergone reform in one or more of their undergraduate science courses. A sample of faculty from eleven of these institutions was selected to participate in this study.

The sample of eleven higher education institutions was selected from the national sample of 103 institutions in the National Aeronautics and Space Administration's pre-college preparation program, NOVA (NASA Opportunities for Visionary Academics). The NOVA program invited the participation of undergraduate faculty concerned with improving entry level undergraduate science and mathematics courses between the years 1996 to 2006. Through NOVA, reform science courses were developed by collaborative teams of faculty in the sciences and education. Participation in NOVA included opportunities for, and commitment to, enhanced knowledge and skills through workshops, exemplary models, grant funding, mentoring, evaluation site visits, and collaboration within and between higher education institutions. The NOVA professional development model was delivered in three *phases*: (1) *planning and preparation*, involving training, collaboration, and action planning for addressing baseline needs in faculty skills and knowledge enhancement; (2) *development and implementation*, involving initial course change, action research, mentoring, and sharing of expertise; and (3) *continuing development and long-term sustaining activity*, involving action research, networking, monitoring including site visits, and dissemination (Sunal et al., 2004).

In a survey of the population from which the sample was selected, it was found that the learning environment in reform courses at these institutions shared four common course features:

1) involving all students in an inquiry/investigative approach to learning science,
2) including fully integrated inquiry/investigative activities that involved the majority of a week's class time
3) using collaborative and cooperative learning groups during course activities,
4) using continuous alternative assessment, rather than using only a few traditional exams. (Sunal et al, 2008a, Sunal & Sunal, 2008b; Sunal, Sunal, Sundberg, Mason, & Lardy, 2008c; Sunal et al., 2008d; Sunal et al., 2008e; Sunal, Sunal, Mason & Zollman, 2008f)

The reformed courses in the sample were developed at various times between 1996 and 2005. All still are being offered at their respective institutions. Reform course student activities involving the science laboratory, during and outside of a class, included about two-thirds of the class time per week (see Table 1). The other one-third of class time involved interactive discussions, use of technology, and lecture. The instructional methods reported for these reformed courses contrast with the emphasis placed on similar course features in sampling of comparison undergraduate science courses at the same institutions (Sunal et. al., 2008d) (see Table 1).

Table 1
Instructional Methods Used in Reform Courses

Instructional Method	Reform Course Average % of Time per Week	Comparison Course Average % of Time per Week
Lecture	15%	63%
Traditional Lab	03%	12%
Discussion/Interaction with student groups	10%	3%

Inquiry Based Integrated lab	68%	16%
Integrated use of technology	04%	06%

Faculty from two sets of courses, reformed and comparison, were selected from each of the sample institutions. On-site case studies were completed with 19 faculty teaching entry level undergraduate science courses at the 11 higher education institutions and with classroom teachers in 41 elementary schools. The sample was geographically diverse, residing in nine states throughout the United States. The higher education institutions, universities and colleges, range in size from 2000 to over 40,000 with an average student population of about 13,000. Carnegie designations of the institutions are six MA granting institutions, two research doctoral granting institutions, and three minority designated MA granting institutions. The 19 undergraduate science courses included in the institutional sample had an average class size of 35 students with a range of 18 to 70 students. Several were one section of a multiple section course with their own lecture/lab/and discussion periods. The course science disciplines included physics, astronomy, physical science, biology, natural science, and geology.

The site visits to each institution's campus were one week in duration. Data were collected from all course activities taking place during the week on campus. Typical activities within one week of a course included two to three lectures, laboratory sessions of all main course sections, and discussion groups of all main course sections. Other common groupings included three multiple hour sessions with integrated lecture, laboratory, and discussion. The time spent observing the undergraduate class activities ranged from six to eight hours. Interviews with course instructors occurred and included laboratory and discussion group instructors. These interviews ranged from 45 to 105 minutes. Other informal discussions also were held with the course instructors during the week.

Two sample sets of pre-service elementary education students who completed the courses and who graduated from the institution also were identified. The graduated students were now in-service elementary teachers in local elementary schools. Three students were selected from each experimental and comparison course at each institution where it was possible. These graduated students were selected using a stratified random sample based on recent graduation, had completed either the reform or comparison undergraduate science course, presently serving as an in-service elementary teacher in a school local to the university, and that they had not begun a Master's degree program. The school system and principals of each school were contacted, followed by an agreement from each teacher allowing the project to observe a science lesson and conduct an interview with the teacher in the individual classrooms. Classroom observations of science lessons ranged from 35 to 75 minutes. Teacher interviews lasted from 30 to 50 minutes depending on the teacher's scheduled duties that day. In some cases, when time ran short, additional data was collected using e-mail.

Quantitative and qualitative analysis involved developing CoRe and PaP-er profiles of each participants' science pedagogical content knowledge, rating of CoRe and PaP-er profiles using rubrics, scoring and summary grouping of RTOP ratings, and comparing results between and among participants at the various sites. Data analysis and interpretation involved comparative and relational analyses investigating (1) comparisons between reform and comparison classes and (2) comparisons between in-service elementary teachers graduating from reform and comparison classes.

Data Collection Instruments

The study collection protocol involved classroom observational field notes, semi-structured interviews, and ratings of observed classroom teaching from multiple instruments and sources. Data were collected during on-site visits from instructors, graduated students, and undergraduate and elementary classrooms. The study data collected from each participant for completion of the Content Representation (CoRe) and Pedagogical and Professional-experience Repertoires (PaP-eRs) included responses to background and demographic questions, individual structured interview responses, and classroom observation field notes supported by reports of teachers' thoughts and actions. The data collected for the Reformed Teaching Observation Protocol (RTOP) ratings were observations made of undergraduate science classroom activities developed over a week period.

The individual background and demographic questions and structured interviews occurred before the undergraduate science class sessions or the in-service elementary science lesson was taught to the students. A description of the instrumentation is presented below. Several NSEUS trained observers participated during each site visit to assure coverage and observer reliability.

Since personal bias is a factor in any study due to the influence of observers' experiences and beliefs (Gall et al., 2003: Janesick, 2003), precautions were taken to avoid this bias. The RTOP, observed class sessions/lessons, field notes, interviews, and the CoRe instrument were scored immediately following observations made in each classroom and after conducting interviews. More than one observer recorded data independently. The observations were then discussed and averaged. Reliability of separate data sources was evaluated to meet a high quantitative criterion of greater than 0.80. After the classroom observations, interviews, and CoRe reports were completed, the information was used to develop the PaP-eR report. Applying the four PCK rubrics to the PaP-eR was used to determine a PCK score. Reliability was again checked and validated.

Content Representation (CoRe) and Pedagogical and Professional-experience Repertoires (PaP-eR)

In an effort to ascertain faculty and in-service teacher's science pedagogical content knowledge (PCK), participants were interviewed using the Content Representation (CoRe) and Pedagogical and Professional-experience Repertoires (PaP-eR) instruments designed by Loughran, Mulhall, and Berry (2004). See Table 2 for questions to be answered while using CoRe and PaP-eR. These questions attempt to access teachers' knowledge about how to teach particular content in science. This data was posted on a chart identified as Content Representations (CoRe) of teachers' thoughts. Pedagogical and Professional experience Repertoires (PaP-er) are detailed descriptions from classroom observations and of interviews with individual teachers as a result of discussions pertaining to the CoRe.

Four PCK rubrics were used to assess the results of the CoRe and PaP-er narratives, (1) teachers' content knowledge of the science concept(s) involved in the lesson, (2) teachers' knowledge or understanding of student thinking related to the science concept(s) involved in the lesson, (3) teachers' knowledge of how to represent the teaching of science concept(s) involved in the lesson, and (4) teachers' professional development in teaching science concept(s) involved in the lesson, collaboration with other faculty/teachers, and leadership roles in teaching of science at their level (Olgletree, 2008). The ratings included use of a continual progression of faculty/teacher responses and actions from Expert, Competent, Emergent, to Novice.

Faculty/instructor interviews and field notes were taken during observation of undergraduate science class sessions taught over a week period. These were conducted for 19 reformed and comparison undergraduate science courses. Interviews and classroom science lesson observations also were conducted with 41 elementary in-service teachers who participated either in the reformed or the comparison undergraduate science courses while at their respective college or university. The in-service observations of science lessons were conducted in the teacher's elementary classroom.

According to Loughran et al. (2004), the purpose of the CoRe is to discuss science teachers' understanding of particular aspects of PCK related to a specific science lesson (e.g., main idea of the class session/lesson; knowledge of alternative conceptions; insightful ways of testing for understanding; known points of confusion; effective sequencing; and important approaches to the framing of ideas). The purpose of PaP-eR is to expand the participant's description of their proposed lesson by observing how such knowledge might inform effective classroom practice (Loughran et al., 2004). A PaP-eR is a narrative account of a teacher's PCK that highlights a particular piece, or aspect, of science content to be taught (Loughran, Berry, & Mulhull, 2006). A PaP-eR specifically is designed to purposefully unpack a teacher's thinking about a particular aspect of PCK in that given content and so, is largely based around classroom practice (Loughran et al., 2006). The PaP-eR is intended to represent the teacher's reasoning, that is, the thinking and actions of a successful science teacher in teaching specific aspects of science content (Loughran et al., 2006). The PaP-eR, thus, develops through the interaction of the prompts, questions, issues, and difficulties that influence the particular approach to teaching that content to which the PaP-eR is tied and reflects the richness of the teacher's understanding of science teaching and learning in that field (Loughran et al., 2004). Accordingly, the more specific a PaP-eR is, the more it informs the relationship between teaching and learning. Every action of undergraduate science instructors that is specifically designed to help students learn science concepts meaningfully is a part of PCK.

Table 2
Co-Re and PaP-eR Questions

Interview Questions	Important Science Ideas/Concepts
What will be the main ideas of this course session/science lesson?	
What do you intend the <u>students</u> to learn about these ideas?	
Why is it important for students to know this?	
What do you anticipate will be some difficulties and/or limitations connected with teaching this idea?	
What knowledge about students' thinking	

influences your teaching of this idea?
What are other factors that influence your teaching of this idea?
a) Describe how you will teach the main ideas in this lesson. b) Why will you be using this procedure to teach these main ideas?
What are specific ways you will use to determine students' understanding or confusion around the idea(s)?

Reformed Teaching Observation Protocol (RTOP)

The *Reformed Teaching Observation Protocol* (RTOP) is a classroom observation protocol designed to measure quantitative characterization of the degree to which a science classroom is "reformed" (Sawada & Pilburn, 2000). The RTOP draws guidelines from documents published by the National Research Council, American Association for the Advancement of Science, Project 2061, and the National Council for the Teaching of Mathematics. For this instrument, the characteristics of reformed teaching practices are based on national standards for science education. The RTOP observer uses extensive note taking that is followed by rating a list of classroom characteristics on a continual scale of 0-4 ("never occurred" to "very descriptive"). The RTOP was found to have high inter-rater reliability (Sawada & Pilburn, 2000). In this NSEUS study, observers trained in its use developed correlation ratings above 0.85 while observing the same reform and comparison classroom settings (Piburn et al., 2002). The RTOP instrument analyses followed the authors' use of categories and weightings for the items (Piburn et. al.).

Interviews and RTOP rating observations were conducted with 19 reformed and comparison undergraduate science course instructors. The RTOP instrument is comprised of 3 sections to be rated by the observer, (1) lesson design and implementation, (2) content (propositional knowledge and procedural knowledge), and (3) classroom culture (communicative interactions and student/teacher interactions). Each section contains specific items to be rated by the observer. In addition, specific criteria are used when scoring items under each section (see Table 3 below).

Table 3

Reformed Teaching Observation Protocol (RTOP) rating Categories

1. **Background Information**

2. **Contextual Background and Activities (Narrative)**

3. **Lesson Design and Implementation (5 rating statements)**

Ratings focus on students' prior knowledge and the pre-conceptions, engagement in a learning community, whether exploration precedes formal presentation, alternative modes of investigation or of problem solving, and ideas originating with students.

4. **Content (10 rating statements)**
   Ratings focus on propositional knowledge (content, coherence, abstraction, and connections) and procedural knowledge (representing, predicting, thought provoking, reflecting, challenging).

5. **Classroom Culture (10 rating statements)**
   Ratings focus on communicative interactions (communication through a variety of means, teacher questions, student talk, student questions, climate of respect) and student/teacher relationships (active participation, alternative strategies, teacher patience, teacher as resource person, and teacher as listener).

Additional comments (Optional)

Results

CoRe and PaP-eR Results for Undergraduate Faculty: Science Pedagogical Content Knowledge

Analysis of the CoRe and PaP-eR (see Tables 4 and 5) considered the following categories, (1) content knowledge, (2) knowledge about how students think, (3) science teaching knowledge, and (4) professional development. Analysis of the data found a statistically significant difference in the total score on the CoRe and PaP-eR between faculty who were instructors in reform and comparison undergraduate science courses, t (17, 3.156) p =.007.

There was a statistically significant difference between reform and comparison faculty in three of the four of the sub-categories of the CoRe and PaP-eR. The categories showing a difference were content knowledge, t (17, 2.115), p =.049; student thinking, t (17, 2.726), p =.014; and knowledge about science teaching; t (17, 2.897), p =.010. There was no statistically significant difference between reform and comparison faculty in the category of professional development, collaboration, and leadership roles, t (17, 1.995), p = .062 which was determined through the use of rubrics.

Faculty teaching in the reform undergraduate science courses were found to consistently exhibit in-depth knowledge of the science concept(s) focused upon in the class session. The rubric mean was a 4.0 out of a possible 4. Language used within the class session was scientifically accurate, descriptive, purposeful, and useful for student's learning of the new concept being taught.

Faculty teaching reform courses consistently demonstrated responses and actions related to a deeper understanding of the way students' think about science, with a rubric mean of 3.20 achieved out of a possible 4. This understanding of student thinking included setting an appropriate learning goal for the students. One faculty member's response during the interview associated with this instrument was

> The important part is not that they know how to draw isomers or how to name compounds, but that they can get comfortable with what carbon can do and that it can do some pretty sophisticated things. I want to make these topics so that they're not totally new to them. So that when they see them again they won't be afraid of them. So, they won't just see a certain term or a structure and say, 'nope, it's beyond my comprehension' and turn off.

Faculty teaching in reform courses consistently demonstrated responses and actions were related to an in-depth understanding and knowledge of a way to represent the teaching of the main science concept(s) that led to student understanding, achieving a rubric mean of 3.20 out of a possible 4. One faculty member's response included "When I go into the class, even though we're not really talking about it, I'll write some key items on the board like 'the four molecules of life' so I can remind of them of the bigger picture of how this connects." Another recalled

> We'll take the 'hydrogens' off of the models and have them separate them again to show how much faster it is and how much easier it is to see the structure than with all the hydrogens. I want them to see how the structure is the same, even without the 'hydrogens', so that when they see a structure later, they won't just see it as a bunch of lines and ignore it because they don't know what it is."

In each of the three categories, faculty/instructors teaching comparison courses were rated significantly lower with the exception of the category of professional development, collaboration, and leadership roles in which no statistically significant differences were found. The faculty responses and actions in each group indicated a similar low to medium level of professional development, collaboration, and leadership roles. The responses and actions indicated limited reflective practice via trying to improve the quality of their students' learning experiences.

Table 4
CoRe and PaP-eR Results for Undergraduate Faculty Teaching Reform and Comparison Courses

CoRe & PaP-eR Categories	Undergraduate Course	N	Mean	Standard Deviation	Standard Error
Content Knowledge	Reformed Comparison	10 9	4.00 3.67	0.000 0.500	0.000 0.167
Student Thinking	Reformed Comparison	10 9	3.20 2.00	0.919 1.000	0.291 0.333
Science Teaching	Reformed Comparison	10 9	3.20 1.89	0.919 1.054	0.291 0.351
Professional Development	Reformed Comparison	10 9	3.10 2.13	0.876 1.269	0.277 0.423
Total Score	Reformed Comparison	10 9	3.47 2.37	0.631 0,802	0.210 0.283

Table 5
CoRe and PaP-eR Independent *t*-test Results for Undergraduate Faculty Teaching Reform and Comparison Courses

CoRe & PaP-eR Categories	*t*	df	Sig. (2-tailed)	Mean Difference
Content Knowledge	2.115	17	0.049	0.333
Student Thinking	2.726	17	0.014	1.200
Science Teaching	2.897	17	0.010	1.311
Professional Development	1.995	17	0.062	0.989
Total Score	3.156	17	0.007	1.097

RTOP Results for Science Faculty: Teaching Undergraduate Science

Analysis of RTOP considered the following categories, (a) lesson design and implementation, (b) propositional knowledge, (c) procedural knowledge, (d) communicative interactions, and (e) student/teacher relationships. Analysis of the data found a statistically significant difference in the total score on RTOP between faculty who were instructors in reform and comparison undergraduate science courses, *t* (17, 2.426), *p* =.027. There was a significance difference in the degree to which specific teacher and student actions characterized the observed science class sessions.

There was a statistically significant difference between faculty teaching reformed and comparison undergraduate science courses in regard to procedural knowledge, *t* (17, 2.448), *p* =.026; communicative interactions; *t* (17, 2.878) *p* =.010, and student/teacher relationships, *t* (17, 2.506), *p* =.023. No statistically significant difference was found between faculty teaching reformed and comparison science courses in the area of lesson design and implementation, *t* (17, 1.934), *p* =.070 and propositional knowledge, *t* (17, 1.153), *p* =.265.

Faculty teaching reformed science courses exhibited a deeper understanding of how to use procedural knowledge to facilitate scientific reasoning through using activities that allowed students to manipulate information, arrive at conclusions, and evaluate knowledge claims. Faculty in reformed courses achieved a mean rating of 2.75 out of a possible 4.00, while comparison faculty achieved a mean score of 1.503. Faculty teaching reform science courses also were more likely to understand the importance of knowledge construction in an environment in which students are allowed to communicate their ideas and understandings with their peers, achieving a mean rating of 2.996, while comparison faculty achieved a mean rating of 1.642. Finally, faculty teaching reform science courses differed from faculty in comparison courses in the quality of student/teacher relationships achieving a mean rating of 3.201 while comparison faculty had a mean rating of 1.991. During observations of the reform science class sessions, students were more likely to be engaged in a variety of thought and action learning activities, generating solution strategies, and interpreting evidence with assistance by the instructor. In such classes, the instructor was more student centered than teacher centered, taking on more of the role of listener and resource person while assisting students in solving problems.

Table 6
RTOP Results for Undergraduate Faculty Teaching Reform and Comparison Courses

RTOP Categories	Undergraduate Course	N	Mean	Standard Deviation	Standard Error
Lesson Design	Reformed Comparison	10 9	2.51 1.61	0.880 1.136	0.278 0.378
Propositional Knowledge	Reformed Comparison	10 9	3.08 2.78	0.433 0.671	0.137 0.224
Procedural Knowledge	Reformed Comparison	10 9	2.76 1.50	1.038 1.197	0.328 0.399
Communicative Interactions	Reformed Comparison	10 9	3.00 1.64	0.894 1.152	0.283 0.384
Student and Teacher Relationships	Reformed Comparison	10 9	3.20 1.99	0.780 1.290	0.247 0.430
Total Score	Reformed Comparison	10 9	2.89 1.88	0.771 1.039	0.244 0.346

Table 7
RTOP Independent *t*-test Results for Undergraduate Faculty Teaching Reform and Comparison Courses

RTOP Categories	*t*	df	Sig. (2-tailed)	Mean Difference
Lesson Design	1.934	17	0.070	0.897
Propositional Knowledge	1.153	17	0.265	0.296
Procedural Knowledge	2.448	17	0.026	1.255
Communicative Interactions	2.878	17	0.010	1.355
Student and Teacher Relationships	2.506	17	0.023	1.210
Total Score	2.426	17	0.027	1.011

During the RTOP class observations, undergraduate students in the reform courses were observed by the researchers to be more engaged with the instructor and with the content for the entire lesson, see Table 8. There was generally a great deal of interaction, student-to-student, teacher-to-student, and student-to-teacher. The instructor usually began the lesson with an activity engaging prior knowledge, followed by a brief lecture to introduce the concepts, and finally, the students were engaged in inquiry investigations and discussions for the rest of the lesson period. Several instructors in the reform courses indicated they learned to use “teaching techniques” in the NOVA professional development program and/or from institutional team members who participated in the program. The reform course instructor demonstrated a positive attitude toward teaching “reformed” type of undergraduate science in the following statement; This [class] works so well that I am trying to change my other classes to not lecture so much because they get the totally glazed-over look. They don’t seem interested at all. And, this class is completely different. You are taking people who have no interest in [science] at all in the first place and, at the end of each unit, I actually ask them to write a little reflection. And, often they will say, “I’ve never liked science before in my whole life. This class is so fun that I’m changing my attitude.

In general, the teaching strategies demonstrated and observed in the comparison courses did not always correlate with what the comparison course faculty member thought he/she was doing in class. Goals expressed for the undergraduate science reform and comparison courses were similar: help increase student interest in science, make science relevant to students and their careers, become science literate, and meaningfully understand the key concepts covered in the course. An example of a goal statement expressed by one reform course instructor that was very similar to those expressed also by comparison course instructors was, “A lot of them [students] do not have the best attitude towards science. It’s not their favorite subject. They’re afraid of it. They don’t enjoy it. I’m trying to get them interested and engaged.”

Based on evidence observed using the RTOP observation instrument, although the comparison and reform instructors had similar goals, the reform faculty were observed to accomplish them while the comparison faculty did not. Reform and comparison course instructors used different strategies for accomplishing their goals. In observations made in the comparison classrooms, students appeared less interested and unengaged with the teacher and the content; there was almost no student-to-student interaction and little teacher-to-student or student-to-teacher interaction. Comparison course faculty were more likely to lecture and show a *PowerPoint©* presentation during class.

Table 8
Undergraduate Science Classroom Observations

Sample of Classroom Observations Made in the Reform Undergraduate Science Course Classrooms	*Sample of Common Classroom Observations Made in Both Types of Undergraduate Science Classrooms*	*Sample of Classroom Observations Made in the Comparison Undergraduate Science Course Classrooms*
• Extensive student-student interaction during the class • Extensive teacher-student interaction during the class • Lectures were short and provided in a “just in time manner” coordinated with students’ inquiry activities • Lecture and laboratory were more often integrated	• Teachers used technology: smart boards, *PowerPoint* etc. • Content presented in both courses was current, appropriate, and accurate.	• Little requested, or planned, student-student interaction • Teacher lecture took up the majority of the time • Students appeared bored and unengaged with the teacher and the content • Lecture and laboratory were separated in time

CoRe and PaP-eR Results for In-service Teachers: Science Pedagogical Content Knowledge

Data were collected to develop a profile of science pedagogical content knowledge for each of the 41 in-service elementary teachers who completed either a reform or comparison undergraduate science course during their undergraduate program. The in-service teachers had graduated from one of the sample universities and as undergraduates, had taken either the reform or comparison science courses. The visits were coordinated with, and selected in cooperation with, the college or department of education at each college or university.

The selection of in-service teachers was through a stratified random process. In-service teachers within a reasonable driving distance of two or less hours from the university, who were graduates from the institution in the past one to four years, were first identified. These in-service teachers' classroom experience would include at least one and up to four years. Next, the identified teachers' course transcripts were scanned to identify the presence or absence of the reformed or comparison undergraduate science course. All students enrolled in a Masters' degree program were eliminated. From each list, three teachers were randomly selected for visitation in the current study. Arrangements were then completed, including IRB applications, with the school district, principal, and teacher.

The data gathering occurred in site visits with each teacher at his or her elementary school. The interview and science lesson observation data were used to develop and complete the CoRe and PaP-eR and evaluate the results using the PCK rubrics. Analysis of the CoRe and PaP-eR rubric data found a statistically significant difference in the total score between inservice elementary teachers who completed either a reform or comparison undergraduate science course during their undergraduate program, t (39, 2.536) p =.015 (see tables 9 and 10).

Data analysis found statistically significant differences between reform and comparison in-service elementary teachers in three of four rubrics used to evaluate the CoRe and PaP-eR for teachers. Significant differences were found in the rubric areas of content knowledge t (39, 2.034), p = .049; knowledge about how students think, t (39, 2.10), p =.042; and knowledge about science teaching, t (39, 2.220), p = .032.

Example statements and observations follow from in-service elementary teachers who completed a reform undergraduate science course during their undergraduate program. Teacher interview statements are in regular font while observer statements appear in italics.

6th grade teacher

Science content knowledge

I was concerned about the fluid that we used to model convection currents in the lab. This is the first time I'm using this in my class – It came with the new science kits. I also wanted to make sure that safety was covered. The liquid is non-toxic, but I was afraid it could hurt their eyes. That's why I had them wear safety goggles.

Knowledge about how students think

I know that the students want to do hands-on activities and it helps them to see the concept directly. Since the students don't have a lot of science background knowledge, the pre-lab is really important to go over.

Knowledge about science teaching
I try to put together what they already know with the new information. I don't want to give the students the answers. I try to ask questions and lead them in the right direction.

Activity: "Mantle Motion." Students complete an activity to generate and observe a convection current. Students read all the instructions and questions out loud before beginning. Teacher guides students to make a prediction about what they think will happen. Teacher walks around the room asking students questions as they make observations. [The teacher] asks them to explain what they are seeing. …. also talks to the whole class, making connections to relevant items like lava lamps and hot air balloons. Students draw and write their observations, and answer questions on a worksheet.

No statistically significant difference was found between the inservice teachers in the area of professional development, collaboration, and leadership roles, t = (39, 1.689), p =.099. The 21 in-service teachers who completed the reform undergraduate science course(s) demonstrated greater proficiency during the interview and while teaching the observed science lesson in understanding science content knowledge achieving a mean rating of 2.90 out of a possible 4.00, in student thinking (mean rating of 2.71), and in science teaching knowledge (mean rating of 2.79). The 20 in-service teachers completing the comparison science course(s) had lower ratings on each rubric with means of 2.40, 2.15, 2.15 respectively.

Example statements and observations follow from in-service elementary teachers who completed a comparison undergraduate science course during their undergraduate program. Teacher interview statements are in regular font and observer statements are given in italics.

2nd grade teacher
Science content knowledge
Molecules move very slowly in cold environments and speed up in warmer environments

Knowledge about how students think
They should learn that molecules move differently in hot and cold environments.

Unfortunately, the students still did not grasp the concept that molecules were farther apart and in lesser quantity in a warmer environment.

[The teacher demonstrated several] *activities but the students did not understand the behavior of molecules due to the levels of energy.*

Knowledge about science teaching
Need to understand that molecules are everywhere

Even though we can't see everything, things are happening

…teacher doesn't really follow up on student answers, so it is not evident that they are learning. He guides them too much.

I want to have students have fun with science. They should understand that molecules are everywhere and move differently at different times.

[Teacher] doesn't consider their prior knowledge.

Table 9
CoRe and PaP-eR Results for In-Service Elementary Teachers Completing Reform or Comparison Courses

CoRe & PaP-eR Subcategories	Undergraduate Course(s) Completed	N	Mean	Standard Deviation	Standard Error
Content Knowledge	Reformed Comparison	21 20	2.905 2.400	0.831 0,754	0.181 0.169
Student Thinking	Reformed Comparison	21 20	2.714 2.150	0.644 1.040	0.140 0.233
Science Teaching	Reformed Comparison	21 20	2.762 2.150	0.831 0.933	0.181 0.209
Professional Development	Reformed Comparison	21 20	2.429 1.950	0.926 0.887	0.202 0.198
Total Score	Reformed Comparison	21 20	2.702 2.163	0.669 0.694	0.146 0.155

Table 10
CoRe and PaP-eR Independent *t*-test Results for Undergraduate Faculty Teaching Reform and Comparison Courses

CoRe & PaP-eR Categories	*t*	df	Sig. (2-tailed)	Mean Difference
Content Knowledge	2.034	39	0.049	0.505
Student Thinking	2.100	39	0.042	0.564
Science Teaching	2.220	39	0.032	0.612
Professional Development	1.689	39	0.099	0.479
Total Score	2.536	39	0.015	0.540

During the interviews, the in-service teachers who completed the reform science courses generally indicated that those courses were more appropriate preparation for teaching than were other undergraduate (traditionally structured) science courses they had taken. These teachers described elementary science in their classrooms most often in terms of the experiences they had in the reform course. One in-service teacher commented as follows.

> Hands-on activities in the classroom. Earth/space to biology, engineering types of stuff. Activities that are hands-on. We got to do activities we can use in the classroom. We were each assigned two activities to present to the class. We had to teach the activities. You have to let the students be involved instead of just feeding it to them.

Another teacher noted,

> The … [reform] science course really excited me. I do a whole space unit. I really enjoyed my biology class because we went out to the creek and dug up animals. I really enjoyed the hands-on past. It is my favorite subject to teach.

Science instruction in elementary classrooms was similarly described by other in-service teachers with reform course experiences. The focus of the comments was on science as interactive and meaningful. “Hands-on. Letting the student do the work. Think the technology helps a lot. The children love going to the board.” “I don’t use many workbooks in science.” “I try to use hands-on as much as possible.” “It was the hands-on that really got me.”

During interviews, in-service teachers who completed the comparison undergraduate science course described elementary classroom science instruction as text-book driven. In describing her science lessons, one comparison teacher reported,

> Once I became a teacher with my own book and my own grade level, I taught science. We adopt textbooks and the textbooks have changed. There’s been lots of change so we have to change what we teach.”

This teacher’s comments were representative of those who had taken the comparison course.

A major barrier to effective science teaching was identified as a lack of time and lack of priority in the curriculum by all of the in-service teachers. Elementary teachers are pressured to ensure their students have high stakes standardized test scores on reading and mathematics. A comment similar to that made by other teachers is the following in which a teacher discusses her science in terms of restrictions placed upon time available for science by the time required to be available for reading and mathematics.

> Time. You have to make time for science. I turn it into a reading lesson. You have science and social studies twice a week. The … core curriculum test. It is very demanding and we are very responsible for it. Reading and mathematics is on the third grade test. It has mostly word problems set up in multiple choice formats.

In summary, based on extensive field notes made during classroom observations and an interview, in-service teachers who completed the comparison undergraduate science courses were more likely to present science lessons as a reading lesson where students read passages out loud and searched for answers to the teacher’s questions. These same teachers were more likely to be over-reliant on the textbook in planning lessons and used the teacher’s guide to ask the students questions about the science textbook readings.

Table 11
Elementary School Science Classroom Observations

Sample of Classroom Observations of In-service Teachers' who Had Completed a Reform Undergraduate Science Course	*Sample of Common Classroom Observations Made in Both Groups of In-service Teachers' Classrooms*	*Sample of Classroom Observations of In-service Teachers' who Had Completed a Comparison Undergraduate Science Course*
• used more hands-on/minds-on activities • relied less on the textbook and more on students activities and discussion • described their science lessons using terms compatible with constructivist pedagogy	• Teachers used technology: e.g. smart boards, *PowerPoint* presentations	• presented a reading lesson using the science textbook • had elementary students read passages out loud, • teacher asked questions, • students searched for answers in passages

Conclusion

Effective science teaching is a complex process requiring specialized knowledge and skills to do it well and facilitate student learning. Reforms in entry-level undergraduate science courses impact students in higher education. There is a need to assure that science instructors transform science content knowledge and represent it in a way to promote student learning (DeJong et al., 2005; Loughran et al., 2000; Van Driel et al., 1998). Today's pre-service elementary teacher candidates participate in entry-level science courses as part of their programs. These candidates, in turn, will teach science to their elementary school students, affecting large numbers of children's science education over time.

It is important to investigate current efforts underway in undergraduate science course reform through the knowledge faculty members have available to implement those reforms and to study the impact of such knowledge on their active teaching and on long term student outcomes in those courses. The current study of a small national and diverse sample investigated undergraduate faculty instructors' cognitive understanding of science content and the connection between this understanding and active instruction provided for students as a critical factor in effective science teaching (Shulman,1986). Quantitative and qualitative analyses in this study identified variations and significant relationships in faculty as well as in-service teacher perceptions and observations of the intended and enacted goals, instruction strategy, concept representations, student difficulties, and rationale for teaching a science concept in observed science lessons.

Faculty instructors who taught reform undergraduate science course(s) were rated higher in science pedagogical content knowledge. The level of PCK for faculty instructors also was found to be significantly related to their observed undergraduate teaching actions, to the teaching and learning experienced by students, to classroom culture, and to learning outcomes. Both PCK and the instruction observed were found to vary along a continuum from reformed to traditional instructor orientation.

In-service elementary teachers who had completed these same reform undergraduate science course(s) were rated higher in science pedagogical content knowledge in their elementary school setting. This is an important finding that predicts cognitive understanding of science content and the connection between this understanding and effective science teaching.

Based on the results of the data reviewed for this sample, science pedagogical content knowledge of undergraduate science faculty predicts patterns in their science classroom teaching. The undergraduate science classroom course context and teaching also were found to be related to the science pedagogical content knowledge of their undergraduate students, who upon graduating became in-service elementary teachers responsible for teaching science in their classrooms.

Implications

Science pedagogical content knowledge is not hard to find in classrooms. The results of several studies provide evidence for the existence and impact of PCK (Ogletree, 2008; DeJong et al., 2005; Loughran et al., 2000; Van Driel et al., 1998) and are confirmed by this study. Every action of undergraduate science instructors that is specifically designed to help students learn science concepts meaningfully is a part of PCK. The results of the current study support connections between instructor knowledge, PCK for teaching specific science concepts, and teaching actions observed in teaching those same science concepts. Pedagogical content knowledge must be related to the specific science concepts to be taught. It is not assumed here that there is a generalized PCK that works for all instructors/teachers in teaching any science concept. The problem lies in knowing what science pedagogical content knowledge is important for each science discipline and for the specific science concept areas in each discipline. Loughran et al. (2000) reported that PCK included a mixture of items that varied with each teaching and learning setting.

This research study is among the first studies to examine PCK of higher education faculty and investigate the relationship of science pedagogical knowledge to the teaching exhibited and observed in science classrooms. If confirmed, implications may have impact on the way faculty are prepared for teaching undergraduates. This may involve several aspects as represented by the questions (1) What needs to be done to prepare for teaching specific science concepts to undergraduates? (2) What needs to take place during undergraduate teaching of these specific science concepts? and (3) How do undergraduate students need to be engaged following teaching science lessons if we are to create more meaningful outcomes in undergraduate students' learning of science? Recommendations for further research include expanding the sample size, investigating both short term and long term effects, including several independent sources of data in addition to PCK, and relating PCK to teaching actions and to student achievement.

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