Targeted Courses in Inquiry Science for Future Elementary School Teachers

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This study reports on targeted science courses for undergraduate childhood education majors. We describe an inquiry-oriented, three-course sequence spanning physical, life, and environmental science. All three courses are hands-on and are designed to reflect the content and pedagogy most important to future elementary school teachers. Science is not learned just as a body of information, but also as a way of knowing, thinking, and reasoning. Future teachers learn science by participating as scientists, not by being told or shown what scientists have learned. Faculty from childhood education, science education, and science collaborated on the development and delivery of the courses. We also describe a preliminary evaluation of the courses that used student performance in a subsequent science methods class, an epistemological survey, and student-completed course evaluations. Results from all three of these methods suggest that the courses are successful at improving student understanding of science and that they are well matched to the needs of the intended audience.

As is typically the case, undergraduate childhood education majors at City College of New York (CCNY) are required to take science content courses as part of their general education core. Historically, options such as survey courses or courses that cover contemporary science topics have been similar to those in many other colleges. These courses are often taught by dynamic lecturers presenting to hundreds of students from many different majors. However, these courses are not necessarily the best options for future elementary school teachers. The content is not relevant to content covered in elementary schools. The lecture-based format is in stark contrast to the interactive hands-on approach that these future teachers are taught to teach. Furthermore, the science content can be too hard for this audience to understand meaningfully. This can exacerbate the fears that many of them have about teaching science. It can also inadvertently foster an epistemology where science is seen as a collection of jargon and formulae presented in an authoritarian way, memorized, and repeated back.

With the goal of improving science education for childhood education majors, faculty at CCNY in childhood education, science education, and science developed a set of interactive, experiment-based courses where future elementary school teachers learn what science is and how it is done as they learn science content that is relevant to those who will be teaching young children. This collaboration began with childhood education faculty approaching science education faculty after recognizing the need for their students to improve their experiences learning science. These two groups had multiple conversations about the needs of the students, certification requirements, elementary science curricula, and pedagogical approaches within the childhood education program. Subsequent discussion with science faculty led to a framework and details of how the new courses would be developed and delivered.

The courses are designed to be accessible, meet CCNY general education requirements, and satisfy state teacher certification requirements. The three courses are entitled Principles of Physical Science, Principles of Life Science, and Principles of Environmental Science. They are coordinated by approach and format and span the domains of science that are most relevant to those who will teach elementary school children. In this article, we describe the three courses and an evaluation of their effectiveness.

Motivation

National reports repeatedly highlight the urgent need for improved science education (e.g., National Research Council [NRC], 2010). Despite the importance of a scientifically skilled workforce and population, the United States continues to do an inadequate job teaching science in our K–12 classrooms (NRC, 2010). In this article, we describe a new approach to teaching science to preservice elementary school teachers.

The typical approach to teaching science to this population is flawed. Elementary school teachers are often certified with an inadequate understanding of scientific concepts and of the nature of science. They are then unprepared to teach science effectively to K–5 students, leaving their students behind academically before they even get to middle school. It is the early years that lay the foundation for future learning in science, and it is also an ideal time to stimulate student interest in science. It is essential that students build solid science skills at this level to prepare for higher level science classes in middle and high school (Epstein & Miller, 2011).

The NRC (2007) describes four strands in which students should be proficient. Students should:

- know, use, and interpret scientific explanations of the natural world;
- generate and evaluate scientific evidence and explanations;
- understand the nature and development of scientific knowledge; and
- participate productively in scientific practices and discourse.

The NRC (2007) recommends the following:

> University-based science courses for teacher candidates and teachers' ongoing opportunities to learn science in service should mirror the opportunities they will need to provide for their students, that is, incorporating practices in the four strands that constitute science proficiency and giving sustained attention to the core ideas in the discipline. (p. 7)

However, most elementary teachers lack the skills described in the four strands and lack the opportunity to develop them in their college science courses. Future elementary school teachers typically enroll in lecture-style, general education survey science courses. These tend to be delivery-based, passive learning environments far removed from what is covered in elementary schools. Assessments are short-answer and multiple-choice questions that focus on memorization and recall. This is all in conflict with NRC's recommendations.

Science by inquiry for elementary education majors

In an effort to meet the aims of the NRC recommendations described previously, the unifying theme of our three-course sequence for childhood education majors is science education built around scientific inquiry fostered through multiple perspectives. Our students learn scientific concepts and theories with authentic understanding, they experience the processes of inquiry, and they reflect on their own learning (NRC, 2005). As they work through the three-course sequence, they learn the content they are expected to teach. Science is not learned just as a body of information, but as a way of knowing, thinking, and reasoning. Future teachers learn science by participating as scientists, not by being told or shown what scientists have learned. They learn a scope of science needed for the interdisciplinary, hands-on expectation of elementary school science curricula.

Curriculum and instruction are not predicated on covering a prescribed body of information or teaching toward a standardized test. These courses are an opportunity to focus on the scientific process and on depth of understanding of an accessible scope of content. Students make observations, ask questions, develop scientific models, reason scientifically, and execute authentic problem solving.

Content and approach align with the *Next Generation Science Standards* (NGSS Lead States, 2013) and the *Framework* from which the standards were based (NRC, 2012). Topical standards relevant to K–5 include Structure and Properties of Matter, Waves: Light and Sound, Energy, Interdependent Relationships in Ecosystems, and Earth's Systems. More important, students focus on themes of the *Next Generation Science Standards* and the Framework including focusing on a smaller set of disciplinary core ideas, fostering scientific practices, and learning crosscutting concepts. As discussed throughout this article, students plan and conduct experiments, make observations, and examine evidence.

Principles of Physical Science

In the Principles of Physical Science course, students learn big ideas of physical science such as operational understandings of mass, volume, density, heat, temperature, states of matter, charge, and magnets. The course is laboratory based. Students execute scientific experimental skills such as measurement, design, control of variables, and interpretation of experimental error. Much of the instructional philosophy (McDermott, 1990) and curriculum are from *Physics by Inquiry* (McDermott, 1996).

For example, students work with assorted objects and an unlabeled pegboard balance. They describe attributes of the objects in their own words and look for patterns of behavior of the objects hung from the balance. They operationally define mass in terms of the number of standard units (at first square nuts, then grams) that balances an object. Students have the opportunity to explore observable phenomena, define technical terms based on ideas they are constructing, and design and execute simple experiments to answer relevant questions (e.g., Does it matter where on the pan I place the objects? Design and execute an experiment to answer the question).

Students explore questions such as: How do we interpret the number obtained by dividing mass by volume? (The technical word *density* does not constitute an interpretation.) How do we interpret the number obtained by dividing volume by mass? How do we visualize, in terms of the kinetic molecular model, the dissolving of a substance in water? Why do we believe there are only two varieties of electrical charge? How can we account for how a charged rod is attracted to a pith ball? (Arons, 1976). Students learn fundamental properties of physical science through experimentation; know how these ideas were constructed; and in the process, learn the tools and language used by the scientific community.

Assessment includes interactions with instructor during laboratory activities, problem-based tests on physical science content, and group-conducted experimental measurements in exam settings. This is in contrast to most other college science course options and is more aligned to the needs of future elementary school teachers.

Principles of Life Science

The Principles of Life Science course seeks to excite students about the evolutionary context of the biodiversity that they encounter daily and to motivate them to bring their future elementary school students outside to experience the nature of New York City's environment (Catley, 2006; Wandersee & Schussler, 2001). As such, the course focuses on plant and animal biodiversity that is readily accessible in New York City, in this case street and park trees and local arthropod species. Students begin by noticing fruit, leaf, flower, and small animal diversity. They then closely examine the characteristics of these living things to identify and group trees and animals by common ancestry. They learn to recognize and group trees on the basis of leaf arrangement, shape, and fruit and flower structure. Similarly, they examine arthropods to determine the characteristics most useful for identifying and grouping these animals together. Students observe insect life cycles and organize their life stages by their similarities and differences. Students use cladistics to make a tree of life of the plants and animals they observed throughout the semester. Once students develop a sense of the patterns of evolution, the class shifts focus to the processes that drive evolutionary change. With a special focus on the evolutionary mechanism of natural selection, students engage in an open-ended inquiry activity to explore the role of variation in natural selection of winged samara fruits (Thomson & Neal, 1989). They then apply what they learned to natural selection generally.

The course is based on indoor and outdoor laboratory activities integrated with interactive instructor-led discussions. Students identify trees and conduct investigations to understand characteristic features that define different groups of living organisms. They design and execute their own research protocol to conduct an independent study of tree life cycle events (i.e., timing of leaf fall). They also use graphs for visualizing and interpreting their data.

Assessment includes performance on life science content tests, independent research project design and execution, natural selection experimental design and execution, and interactions with instructor during in-class laboratory activities.

Principles of Environmental Science

In the Principles of Environmental Science course, students engage with the big ideas of environmental science, including systems and interactions, patterns of change, and measurement and uncertainty. The students investigate the components of Earth System Science, making observations and collecting data on the atmosphere, hydrosphere, pedosphere, and biosphere. Through these investigations they learn content appropriate to elementary school science including weather, water, and soils. They also gain an understanding of how these components interact. By observing and interpreting data regarding these interactions, they gain understanding of natural phenomena.

Students are able to execute scientific process skills such as observation and inference, classification, experimental design, control of variables, data analysis, and interpretation of experimental error. Students also engage in a long-term investigation on plant phenology, which allows them to deepen their understanding of biogeochemical cycles within an accessible context for both elementary teachers and students (Bombaugh, Sparrow, & Mal, 2003). Students use graphs for visualizing and interpreting their data. They conduct environmental testing using GLOBE protocols (www.globe.gov) by collecting atmosphere, soil, and hydrologic data from the local environment to increase their understanding of the interactions between Earth systems and the big ideas of environmental science. Supplementary readings help students to deepen their understanding of science concepts and processes. Students also access secondary data sources using the internet to deepen their understanding of global climate change and its consequences for the New York City region.

Assessment includes performance on environmental science content tests and individual long-term science investigation involving budburst and green-up that culminates in a formal research report. It also includes a group problem-based learning activity in which the students are asked to research the effects of global climate change on New York City and propose a possible intervention to deal with the consequences of global climate change on the local environment. The students present their findings at a mock City Council hearing, and the class evaluates the different proposals.

Gauging success

Qualitative feedback has been extremely positive. Waiting lists for the courses fill early as we have been phasing up the offerings of the courses. Unsolicited feedback to the instructors and childhood education advisors has been strong. In addition, the following evaluations suggest that the instruction is successful.

Science in elementary education grades

It is hard to document learning in courses such as the science principles sequence. It is even harder to compare with other course options, particularly because prior to the science principles sequence, students chose from a large array of standard general education science course options. However, we do have a window into student performance beyond their work in our courses. There were 154 different students who completed at least one of the science principles courses by the fall of 2013. Of these, 61 had taken the required subsequent Science in Elementary Education course (EDCE 42000) and received a grade by the spring of 2014. EDCE 42000 is a course without content alignment to the science principles courses. Although EDCE 42000 is not a science content course, there would be a benefit to having a solid understanding of the process of science to succeed in the course.

In EDCE 42000, childhood education students who graduated from at least one of the science principles courses outperformed those who graduated from all other science course options:

Average grade (Principles of Science graduates): 3.50 / 4.0 ($N = 61$)

Average grade (all other students): 3.27 / 4.0 ($N = 167$)

The differences in mean and median are statistically significant (one-sided p-value = .0076 and .035, respectively) between students who had taken a science principles class and those who had not. A total of 39% of students who had taken a science principles class received an A in EDCE 42000 as opposed to 25% of students who had not. Only 3% of students who had taken a science principles class received a grade of C or less in EDCE 42000, as opposed to 6% of students who had not.

The improved performance is significant despite the high average of all students and nonoverlapping subject matter. Furthermore, because the science principles courses are relatively new, 48 of the 61 students took only one course of the three-course sequence. These results suggest that taking even a single science principles course improves scientific understanding enough to impact performance in a course on the teaching and learning of science.

Epistemological survey

In one of the courses (Principles of Physical Science), a 17-item epistemological survey (based on Redish, Saul, & Steinberg, 1998) was administered pre- and postinstruction to a class of 16. For each question, students were asked whether they agree or disagree with each item. A response of 1 indicated *strongly disagree* and 5 *strongly agree*. As detailed in the Redish et al. (1998) article, each item is intended to probe how students think about science and how it is learned.

TABLE 1

Representative epistemological survey items with average pre- and postresponse scores.

	Item	Preresponse average	Postresponse average
1	When real-life experiences differ from what is learned in a science textbook, the real-life experience should be ignored in order to learn the science well.	1.47	1.13
5	Creativity is a useful skill that is often utilized in learning science.	4.00	4.09
6	Learning science is a matter of acquiring knowledge that is specifically located in the definitions, principles, and equations given in class and/or the textbook.	2.73	1.06
13	Each field of science has its own set of theories, equations, and definitions, few of which have connections with the other fields.	2.33	1.50
15	A good textbook is the most useful tool in learning science.	2.60	1.56
16	When learning science, understanding the concepts and the connections between them is more important than memorizing formulas and definitions.	4.33	4.91

Representative survey items are shown in Table 1. From this table, items with which most experts would want students to agree are numbers 5 and 16. Items with which most experts would want students to disagree are numbers 1, 6, 13, and 15.

For each of the 17 survey items, the average student response moved in the direction toward agreement with expert perspective. Table 1 includes pre- and postaverages for the items listed. The average change for all 17 items was 0.83. The average agreement with experts on the presurvey was 3.59 out of 5. The average agreement with experts on the postsurvey was 4.42 out of 5. (In these averages, data for the items where experts would disagree were inverted so that 5 was most expert-like and 1 was least.)

On the survey, students were given the opportunity to include any comments for each item. For item 6, Hoda (not her real name) wrote on the presurvey: "In order to know science, it is crucial to acquire knowledge from textbooks that we can then later use in real life" while circling 4. On the postsurvey, Hoda wrote: "Learning science happens everywhere even outside a classroom setting" while circling 1. Rosa wrote next to this item on the posttest: "You can't learn everything from a book. In fact our book gave us questions to answer not answers to our questions."

As another example, for item 15, Lakeeta wrote on the presurvey: "Textbooks help with memorizing key formulas and theories" while circling 3. On the postsurvey she wrote: "Textbook can enrich understanding but it does not teach the science" while circling 2.

Course evaluations

We administered anonymous questionnaires in each of the three courses. The evaluation asked, "How effective do you feel each of the following items were in helping you learn science?" Students were then given a 5-point scale with 1 being *not at all helpful* and 5 being *extremely helpful*. Between 5 and 7, major course-specific activities were then listed—for example: "properties of matter activities" for Principles of Physical Science, "tree identification activities" for Principles of Life Science, and "long-term investigation: budburst/green up" for Principles of Environmental Science. In addition, students were given the opportunity to add other comments related to the course.

The average response was 4.46 +/-0.74 out of 5 across all courses and items (a total of 5 sections and 98 student responses), with 58% of all responses being 5 and 31% being 4. Open-ended comments were also uniformly supportive. Representative comments follow:

- "Hands on activities along with allowing us to think for ourselves helped us actually learn better and gave a greater excitement to being correct than memorization and repetition."
- "This course has made me feel comfortable and confident about science. Thanks!"
- "Great class. Love the hands on work, it was the most valuable and fun thing about the class."
- "I valued that during the semester we were able to conduct real investigations and relate it to the concepts of environmental science."
- "You kept reinforcing that science education is about action and hands on, not about memorizing. But the best part was that you practiced what you preached and had us actually do it and that was a beautiful thing. I honestly won't forget this stuff for the fact that I didn't have to memorize babble from a book."

Conclusions

We found that undergraduate childhood education majors thrive when given the opportunity to participate in our targeted science courses. They learn content relevant to what they will teach. They dramatically improve their perspectives on the nature of science and how it is learned. They participate enthusiastically. Our results suggest that their experience has positive lasting effects. The keys to our approach include active, contextual inquiry-based curricula; cooperative participation of science and education faculty; and a coordinated approach through the different required science courses.

We believe that the basic approach that we have used can be replicated at many institutions with an undergraduate childhood education program. CCNY is an urban public college with a diverse student demographic. However, our childhood education majors are typical of many future elementary school teachers. They are enthusiastic students and learners with limited backgrounds in math and science. They focus their studies on preparing for their future careers, but they complete a standard general education curriculum including several science classes. The most important feature of our ability to implement these courses was faculty in science with knowledge of science education collaborating with faculty in childhood education. We then together leveraged appropriate existing curricula that match local context and used the philosophy described in this article. ■

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