

A 20-year Journey in Elementary and Early Childhood Science and Engineering Education: A Cycle of Reflection, Refinement, and Redesign

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Abstract

Over the past two decades, science and engineering education faculty at Towson University have implemented a number of course innovations in our elementary and early childhood education content, internship, and methods courses. The purposes of this paper are to: (1) describe these innovations so that faculty looking to make similar changes might discover activities or instructional approaches to adapt for use at their own institutions and (2) provide a comprehensive list of lessons learned so that others can share in our successes and avoid our mistakes. The innovations in our content courses can be categorized as changes to our inquiry approach, the addition of new out-of-class activities and projects, and the introduction of engineering design challenges. The innovations in our internship and methods courses consist of a broad array of improvements, including supporting consistency across course sections, having current interns generate advice documents for future interns, switching focus to the NGSS science and engineering practices (and modifying them, if necessary, for early childhood), and creating new field placement lessons.

Introduction

Over the past two decades, science and engineering education faculty at Towson University have implemented a number of course innovations in our elementary and early childhood education content, internship, and methods courses. Some of these changes were the result of external factors – such as the switch in national standards to the *Next Generation Science Standards* (NGSS Lead States, 2013) – while others were enacted to address internal challenges.

The innovations in our content courses can be categorized as changes to our inquiry approach, the addition of new out-of-class activities and projects, and the introduction of engineering design challenges. The innovations in our internship and methods courses consist of a broad array of improvements, including supporting consistency across course sections, having current interns generate advice documents for future interns, switching focus to the NGSS science and engineering practices (and modifying them, if necessary, for early childhood), and creating new field placement lessons. These modifications are described in detail in this comprehensive overview of our science education courses from 2001 to the present day.

The purposes of this paper are to: (1) describe our course revisions so that faculty looking to make similar changes might discover activities or instructional approaches to adapt for use at their own institutions and (2) provide a comprehensive list of lessons learned so that others can share in our successes and avoid our mistakes.

Institutional and Historical Context

Institution, department, and program structure

Towson University (TU) began as a teachers college, and the tradition of developing highly qualified teachers continues as our institution graduates the largest number of education majors among all universities in our state. Currently 1,274 undergraduate and 1,286 graduate students are enrolled in TU teacher education programs. Over 1,100 of those undergraduate students are working toward an elementary education (ELED) degree, early childhood education (ECED) degree, or dual degree involving one of those specialties. ELED certification is for grades 1-6, and ECED certification is for birth through grade 3.

TU is one of the few universities nationwide to have a significant number of education faculty housed in its science content departments. For example, our home department – the Department of Physics, Astronomy & Geosciences (PAGS) – includes six tenured and tenure-track education faculty members, all of whom teach science and engineering education courses for early childhood and/or elementary programs. These positions are not joint appointments with education departments, but positions solely within our content department. These education faculty have the same qualifications as science education faculty in any college of education, including a doctoral degree in science education, curriculum & instruction, or a closely related field.

Each year, the PAGS department offers approximately 50 sections of elementary and early childhood science/engineering content, methods, and teaching internship courses. Typically, 48% of sections are taught by tenured or tenure-track faculty, 10% are taught by other full-time faculty (lecturers and coordinating staff), and 42% are taught by part-time faculty.

Science coursework in the elementary and early childhood programs

Table 1 shows the required science content, internship, and methods courses for elementary, early childhood, and dual education majors at TU.

Table 1 (Click on image to enlarge)

Required Science Content, Internship, and Methods Courses at Towson University

Course	Elementary Education Majors	Early Childhood Majors	Dual Majors
Physical Science I	X	X	X
Biology: The Science of Life	X	X	X
Earth-Space Science	X		some
Life Sciences	X		some
Teaching Science in Elementary School	X		some
Teaching Science in Early Childhood		X	

Notes: X = required course for the major. Some = required course for some dual majors. Dual majors include elementary education/special education, elementary education/early childhood, and elementary education/deaf studies.

ELED and ECED majors are competitive (“screened”) majors, so interested students initially enroll as pre-ELED and pre-ECED majors. Physical Science I and Biology: The Science of Life are taken during the pre-major period. Later in their academic careers, junior-level ELED majors complete a “mathematics and science” semester, which is a semester solely dedicated to the content and methods of mathematics and science instruction. The science courses taken during this semester are Earth-Space Science, Life Sciences, and Teaching Science in Elementary School (a teaching internship). Instructors of the ELED internship and content courses collaborate during the mathematics-science semester in cases where the elementary interns teach science content that is concurrently being learned in the life science or Earth-Space courses. The only science course taken by ECED majors after the pre-major courses is a junior-level methods course: Teaching Science in Early Childhood. The ELED and ECED junior-level courses are taught in a cohort format, meaning that the same group of students takes all of their courses together.

Table 2 shows how many sections of each science education course are offered by PAGS. The life sciences courses are offered by another department, so they are not discussed here.

Table 2 (Click on image to enlarge)

Number of Sections per Semester for Each Science Education Course

Course	# of course sections per semester	Maximum enrollment per section
Physical Science I	5	28
Earth-Space Science	5 to 8	18
Teaching Science in Elementary School	5 to 8	18
Teaching Science in Early Childhood	3 to 4	18

Physical Science I (4 credits, 6 hours of weekly class time). Students investigate topics in physics and chemistry. In this active learning course, students increase their understanding of science concepts via hands-on and computer-based investigations, connections to prior knowledge and everyday experience, and small-group and whole-class discussions.

Earth-Space Science (3 credits, 4 hours of weekly class time). This is similar to Physical Science I in pedagogical style and structure, except that it focuses on light, geology, astronomy, and climatology, and includes a component in which students engage in engineering challenges that are connected to each of the science content units.

Teaching Science in Elementary School (3 credits, 4 hours of weekly class time). This is an internship course with embedded teaching methods that meets once per week at an elementary school site. Typically, each section of the course is placed in a different school. The course helps preservice elementary teachers (“interns”) learn and practice methods of standards-based science teaching and engage in self-reflection and improvement. Course activities include the weekly teaching of a 45-to-60-minute science and/or engineering lesson, coaching from the classroom mentor teacher, lesson planning under the supervision of the course instructor, and methods/content discussions and activities. The planning sessions and methods/content activities are typically conducted in a central meeting space (e.g., an unused classroom) provided by the school.

Teaching Science in Early Childhood (2 credits, 2 hours of weekly class time). This methods course for preservice early childhood teachers meets once per week. There is a limited internship component, in that the interns teach three different science and/or engineering lessons (e.g., Lottero-Perdue, Bolotin, Benyameen, & Metzger, 2015; Lottero-Perdue et al., 2016; Lottero-Perdue, Sandifer, & Grabia, 2017) in local pre-school, kindergarten or first grade classrooms.

Historical background: Guiding principles of instruction

From 1970 to 2000, the pedagogies in TU’s science content, internship, and methods courses were largely based on a three-part learning cycle borrowed from the Science Curriculum Improvement Study (Karplus, 1964): exploration, concept development, and concept application. At that time, the course philosophy was such that lessons were only lightly guided by the instructor as students engaged in an open-ended exploration of science equipment and ideas. Classroom activities were typically adaptations of lessons from the well-known science curricula developed in the 1960s, such as Elementary Science Study (Elementary School Science Project, 1966) and the Conceptually Oriented Program in Elementary Science (Center for Educational Research, 1967).

Course Innovations Over the Past 20 Years

One purpose of this paper is to focus on course-level improvements occurring after year 2000 that help our preservice teachers better understand science and engineering content and teaching methods. Thus we describe here the major instructional innovations that have been implemented in four of the core ELED/ECED science education courses offered by the PAGS department:

- **Physical Science I:** We switched to a more structured/guided form of scientific inquiry and introduced at-home experiments, field trips, and video projects.
- **Earth-Space Science:** We incorporated science-integrated engineering design challenges (i.e., challenges that reinforce and apply science content knowledge).
- **Teaching Science in Elementary School:** We ensured consistency across all course sections, introduced peer advice documents (see below), and switched focus to the *NGSS*
- **Teaching Science in Early Childhood:** We added a field placement component, switched from an inquiry focus to an emphasis on *NGSS* practices, and distilled and reworked those practices into a smaller subset appropriate for early childhood.

Physical Science I

Switching to a more guided/structured form of scientific inquiry. In its early years (1970s to early 2000s), in its low-guidance open inquiry format, this course had been a common source of complaints from students, part-time faculty, and education department chairs. In overhauling the course from 2003 to the present day, hundreds of hours have been spent writing and rewriting a new course text and accompanying teacher’s manual (Sandifer, 2019). Overall, the text was transformed from a loose set of investigative guidelines into an active learning workbook representing a structured/guided inquiry format (Banchi & Bell, 2008), which has been successful in improving student learning and reducing course complaints.

Appendix A shows “before” and “after” versions of a specific activity on area and volume, demonstrating how densely packed statements, questions, and guidelines were transformed into a more structured activity that provided more blank space on the page for student notes and results.

Comparing student grades prior to the curriculum change (1998-2003) to grades immediately afterwards (2003-2005), over one-quarter of the students (28.2%) regularly received a D or F in the physical science course before the curricular change and fewer than one-tenth of students (6.8%) received a D or F in the course after the change. Some of the class instructors from 1998-2000 also taught during 2002-2004, so the differences in grade distributions cannot be solely attributed to differences in instructors, grades, or expectations.

The revised curriculum is still in use by some Physical Science I instructors. Other instructors use *Next Generation Physical Science and Everyday Thinking* (Goldberg et al., 2018), which is similar in its structured approach.

At-home experiments. Nationwide, science education faculty have a strong commitment to helping students connect science content and investigations to their everyday lives. At our institution, we’ve modified our courses over time to meet this goal in a variety of different ways.

In Physical Science I, one real-life connection has been the addition of at-home experiments. In these experiments, the class is presented with a focus question (aka inquiry question or essential question) that individual students must investigate on their own over an extended timeframe: from one to two weeks to a full month. An at-home experiment involves classroom pre-discussions (including relevant safety issues), obtaining the necessary equipment (from our STEM Education Resource Center, if needed), conducting the experimental procedures, a brief write-up of procedures and results, a sharing of data with group members and the entire class, and a final whole-class consensus on the valid scientific conclusions that can be drawn from the students' collective data.

Early iterations of the at-home experiments were not as successful as we hoped, so the at-home portion of the course text has been augmented with increased pre-experiment support. For instance, in our at-home experiment on the factors affecting evaporation, we initially left it up to the students to determine how to operationally define and measure evaporation rate, which meant that different students ended up with very different measurement procedures—which made it difficult to draw valid conclusions during the consensus discussion. In the latest version, a comprehensive in-class discussion occurs prior to experimentation so that students can agree on acceptable procedures (among other issues) before the experiments begin.

Appendix B is an excerpt from the course text that illustrates the pre- and post-experiment discussions and final expected write-up.

Field trips. To help make Physical Science I more realistic and relevant, some course instructors take students on field trips to local science centers, nature centers, or local attractions (e.g. bowling alley, laser tag facility, indoor skydiving facility, railroad museum). Over the years, different group assignments (three to four students per group) have been associated with these trips:

- Critiquing the field trip site by making a PowerPoint photo journal that describes 10 attributes of the site and 10 challenges or downsides of the site.
- Writing a two-page paper about how they would plan/conduct a trip for early childhood or elementary students to the site, including recommendations for parent chaperones.
- Creating a brief video that makes connections between the course content and the local science center/museum or attraction. For example, one course instructor takes students to a local bowling alley and asks students to create a six-minute infomercial video which explains how course content (e.g. motion, interactions, and forces) can be related to bowling.

To ensure field trips run smoothly, faculty members have students complete liability waiver forms for both the university and field trip site (if needed) prior to the trip; the forms are brought along since they contain emergency contact information. If students drive to the site

on their own, it is helpful for faculty members to provide students with the meeting location and parking information.

Earth-Space Science

Although we continuously improve all aspects of the Earth-Space Science course and its associated course text (Sandifer & Lottero-Perdue, 2018), the most significant change over the last decade has been the incorporation of “science-integrated” engineering design challenges, which are engineering challenges that reinforce or apply science content knowledge. This effort began in 2008 when the second author, having received training at the Engineering is Elementary (EiE) Teacher Educator Institute, incorporated a geotechnical engineering unit into her instruction: *A Stick in the Mud: Designing a Landscape* (EiE, 2011a).

Unlike the *National Science Education Standards* (NSES, 1996), the *Next Generation Science Standards* (NGSS) (NGSS Lead States, 2013) explicitly include engineering as a part of science education for kindergarten through grade 12. With the release of the NGSS, it became clear that engineering learning experiences for early childhood and elementary majors at our institution (a) shouldn’t be limited to a single instance and (b) should be available to all students, no matter who their instructor might be. To accomplish these goals, we incorporated a science-integrated engineering design challenge into each unit: using mirrors to cause a laser beam to hit a target in the light unit; building and using a quadrant to track the height of the Moon (Lottero-Perdue & Sandifer, in press) in the astronomy unit; and identifying the best build site for a TarPul transportation system (a modified EiE geotechnical activity, used with permission) in the geology unit. Additionally, we created a short unit to be taught during the first week of class to introduce students to engineering and an end-of-semester project in which students create a video presentation (see Appendix C) to describe their design.

Teaching Science in Elementary School

As much as we value our science teaching internship, this course has faced significant problems over the years. From 2001-2005, instructor and intern complaints about the course had been steadily increasing, prompting us to tackle different challenges to provide a better experience for all parties involved. Follow-up investigations revealed that different sections of the course were no longer uniform in terms of the number of lessons taught, the number of interns per classroom, feedback on the interns’ science teaching, and the degree to which each section focused on the national standards. We were awarded a Physics Teacher Education Coalition grant to address these significant issues (Sandifer, Lising, Tirocchi, & Renwick, 2019). The project team, including a full-time elementary teacher-in-residence, engaged in a number of activities to improve the course. The grant-related modifications and

subsequent changes led to the creation of a unique course unlike most other science teaching internships. The grant ended in 2007, but all course innovations have been sustained to the present day.

Course logistics. The Teaching Science in Elementary School course is not a methods course, but a teaching internship in which our junior-level ELED students (“interns”) learn to teach by teaching. The course meets once per week for 3 hours and 50 minutes. The first two to three weeks of class take place on the university campus; after that, class meets at the elementary school site. When the interns enter the course, they possess general knowledge about planning, teaching, and assessment in the context of literacy and reading – but nothing related to science and engineering instruction in particular.

During the on-campus sessions, the instructor has the interns engage in methods activities pertaining to specific instructional topics (e.g., the NGSS scientific practices), observe videos of real-life science instruction, experience NGSS-aligned science lessons (usually related to the science content that the interns will be teaching), and participate in pedagogical discussions about all of the above.

When the interns’ elementary school teaching begins, the class becomes a blend of preparation, teaching, reflection and methods. Table 3 shows a sample schedule for a class meeting.

Table 3 (Click on image to enlarge)

Sample Daily Schedule for Teaching Science in Elementary School

Activity	Start and End Time	Duration
Teaching preparation	12:30 to 1:00 pm	30 min
Teaching and clean-up	1:00 to 2:00 pm	60 min
Methods instruction	2:00 to 3:00 pm	60 min
Content review	3:00 to 3:30 pm	30 min
Lesson planning	3:30 to 4:20 pm	50 min

One key innovation is that we place multiple interns in the same classroom at the same time, with each intern (or pair of interns) teaching science to his or her own small group of four to six students (Sandifer, Hermann, Cimino, & Selway, 2015). For some teaching sessions, interns in the same classroom teach the same lesson in parallel to their own groups; for other teaching sessions, the interns plan a stations-based lesson in which students rotate from station to station (i.e., from intern to intern) to participate in different activities related to the same general topic (e.g., forces). To foster collaboration and the creation of high-quality lessons, all interns sharing a classroom plan their science lessons together with the help of the course instructor.

The benefits of a multiple-interns-per-classroom teaching structure include:

- For each course section, it is only necessary to recruit three to five classrooms at a single elementary school.
- Since all interns are placed at the same school, it is possible to mentor every intern every day and observe each intern regularly.
- Interns who are new to teaching are less intimidated when instructing a small group of students, as opposed to an entire class.
- By the end of the course, most interns have learned that collaborative lesson planning is a useful process that results in better lessons than what any one intern could produce individually. Ideally, the interns continue to plan lessons collaboratively during student teaching and after graduation.
- In a small-group setting, the interns get to know their students' thoughts, strengths, and personalities in a deep and meaningful way, and are able to focus squarely on the pedagogical issues that are relevant to inquiry-based science teaching (idea development, questioning, etc.).

The burdens placed on the host schools and mentor teachers are minimal. Each school provides a single meeting space, and the mentor teachers are responsible only for briefly observing 1-2 interns per school visit. The primary benefits to the teachers and students are: (a) the mentor teachers are paid \$35 per supervised intern (from our college budget) and (b) the elementary students receive high-quality science instruction that they might not otherwise receive because science is sometimes omitted in local K-5 classrooms in favor of additional mathematics or literacy instruction.

The science curriculum. The course instructor provides lesson outlines to the class for all teaching sessions. These are modified versions of lessons from the school district's science curriculum, and are provided 1 to 2 weeks in advance of the interns' actual instruction. Parts of each lesson outline ("lesson template") are filled in by the instructor and parts are left blank. (See Appendix D for an example.) During planning, the interns work together to fill in the missing portions of the lesson outline; missing sections might include key science concepts, focus questions, lesson engagement, or specific lesson activities. As the semester progresses, the fraction of each lesson plan that must be filled in by the interns is gradually increased.

The science lessons provided by the school district are modified by the course instructor to fit into the allotted teaching time, to ensure a smooth conceptual flow from one lesson to the next, and to more fully align with the NGSS scientific practices. In this manner, we aim to close the theory-to-practice gap by ensuring that the teaching methods taught in the internship are actually implemented in schools. Similarly, we emphasize throughout the course that standards-driven lesson modification is expected and encouraged after graduation, as long as the key science concepts are preserved.

On-site methods instruction. Once the class shifts to teaching at the school site, discussions about effective instruction continue whenever instructional issues arise; these discussions are typically in person, though they are occasionally over email. As appropriate, ongoing methods discussions take a variety of different forms: one-one-one discussions between the course instructor and the involved intern, small-group discussions between the instructor and the intern group assigned to a particular classroom, and whole-class discussions regarding common instructional issues. The discussion topics might include active learning, the scientific and engineering practices, the 5E lesson format, pedagogical content knowledge, safety, or class management.

Typically, interns are officially observed four times per semester: twice by the course instructor and twice by their mentor teacher. The interns receive a written report after each observation. As their schedule allows, each mentor teacher will also meet with their intern group to provide feedback, share words of wisdom, and take questions from the interns about specific students, science instruction, or teaching in general.

Faculty from other institutions are sometimes surprised to learn that our institution does not have a science methods course for ELED majors, per se, but it is a 50-year-old feature of our elementary program that we appreciate and value. The immersive structure of our internship allows instructors to organically and spontaneously address issues “in the moment” as they arise via reflections, post-teaching debriefings, and observations from mentor teachers and university instructors. The internship in this manner resembles an apprenticeship model of learning within a community of practice (Lave and Wenger, 1991) in which the interns learn by doing and through scaffolding by the university instructor, mentor teacher, and curriculum.

Maintaining a consistent focus on inquiry- and standards-based science and engineering instruction. When concerns about our internship course first arose, it became obvious that there was insufficient attention given to the mentoring of full- and part-time instructors in the different course sections. Prior to our improvement efforts, the only support provided to new instructors was a course syllabus, which unsurprisingly led to dramatic differences in course implementation. Once the deeper organization and oversight issues of the internship course were unearthed, faculty became motivated to rein in the course by reestablishing course goals, teaching certain course sections themselves, and providing instructor and mentor teacher workshops.

Three years of data collected from teaching observations, end-of-semester surveys, and course assignments revealed that, as a result of our course improvements: the interns spent more time teaching and less time observing; the interns’ science lessons focused more frequently on scientific investigations and the communication of ideas rather than scientific demonstrations and lectures; and the interns’ attitudes and beliefs about science and science teaching shifted in a more positive direction (Sandifer, Lising, & Renwick, 2007; Sandifer, Lising, & Tirocchi, 2006).

The sustainability aspect that has proven to be most effective in maintaining our successes and innovations has been the hiring of a full-time Elementary Science Internship Coordinator. This staff member's job duties include teaching one section of Teaching Science in Elementary School per semester, conducting the instructor and mentor teacher workshops, ensuring that mentor teachers are paid for their course participation, observing new instructors, serving as liaison with our College of Education, negotiating with schools about the science units to be taught, helping instructors obtain access to the district science curricula, and other key components of course management.

The instructor workshops consist of two 90-minute sessions that cover all aspects of the course (assignments, course logistics, the philosophical underpinnings of the course, interfacing with schools, the campus- and school-based course meetings, and so forth), whereas the mentor teacher workshops are single-session, 90-minute overviews that cover general course goals, connections between the interns' science lessons and the national standards, and the responsibilities of the course instructor and mentor teachers. Teaching Science in Elementary School is a mid-program internship that is significantly different from student teaching, so the responsibility for the course activities rests primarily on the shoulder of the university instructor rather than the mentor teachers. As such, the only requirement for being a mentor teacher is having at least three years of teaching experience.

Introduction of peer advice documents. As a means of making the internship course more meaningful and authentic, a novel assignment was introduced into the course. The assignment requires each semester's interns to write an end-of-semester advice document directed at the following semester's interns. The purpose of the document is to provide direct but friendly guidance about the internship's teaching activities and the course in general. This is the brief "advice document" question that each intern answers independently as part of the final exam:

What general advice would you give next semester's interns about effective elementary-level science teaching? (I will compile all of your advice into a handbook and distribute it to next semester's interns.) [500 words minimum]

The interns take the assignment seriously, often writing far more than the suggested 500 words – in part because they received a similar advice document at the start of the semester and appreciated its honesty and usefulness.

A detailed analysis of four years of advice documents (Sandifer, 2010) found that the interns' advice statements tend to fall into four categories: emotional support and encouragement, teaching tips, expectations and tips related to the research context, and philosophical and motivational advice about professional growth. Only two percent of advice documents contain what might be construed as "bad" advice. Ultimately, the advice document has been deemed a success, both as a summative reflection for current interns and help and support for future interns.

Recently, we have implemented a change that the advice documents are not only reflected upon at the beginning of the semester – they are also revisited in mid-semester. During the first few weeks, the interns are just starting their journey and the lessons that they take away from the advice documents are extremely broad: that everything will be all right, that the course instructor is an important source of support, and that they will survive and grow as a science instructor. As the semester progresses, the interns are eager for more detailed bits of wisdom, such as strategies for encouraging discussion and managing equipment. Thus re-exposing the interns to the advice document halfway through the semester has proven to be an invaluable source of inspiration and insight for our preservice teachers.

Including science-integrated engineering design. Since the 1970s, the units taught by the interns to local elementary students had always been pure science units (e.g. geology, astronomy, and the physics of motion). This changed in 2012, when some sections taught integrated science and engineering. Currently, in each course section, the decision to use a pure science or blended science/engineering unit is based upon the school system's curriculum and the interests of the host teachers and university instructor.

A recent science/engineering unit integrated rocks and minerals science with the materials engineering from the EiE unit *A Sticky Situation: Designing Walls* (EiE, 2011b; Lottero-Perdue, 2017). Other blended units taught by interns include pollination and agricultural engineering (EiE, 2011c), light and optical engineering (EiE 2011d), and environmental engineering challenge related to weathering and erosion (Lottero-Perdue, Haines, Baranowski, & Kenny, in press). Altogether, over 155 interns total have taught a science-engineering unit in the internship since 2012.

Switching focus to the NGSS scientific practices. As mentioned previously, the advent of the NGSS caused us to move our language away from “inquiry” toward scientific and engineering practices. To help our students grasp this new approach, we devised a document (see Appendix E) that summarizes: 1) the three-dimensional structure of the NGSS and 2) how scientists and elementary children engage in each of the science and engineering practices.

Throughout the semester, individual practices are addressed as they arise in particular lessons. In any given semester, there are approximately 10 teaching visits and thus 10 lessons, leaving ample room to address most or all of the practices. For each lesson, the internship instructor selects a relevant practice to highlight, and then the interns describe in their lesson plans the ways in which the lesson addresses different aspects of the chosen practice. For example, for a lesson in which the elementary students make sense of an experiment and explain the results, the interns may have to describe in their lesson plans how students will be Engaging in Argument from Evidence (Practice 7). A lesson in which elementary students create and test a design to solve a problem would likely involve the interns describing how their students will engage in Designing Solutions (Engineering Practice 6).

Teaching Science in Early Childhood

Throughout its history, the two biggest challenges with the ECED methods course have been that 1) we have so little time to teach it (only two hours per week) and 2) this single course is the entirety of science and engineering methods education for these future teachers, partly because ECED majors are unlikely to teach science or engineering during student teaching.

Adding a field placement. One of the earliest changes was to add a field placement to the course. We wanted to make the teaching methods more authentic, enabling the interns to see how the larger ideas are relevant to real children's science learning. We began by having the interns teach at an on-campus childcare center, but as the program grew and we desired to focus on a slightly older student population we switched to kindergarten and first grade classrooms.

Our placement involves three teaching visits. As with our elementary science internship course, we typically have four or five interns per classroom, with each intern teaching a small group of children. The field placements are sufficiently important that we dedicate over one-fifth (6 hours) of the 30 semester hours to the placements.

Including and modifying the NGSS practices. Older versions of the ECED course emphasized the principles of inquiry (see Appendix F) that we created and refined over the years, which were aligned with the *National Science Education Standards* in effect at the time (National Research Council, 1996, 2000). With the release of the NGSS, we shifted from our inquiry principles to the NGSS practices.

Our early attempts to address the practices taught us that it is not feasible to address all eight scientific/engineering practices with equal depth and attention in a meaningful way, particularly given the time constraints of the course. So we chose to emphasize a subset of practices that serve as the basis of most high quality hands-on investigations for early childhood: Making Reasoned Predictions, Carrying Out Investigations, Analyzing and Interpreting Data, and Engaging in Argument from Evidence.

Technically, reasoned predictions fall under "Engaging in Argument from Evidence" in the NGSS, but we split off predictions into a separate practice to more strongly encourage our interns to prompt students for predictions and reasons. Experience has shown that, when implementing science lessons at the field placements, interns frequently forget to ask for predictions at all – and when they do they often forget to request that students share their reasons.

With regard to the engineering practices, we emphasize the need for children to be able to articulate the problem, constraints, and criteria in their own words. For kindergartners and younger students, we refer to the latter two constructs together as the "rules" for a challenge (Lottero-Perdue et al., 2016). We also emphasize the importance of children designing solutions in a systematic, iterative way through the use of a design cycle. In this way, we are

addressing the Defining Problems and Designing Solutions within the NGSS practices (NGSS Lead States, 2013). A critical piece was the creation and inclusion of a simplified engineering design process for early childhood: Ask, Imagine, Try, and Try Again (Lottero-Perdue et al., 2016), which is a modification the EiE design process (Ask, Imagine, Plan, Create, Improve) used in our ELED courses. The ECED engineering design process is introduced via a tower design challenge (Lottero-Perdue et al., 2015). We also include two science-integrated design challenges that illustrate how engineering challenges can reinforce and apply science content learning (Lottero-Perdue et al., 2016; Lottero-Perdue, Sandifer, & Grabia, 2017).

Student-centered science instruction. When we switched the course focus from our home-grown inquiry principles to the NGSS practices, certain methods topics got lost in the transition. To reintroduce these important topics, we identified two key “rules” of student-centered instruction: 1) let students figure “it” out first (where “it” is the answer to the focus question, their claims and supporting evidence, etc.); and 2) give students time to discuss and reflect. Prior experience taught us that the term “student-centered” is vague and that our interns consider any hands-on activity to be necessarily student centered. While we value hands-on instruction, the two rules stretch our students beyond the idea that hands-on = student-centered into a more robust understanding of student-centeredness and effective science instruction.

Analysis and reflection tools. To help interns refine their understanding of teaching methods and high-quality science instruction, we developed tools for interns to critically analyze the extent to which our classroom lessons, lessons found on the internet, and potential field placement lessons are in alignment with our practices and rules for student-centered instruction. The tools include alignment matrices and sliding scales (e.g., to place an X on a line between “students are told first” and “students figure out first”). Students have time to discuss their matrix and scale analyses in small groups, with the whole class, and with the instructor throughout multiple class sessions. They also complete a lesson analysis homework assignment and describe alignment to practices and/or rules within their lesson plans.

Challenges and Lessons Learned

As course innovations are shared and adapted across institutions, it is not only important to share descriptions of the innovations themselves, but also to provide implementation advice, describe potential challenges, and outline any lessons learned. Sharing this information is the purpose of this section.

Switching to the NGSS scientific practices: Addressing common confusions and improving lesson implementation

As a result of restructuring our methods and internship courses to be better aligned with the NGSS science practices, we discovered preservice teachers struggle to develop technically accurate, yet robust understandings of certain practices – none of which are as straightforward as they first appear. Based on our experience, 30-60 hours of class instruction isn't sufficient to help interns develop anything approaching an expert understanding of the eight scientific practices unless they become the sole focus of the course.

The following are examples of practice-related questions that our interns continue to struggle with, even after participating in comprehensive methods activities (Sandifer & Lottero-Perdue, 2014).

- I went outside and drew the Moon on different nights. Do my drawings count as models?
- What counts as an investigation, exactly? Only scientific experiments? What about classroom demonstrations and researching data online?
- Is there a difference between data and evidence? Do classroom observations, past experiences, prior knowledge, and common sense all count as data and/or evidence?
- What is the difference between analyzing data and interpreting data?
- Is any spoken or written answer an explanation? If so, why? If not, why not? What exactly counts as an explanation?

A successful tactic in dealing with confusion about the scientific practices is to not only make explicit what the practices *are*, but what they are *not*. Negative counterexamples typically result in “light bulb” moments for the preservice teachers. Consequently, we have incorporated numerous counterexamples into our course texts (e.g., “these are examples of this practice... and these are *not* examples of this practice, for these reasons...”) to help the interns better understand the practices’ trickier aspects.

Being explicit about what something is *not* is a powerful method of helping people develop deeper understandings of the more confusing aspects of science and engineering instruction. Similarly, in helping interns avoid lesson implementation that is in conflict with the NGSS practices, it helps to provide explicit guidance on what interns should *not* be doing in the classroom – not just on what they should be doing. For instance, we discuss in detail “things to avoid” in teaching a 5E science lesson (see Appendix G).

Mentoring new science education faculty to teach our courses

General strategies. Learning to teach a new content, methods, or internship course can be overwhelming, and the mentoring of new tenure-track faculty, lecturers, and part-time faculty is critical for ensuring a positive course experience. Although the development and implementation of a mentoring plan is a time- and effort-intensive process, it reaps great rewards in terms of instructor retention and the satisfaction of all stakeholders: students, parents, instructors, department chairs, and other administrators.

For our content courses, we have an initial meeting with new instructors in which we go over the course syllabus in detail and address various topics, including:

- *Noise control*. Calling on students by name; group rotation.
- *Tests*. Expected exam content and style; rearranging tables; make-up tests.
- *Logistics*. Making copies; teaching supplies; faculty office space; support meetings; parking; online records and class communication; teaching observations; projecting video.

Once the semester has begun, the course coordinator meets weekly or biweekly with the new instructor to review upcoming course activities, making sure that the new instructor is aware of the purpose of each activity, the relevant scientific concepts, where to find the experimental equipment, common student difficulties, and connections between the current activities and upcoming activities.

The mentoring of newly hired internship and methods instructors is even more dramatic than content course mentoring, as pedagogy courses have a large number of moving parts and potential pitfalls. There are so many topics that our “single meeting” orientation has now been split into two meetings: one meeting before the start of the semester and another meeting a few weeks into the semester, which is after the instructor has started experiencing challenges and problems and is seeking specific help.

In mentoring, we have learned the valuable lesson that the most effective approaches are proactive rather than reactive. Having new instructors contact experienced instructors on an as-needed basis can be useful, but it doesn’t always lead to uniformly positive outcomes. This is because new instructors are reluctant to interrupt their busy colleagues, their requests tend to be last-minute, and they typically don’t know enough about the course to know which vital questions to ask.

Learning to teach engineering education. Science educators new to engineering instruction often express the opinion that the disciplines of science and engineering are extremely similar, and that transitioning from teaching science methods to engineering methods will be a painless exercise. Perhaps unsurprisingly, many engineering educators would disagree, arguing that doing and teaching engineering is uniquely different than doing and teaching science (Cunningham & Kelly, 2017; Lottero-Perdue, 2017a). We have discovered it doesn’t take weeks or months, but *years* of mentoring to help university colleagues understand (a) how science and engineering education are fundamentally distinct and (b) how to effectively implement and design engineering education activities.

As a first step, we provide the chapter *Engineering Design into Science Classrooms* (Lottero-Perdue, 2017a) as a resource and offer mentoring and peer support to those who have questions about implementation of design challenges. Examples of key mentoring topics are: the idea that there is no one right answer (or one right design) in engineering; failure is a

normal part of engineering design, and how students and the teacher respond to failure is important (Lottero-Perdue & Parry, 2019); and the use of design challenges that not only teach the engineering design process, but also reinforce the application and development of scientific knowledge.

Conclusion

There is more we could share about the changes in our content, internship, and methods courses over the years. These changes continue even today, such as our current attempts to determine effective methods of teaching online and hybrid courses, identifying ways that interns might interact with simulated student avatars and classroom environments to improve their teaching skills, and more frequently engaging our students in generating and answering questions via project- and problem-based learning.

This 20-year retrospective is a reminder that every course is in a constant state of iterative change. Worldwide, science education faculty continually revise their course activities, assignments and assessments, and when these revisions are grounded in a context of caution and reflection – with constant questioning about what is working and what is not – the experiences that we provide our students can be improved. Course activities and structural changes imported from an outside institution need to be adapted to fit one's own local context, but our hope is that sharing a comprehensive history of innovations and lessons learned will assist faculty who share in our joyful and satisfying quest for course perfection – or something close to it.

Supplemental Files

[Appendix-A.docx](#)

[Appendix-B.docx](#)

[Appendix-C.docx](#)

[Appendix-D.docx](#)

[Appendix-E.docx](#)

[Appendix-F.docx](#)

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