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Reforming Science and Science Education Courses for K-8 Preservice Teachers:
The University of Delaware Teacher Professional Continuum Project

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We describe our continuum of science and education coursework for K-8 preservice teachers, designed in response to calls by the National Research Council ([NRC] 1996, 2000, 2001) and National Science Foundation ([NSF] 1996) to give preservice teachers opportunities to learn science through meaningful, inquiry-based experiences that prepare them to use similar approaches with their future students. There is broad agreement that well-prepared teachers foster better student performance, and that students’ understanding of science benefits from inquiry-based teaching (NRC, 2000). Learning is also enhanced when instructors use real-world contexts and integrated content (Loucks-Horsley et al., 1991), recognize that learning is a social activity, and address students’ prior knowledge and misconceptions (NRC, 2000, 2001). In response to these concerns, we have developed a sequence of science and education courses that emphasize active learning, inquiry-based and problem-based approaches, integrate content and pedagogy, and rely on cross-department collaboration. The continuum includes a “Gateway” introductory course for first-year teacher education majors; the “Science Semester,” three science and science education courses taken simultaneously in the sophomore year; and an advanced problem-based science course and science-focused student teaching experience in the senior year. The program is grounded in the model of Pedagogical Context Knowledge (PCxK) (Barnett & Hodson, 2001). PCxK integrates the research perspective of teacher personal practical knowledge (Clandinin, 1985; Clandinin & Connelly, 1995) with the construct of pedagogical content knowledge (Shulman, 1987; Gess-Newsome & Lederman, 1999) to examine four components of teacher knowledge: academic and research knowledge, pedagogical content knowledge, professional knowledge, and classroom knowledge. We seek to understand how the dimensions of PCxK develop, separately and interactively, within our K-8 preservice teachers as they pursue their teaching degrees.

### Inquiry-Oriented Courses for Prospective Elementary Teachers

Published accounts of inquiry-based science and education courses for prospective elementary teachers (and/or students reactions to those courses) describe reform-based, stand-alone science or methods courses (e.g., Smith, 1999, 2000), interdisciplinary science courses (e.g., McLoughlin & Dana, 1999), and sequences of coordinated courses (e.g., Beiswenger et al., 1998). Accounts of the science course redesigns typically emphasize efforts to select content and hands-on activities that are aligned with national standards (NRC, 1996) and easily adapted for use in elementary classrooms (Goodman et al., 2006; Guziec & Lawson, 2004). Some authors focus on deeper, sustained investigations (Friedrichsen, 2001), or guided and open inquiry approaches to try to enhance prospective teachers’ attitudes toward science and science teaching (Weld & Funk, 2005) and to encourage undergraduates to begin to develop scientific discourses and practices to use in their future teaching (Smith & Anderson, 1999). Cross-disciplinary content courses often involve faculty teams of scientists and science teacher educators (Bieswenger et al., 1998; Krockover et al., 2002; McLoughlin & Dana, 1999; Stepans et al., 1998).

Reform-based science education methods courses focus on using students’ inquiry learning and teaching experiences to stimulate critical reflection and more positive attitudes and beliefs about inquiry approaches. In these methods courses, researchers provide prospective teachers with sustained experiences in particular models of inquiry teaching and learning, such as problem-
based learning (Peterson & Treagust, 1998; Watters & Ginns, 2000), constructivist approaches to learning (Kelly, 2000), and emphasis on the development of robust beliefs of the importance of inquiry teaching (Stuart & Thurlow, 2000). Several authors have used instructional technologies to enhance prospective teachers’ opportunities to practice and reflect on inquiry pedagogies (Capobianco, 2007; Schwarz et al., 2007; Watters & Diezmann, 2007).

There are also a few reports of broader programmatic reform efforts that involve groups of science and/or science methods courses in elementary teacher education degree programs (Boone & Gabel, 1998; Lee & Krapfl, 2002; Luera & Otto, 2005; Stepans et al., 1995). A further step in cross-disciplinary integration is achieved by teaching inquiry science and methods courses as a coordinated block. For example, the Integrated Credential Program, at California State University San Marcos, includes a science-themed semester with one course each in science content, science methods, and science and society (Norman, 2000; Norman & Yamashita, n.d.). The courses are freestanding but linked by a few shared assignments to encourage integrated learning (Norman & Yamashita, n.d.). These studies, in particular, informed the design of our reform-based continuum.

**Instructional Framework**

The University of Delaware (UD) Teacher Professional Continuum is a graduated series of key elements for elementary/middle school education (ETE) majors designed to spur development of critical understandings, skills, and attitudes. It consists of the following elements:

**Gateway Course:** The Gateway course is offered as a required, first-semester course for all entering ETE majors. To accommodate all 100-150 students per year who need the course, the format is traditional in terms of enrollment and the use of large lecture halls, but utilizes active learning, guided inquiry, and problem-based learning (PBL) approaches. The content of the course rotates each year through the general education requirements of earth, life, or physical science. Along with an interdisciplinary perspective, there is a strong infusion of the nature of science and quantitative reasoning skills. All students take one Gateway science course.

**Science Semester:** The Science Semester is offered each spring semester to 60 sophomores (approximately one-third to one-half of the students who have taken the Gateway course). It integrates two 4-credit science courses (i.e., earth science, life science, physical science – the two courses not represented by the Gateway course) and a 3-credit elementary science methods course, all of which are required courses in the major. The courses are fully integrated in an 11-credit block. With the smaller enrollment size, instructors are able to utilize a problem-based, group learning format. The semester consists of a series of 4-6 PBL-based interdisciplinary investigations, team instruction, field experiences, and student investigations of science topics and K-8 curriculum materials.

**Bridge Course:** During their senior year, K-8 science concentration preservice teachers take an advanced problem-based learning science course that strongly links students to school-based experiences. This course builds on the content and instructional techniques of the Science Semester by engaging students in problem-based learning investigations of interdisciplinary science and classroom applications. It is taught in seminar format, in classes of 10-20 students.
middle school science curriculum and instruction course is taught concurrently, though not integrated with the course.

**Science Student Teaching:** In the semester following the advanced PBL science course, middle school science concentrators are placed in a middle school science classroom for an 8-week student teaching placement. This is a traditional field-based student teaching experience, with gradually increasing responsibilities for teaching, and supervision by clinical faculty.

Not all ETE majors experience all elements of the continuum. The Bridge Course is an advanced content course taken by students seeking middle school science certification, which is only about 10 percent of our ETE population. The Science Semester has limited capacity due to instructor availability and the use of the PBL model. In addition, a small number of transfer students do not take the Gateway or Science Semester courses, but do enroll in the Bridge Course.

**Curriculum Framework**

Our continuum courses use the following research-based design principles to support inquiry-based science instruction: (1) **Problem-Based Learning** (PBL). This model of case-based science instruction derived from medical education is our framework for instruction (Engel, 1997; Levin, 2001). In PBL, student learning is driven by long-term investigations of real-life issues. Students work in collaborative groups to determine the path and focus of the investigations. In contrast to the traditional lecture format, PBL allows the instructor to focus more on listening and reacting to students, guiding them, and helping the students develop critical inquiry skills— all elements strongly advocated by national reform efforts (NRC, 2007). (2) **Cross-Disciplinary Content.** Stand-alone courses in science and pedagogy are not well suited for developing the integrated understandings of science, teaching, and learning that are needed in an inquiry science curriculum (Anderson & Mitchner, 1994). Our courses are structured flexibly, mixing science content and pedagogy together within PBL investigations. Topics such as cancer clusters and environmental contamination and the evaluation of commercial science kits allow content to be examined from disciplinary and integrated perspectives in the Science Semester, and then revisited in deeper investigations such as a consideration of watersheds, K-12 content standards, and global water issues in the Bridge Course. (3) **Socioscientific Topics.** A key feature of successful inquiry is sustained engagement on the part of students (NRC, 1996). To foster this engagement, our PBL scenarios and content are locally contextualized, have socioscientific elements (Aikenhead & Solomon, 1994; Zeidler, Sadler, Simmons & Howes, 2005), and explicitly connect the science content to elementary learners and curricula (Ford, 2005; Allen, 2007). Our investigations are designed to engage our students on two levels: that of their current roles as college students who are interested in learning about science that directly affects their well-being, while also appealing to their desire for science that is closely connected to the science topics they will someday teach.

**Theoretical Framework**

We use Barnett and Hodson’s (2001) model of Pedagogical Context Knowledge (PCxK) to examine four components of teacher knowledge: academic and research knowledge (ARK) (the formal content of science and pedagogy), pedagogical content knowledge (PCK) (knowledge of
curriculum-specific instructional practices), professional knowledge (PK) (the knowledge held and shared by teachers in practice) and classroom knowledge (CK) (understanding of the particular needs of children in the classroom context).

Barnett and Hodson’s model of PCxK was based on work with practicing teachers. In order to consider this model with prospective K-8 teachers, we are building on the model by considering the developmental dimensions of PCxK as evidenced in our students as they move through the components of our teacher education program. We have placed Barnett and Hodson’s PCxK framework on a developmental trajectory to represent the path from entry into the program – as students with a student-based perspective on teaching, teachers, and students to completion of the program and entry into the profession – as teachers with a teaching-based perspective. As prospective teachers move through the components of our reform-based program, elements of PCxK will change, come to the foreground, or recede to the background with the various contextual and personal factors encountered. The presentations in this symposium highlight different dimensions of the PCxK model and our students’ development (see Figure 1).

Figure 1. The modified Barnett and Hodson PCxK model.

The PCxK theoretical framework informs our research questions and design. We seek to understand how the dimensions of PCxK develop, separately and interactively, within our K-8 preservice teachers as they pursue their teaching degrees. To illustrate, selected project research questions are shown aligned with elements of PCxK (see Figure 2).
In this paper, we report on selected findings that examine the following research questions related to elements of PCxK:

- **ARK** – How do pre-service K-8 teachers’ understandings of energy flow and matter cycling in ecosystems change during their first two science courses in the continuum?
- **PCK** – How do pre-service K-8 teachers’ understandings of inquiry change during the Science Semester?
- **PK** - How does pre-service K-8 teachers’ science teaching self-efficacy change during the Science Semester?

### Research Design

We have collected longitudinal and cross-sectional data from: first-year students in the Gateway course (n=456); students enrolled as sophomores in the Science Semester (n=215); and seniors enrolled in the Advanced PBL course (n=19). At the population level, data sources include open-ended surveys of conceptions of teaching and learning and content knowledge, and science
teaching efficacy (STEBI-B, Enochs & Riggs, 1990). Case study data (n=65) includes focus groups and individual interviews. In this paper, we report on select results from our ongoing analyses, focusing on one cohort of the Gateway Course (n=115), and six cohorts of the Science Semester (n=312).

Data Sources

Knowledge, belief and efficacy surveys. We report on three of the measures to evaluate our students’ understandings of inquiry, content, and their science teaching self-efficacy. The first was an open-ended survey on conceptions of teaching and science administered as an in-class writing assignment on the first day of class (pre) and again on the final day of class (post) in the Science Semester. The survey included nine open-ended questions that probed dimensions of the students’ understandings of inquiry, science teaching, and science learners, and took approximately 20 minutes to complete. We received a total of 159 complete pre and post surveys from the 2003-2005 cohorts. In this paper, we report on responses to questions about science teaching methods. Content understandings of ecological/interdisciplinary science were measured using an open-ended essay on ecosystems. The essay prompts a typical diagram showing the sun and representative organisms at various trophic levels, with arrows drawn between organisms. The essay prompts the respondents to elaborate upon the interactions that are represented in the diagram. Essay administration is embedded (pre- and post-instruction) in course activities; however, the diagram is never used nor is the essay question directly discussed in the context of formal instruction. In this paper, we report on ecosystems essays collected from one cohort of the Gateway course (n=117) and two cohorts of the Science Semester (n=110). A subset of this data is longitudinal, collected from 55 students who were enrolled sequentially in both courses. To measure changes in student self-efficacy for science teaching, the Science Teaching Efficacy Belief Instrument-version B (Riggs & Enochs, 1990), was distributed on the first and last day of class for to 153 students in three cohorts of the Science Semester, and took approximately 15 minutes for students to complete. STEBI-B consists of two subscales: the Personal Science Teaching Efficacy (PSTE) scale measures respondents’ confidence in their abilities to be effective science teachers; and the Science Teaching Outcome Expectancy (STOE) scale relates to respondents’ beliefs in the relationship between certain teaching practices and student learning.

Focus Group Interviews. A select number of students (54 across two cohorts of the Science Semester) were interviewed in a focus group format multiple times during the semester by two members of the research team. These students volunteered to participate in guided discussions about their reflections on the Science Semester within the first few weeks of the semester, mid semester, and at the end of the semester. Interviews were conducted outside of class time, audiotaped, and lasted approximately one hour. The interviews explored students’ past experiences in school science, their beliefs about teaching and learning, and their reactions to the Science Semester.

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1 The STEBI-B was revised to improve the reliability of the Science Teaching Outcome Expectancy subscale by removing the qualifier “some” from items 10 and 13, as recommended by Bleicher (2004).
Data Analysis

**STEBI-B.** We analyzed the STEBI-B results using paired-sample *t* tests. The sample size of each Science Semester cohort, the mean and standard deviation of pre- and post- score on the PSTE and STOE subscales are shown in Figure 1. For example, the pre- PSTE mean score of the 2006 cohort (*N* = 59) was 44.85 (*SD* = 6.63), and the post- mean of that cohort was 51.00 (*SD* = 6.40). One group paired-sample *t*-test was used to test significant difference in the pre- and post-scores.

**Open-ended assessment and interviews.** All open-ended survey responses and interview audiotapes were transcribed, and the resulting information was analyzed by two or more members of the research team. For the science teaching conceptions survey, we developed our coding rubric using themes derived from our course definitions of inquiry (Krajcik & Czerniak, 2007; NRC, 2000) and through multiple readings of the student surveys and interviews. An in-vivo coding method was used to build the final rubric from both pre and post data for each question. The content essays were scored by two or more readers using rubrics developed to capture content accuracy and concept range (i.e., alternative conceptions within each accuracy level) (see Table 1).

**Table 1. Scoring rubric for ecosystems essays.**

<table>
<thead>
<tr>
<th>Rubric Level</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Response includes energy flow (beginning with sun, one way from producers to consumers to decomposers), including heat loss, and matter cycling, including roles of photosynthesis and respiration</td>
</tr>
<tr>
<td>3</td>
<td>Talks about energy flow and matter cycling, but doesn’t mention loss of energy to system in form of heat OR photosynthesis OR decomposers</td>
</tr>
<tr>
<td>2</td>
<td>Does not mention the relative roles of photosynthesis and respiration, doesn’t mention heat loss</td>
</tr>
<tr>
<td>1</td>
<td>Doesn’t mention energy flowing, although may talk about trophic levels and matter</td>
</tr>
</tbody>
</table>

The resulting data is descriptive, allowing us to compare both the number of responses corresponding to each coding category, as well as the number of total responses for any survey question. From this data, we computed the percentage of responses for the individual categories out of the total number of responses. Percent agreement among readers was 88 for the conceptions surveys, and 86 for the content essays. For the interviews, two members of the research team qualitatively coded the transcripts to identify key interpretive motifs circulating among the students that semester (Patton, 2002). The identified themes are reported in the findings section.

**Findings**

We report on development of students’ understandings of inquiry science teaching (PCK), content knowledge (ARK), and self-efficacy (PK) within the Gateway and Science Semester courses in the continuum.
Pedagogical Content Knowledge

Our ETE majors, much like others reported in the literature (Howes, 2002; Hubbard & Abell, 2005), felt that elementary teachers should use active learning approaches when they teach science. Eighty percent of our students’ pre-semester survey responses regarding appropriate teaching methods for science mentioned “hands-on” activities (see Table 2).

Table 2. Prospective elementary teachers’ conceptions of inquiry, measured pre and post Science Semester.

(Values represent percent of total responses obtained from 159 students.)

<table>
<thead>
<tr>
<th>Inquiry Level</th>
<th>Pre(%)</th>
<th>Post(%)</th>
<th>Sample Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terminology only</td>
<td>16</td>
<td>0</td>
<td>Experimentation [229pre]</td>
</tr>
</tbody>
</table>
| Hands-on for fun, activities | 11 | 25 | I want to do a lot of hands-on activities…rather than lectures [220pre]  
I would like for them to be excited about science and be very active in their learning, engaging in activities & having fun. [224post] |
| Hands-on for exploration, discovery, learning | 69 | 50 | I think my students would best understand the topics covered … through hands on activities [300pre]  
I want them to investigate things that are interesting or important to them. [188post] |
| Investigating to find answers to student-generated questions/interests | 3 | 25 | I should be viewed not as a presenter of knowledge, but rather as a guide, encouraging students to learn on their own & carry out experiments to find results. [255pre]  
To teach through investigations. Where students ask questions and try to answer them through investigating different topic areas to get the answer. Also, that it can be integrated w/ other subject areas. [246post] |
| Inquiry as systematic investigation (model of scientific reasoning) | 0 | 0 | |

The hands-on approach was also frequently mentioned in the focus group interviews, where the memories of enjoyable science learning that stood out the most reflected active learning experiences. Students recalled bowling in the classroom to learn about Newton’s laws, designing containers for the ever-popular egg-drop activity, and building models of cells “out of whatever we wanted to make them out of.” Through these enduring memories students attributed a particular potency to hands-on activities. Beyond their immediate utility to excite students and hold their attention, hands-on activities “stick with you over the years.”
On the post survey, the responses shifted to activity as exploration and finding answers to questions. The terms “inquiry” and “investigation” replaced “hands-on” or “activity.” While none of the students exhibited a deep understanding of inquiry within the confines of this survey, 25% moved to partial understandings of the inquiry frameworks highlighted in class, namely, questioning and using investigative strategies. We consider this an appropriate learning shift for sophomores in a teacher education program, and a productive, intermediate understanding of inquiry that can serve as the starting point for more advanced study during the final years of the program.

In addition, we were encouraged to find that students expressed a meta-awareness of the parallels between the methods of instruction in the Science Semester and elementary inquiry science teaching. It was not just that the students learned about inquiry pedagogy, but they also recognized it in action, and appreciated our attempts to practice what we preached about inquiry. As one student said in an interview near the end of the semester, “I understand what they’re trying to do. I absolutely understand it. …I want to be a good teacher. And I think that this experience has helped me a lot.”

**Academic Research Knowledge**

To examine our students’ developing concept understandings, we report on results of the open-ended ecosystems assessment (food webs). Analyses of essays written when students enter our curriculum reveal ecosystem understandings consistent with the objectives stated in the National Science Education Standards (NRC, 1996) for elementary school children (“All animals depend on plants. Some animals eat plants for food. Other animals eat animals that eat the plants.”) (see Figure 3).

**Figure 3. Initial conceptions of energy and matter in ecosystems.**

The teleological perspectives often reported for children (Driver et al., 1994) predominate. Energy is often mentioned, but entirely in the context of the sun’s energy – no connections
between energy, matter, and food are evident. The Gateway cohort received formal instruction on energy and matter interactions in the physical world; subsequently the majority of respondents in their post essays supplant the food chain conception of the ecosystem with that of an energy chain. However, approximately 35% regress again to the food chain construct as sophomores, as evident in pre-tests collected longitudinally from a subset of the initial group. Figure 4 illustrates student pre post scores from four points across their continuum courses (Gateway (First Course) pre and post, and Science Semester (Second Course) pre and post).

**Figure 4. Change in understandings across four points in time.**

Formal instruction in the Science Semester, with its inclusion of activities related to biological energy transformations, leaves its imprint in the post essays as a mix of initial understandings (aligned with middle school student expectations in related areas of the National Science Standards) or more expanded understandings (high school level of the Standards or introductory college level; (Smith & Anderson, 1984; Songer & Mintzes, 1994) of the processes of respiration and/or photosynthesis, loss of useful energy with transfers and transformations, decomposition and matter cycling.
Professional Knowledge

The preservice elementary teachers showed gains in their beliefs about their own abilities to teach with inquiry, as seen in results from the *PSTE* subscale on the STEBI-B (See Figure 5).

**Figure 5. Descriptive statistics and T-test of PSTE and STOE scores from STEBI-B.**

<table>
<thead>
<tr>
<th>Cohort</th>
<th>N</th>
<th>Pre-SD</th>
<th>Post-SD</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSTE</td>
<td>2006</td>
<td>59</td>
<td>44.85</td>
<td>6.63</td>
<td>51.00</td>
</tr>
<tr>
<td></td>
<td>2007</td>
<td>53</td>
<td>44.98</td>
<td>5.13</td>
<td>46.67</td>
</tr>
<tr>
<td></td>
<td>2008</td>
<td>41</td>
<td>47.78</td>
<td>5.04</td>
<td>52.76</td>
</tr>
<tr>
<td>STOE</td>
<td>2006</td>
<td>59</td>
<td>35.36</td>
<td>4.65</td>
<td>36.14</td>
</tr>
<tr>
<td></td>
<td>2007</td>
<td>53</td>
<td>35.60</td>
<td>3.48</td>
<td>35.17</td>
</tr>
<tr>
<td></td>
<td>2008</td>
<td>41</td>
<td>34.98</td>
<td>4.01</td>
<td>35.93</td>
</tr>
</tbody>
</table>

One group paired-sample *t*-test was used to test the significant difference in the STEBI scores. There were mixed results for gains in self-efficacy as a result of participation in the Science Semester as measured with the two sub-scores from the STEBI-B. A significant increase in the *PSTE* score was found with all three cohorts of teachers, suggesting students felt more confident in their abilities as science teachers. However, no significant difference was found in the *STOE* score, suggesting no change in their beliefs about the effects teachers can have on student science learning. These findings – significant change in the *PSTE* subscore and no change for the *STOE* sub-score - is consistent with findings from other studies on preservice teachers using the STEBI-B (Bleicher, 2004, 2006).

**Discussion**

The work presented here illustrates prospective K-8 teachers’ emergent content knowledge, PCK, and efficacy as evidenced within a reform-based design of undergraduate science and science education courses. The extent to which these understandings are a product of reform or merely par for the course is currently under analysis (through comparisons with control groups within non-reform elements of the program).

**Instituting Reform**

The structural impediments to cross-disciplinary inquiry reforms such as this are indeed daunting (Sunal et al., 2001). Our challenges ranged from identifying willing participants in each science and education department, to finding a way to move three courses into a single semester and add new science course in students’ crowded course requirements, to getting access to classrooms suitable for PBL. To make the program work, we needed to stay abreast of programmatic developments in four academic units, think creatively about scheduling, present convincing justifications to administrators and staff, and adapt to changing circumstances. Over the course of our funding, the Science Semester went from four courses to three courses in response to an overhaul of our teacher education program driven by No Child Left Behind, and then, sadly, went on hiatus in 2010 due to staffing and scheduling issues.
Although we remain committed to cross-disciplinary inquiry in our courses, we could not sustain our effort under workload policies designed for conventional courses. Effective collaboration required extra time for instructional planning, and we believed it was important to have more than one instructor in class to cultivate cross-disciplinary perspectives. This increased our instructional contact hours well beyond our departmental assignments. We have no regrets about the time we invested in the Science Semester. It changed our perspectives on our disciplines and our ongoing courses. But this experience also taught us about the cumulative toll of working under institutional policies that can be bent for a time, only to snap back into place in the absence systemic changes that are beyond our control (Justice, et al., 2009).

But even reforms that are not sustained can have important consequences. Recently some of us have taught former Science Semester students in an advanced PBL science course and noted that as juniors and seniors they have abilities as inquiry learners that they did not have as sophomores. Encouraging findings from longitudinal research on the effects of pre-service teachers’ inquiry learning experiences on their subsequent teaching (Adamson, et al., 2003) suggest that the consequences of the Science Semester will continue to emerge in our students’ lives, and in the learning of their future students.

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Author’s Note

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References


