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Two Departments, Two Models of Interdisciplinary Peer Learning

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On graduation, teacher candidates (TCs) are typically underprepared to teach science, particularly physical science, whereas physics graduates frequently lack training in teaching or effective communication. In response, we created two models for interdisciplinary peer learning where TCs were paired with either graduate or undergraduate physics students. In both models, physics students teach TCs content knowledge relevant to a given area of either classical or quantum physics, which TCs then use to design and implement a short lesson for K–5 students. Overall, both models were successful, with the two sets of students reporting benefits in each case. Affordances for TCs included increased confidence to teach physical science and an appreciation for collaboration with experts. Physics students described increased awareness of the complexities of communicating science to general audiences and stronger community with their classmates. Students from both groups cited insufficient project time as a constraint, whereas physics students found it challenging to align their project and coursework. In moving away from traditional lecture, these interdisciplinary collaborations also benefitted us as instructors, giving us new perspectives on teaching. In light of our findings we propose improvements to these proof-of-concept models to enable their future scale-up and replication in other disciplines.

Interdisciplinary work has long been hailed as beneficial to both students and instructors (Fox, Baloy, & Sens, 2014), particularly at the postsecondary level (National Academies of Sciences Engineering and Medicine [NASEM], 2016). However, Steele (2011) noted that "interdisciplinary collaborations are not the norm for instructors in post-secondary institutions. Traditional methods of individual lecturers teaching in isolation persist," (p. 5). In this article we detail our approach to stepping away from traditional pedagogical methods by engaging our students in interdisciplinary collaborations. The first author teaches science methods to elementary teacher candidates (TCs), and the second author teaches undergraduate and graduate courses in physics.

Our collaborations arose from the observed needs of both student populations. Regarding TCs, recent research has shown that only 36% of K–5 elementary teachers meet the National Science Teachers Association course-background standards by completing coursework in life, Earth, and physical sciences (Trygstad, 2013). Delving deeper, the same study found that only 17% of K–5 teachers feel "very well prepared" to teach physical science (vs. 29% and 26% in life and Earth sciences, respectively). Because of weak science content knowledge, elementary teachers may shy away from teaching science as inquiry (Davis, 2003) or perpetuate misconceptions in their students (Bulunuz & Jarrett, 2009; Burgoon, Heddle, & Duran, 2011). That physical science is the weakest area for elementary teachers underscores the need to increase content in this area in elementary science methods courses.

As for the needs of the physics student population, new physics faculty often occupy teaching-intensive positions (Anderson & Mulvey, 2013), but research has shown that they typically undergo negligible teacher training (Ebert-May et al., 2011; Stamp & O'Brien, 2005). In addition, although "soft skills" such as effective communication and collaborative teamwork are highly sought after for academic and nonacademic careers alike (Borowczak, 2015; National Association of Colleges and Employers, 2014), employers note that graduates of the hard sciences are frequently underprepared in precisely these areas (NASEM, 2016). Unfortunately, formalized opportunities for hard science students to improve teaching and communication skills are scarce in traditional university settings (NASEM, 2016).

Therefore, in response to these identified needs in the preparation of both elementary science teachers and physics students, we designed and implemented two separate collaborative projects: the Physics & Preservice Teachers Partnership Project (P^4) and the Quantum Physics for Elementary STEM (QuEST) project. Interdisciplinary in nature, P^4 and QuEST were grounded in the concept of peer learning: "the acquisition of knowledge and skill through active helping and supporting among . . . matched companions . . . who are not professional teachers helping each other to learn and learning themselves by so doing" (Topping, 2005, p. 631). As such, we anticipated that in both projects, TCs would learn more about physical science, and physics students would learn more about teaching, while practicing communication and collaboration.

To evaluate these pilot projects, we sought to ascertain the affordances and constraints of each one so they may be effectively scaled up in the future. Note that although these proof-of-concept collaborations center on physics and physical science topics, we believe these models could be easily replicated in other disciplines.

Project descriptions

Through P^4, physics graduate students delivered content on a physics topic to TCs. In groups of three, the TCs then used this content to plan and execute a 15-minute science center for elementary children, compatible with state science standards. Each 15-minute science center is part of a larger rotation of four centers focused around similar topics chosen by the elementary teachers to coordinate with what they are currently teaching in the classroom. The lesson is taught eight times (2 hour-long rotations; for more detail, see Kittleson, Dresden, & Wenner, 2013), and the TCs have time for reflection and lesson adjustment between lessons. Standards surrounding basic topics in energy and electrical circuits were the focus of this particular iteration of the science centers. See Table 1 for details.

In QuEST, undergraduate physics majors in a quantum physics course

TABLE 1

Logistical details of the two-peer learning models.

	P^4	QuEST
Content addressed	• Four 4th-grade state science standards for physical science: • Potential/kinetic energy • Energy transfer via collisions • Electrical circuits (2 on this topic) • 4th-grade teachers requested these standards be covered, given the timing of the centers	• Quantum physics topics, including atomic orbitals, quantization, probability, and uncertainty. • Topic was chosen on the basis of giving students something different than they might encounter in school.
Final product	A 15-minute science center lesson on energy for 4th-grade students (Kittleson et al., 2013, describe this instructional model)	A quantum physics drop-in activity at an elementary school Family STEM Night
Participants	• 23 TCs in an elementary science methods course (11 consented to research) • 4 graduate students in a dual-level quantum mechanics course • Group size: 5–6 TCs with 1 graduate student, total size 6–7 students	• 8 TCs in an elementary science methods course • 24 undergraduate physics majors in a quantum mechanics course • Group size: 2 TCs with 6 physics students, total size 8 students
Project steps (enacted over ~ 1 month for each project)	1. Instructors met with graduate students for 2 hours to discuss inquiry-based instruction. 2. Assigned 4th-grade standards groupings to each graduate student. Two graduate students focused on energy while the other two graduate students focused on electrical circuits. 3. Graduate students created lesson plans to teach TCs. 4. Instructors gave feedback on graduate students' lessons. 5. Graduate students taught content to TCs for 2 hours. 6. TCs created lesson plans for 4th graders. There were two different lesson plans on energy and two different lesson plans on electricity per classroom implementation. 7. Graduate students and instructors provided feedback on TCs' lesson plans. 8. TCs taught the lesson to 60 4th graders. 9. TCs and graduate students submitted written reflections on the project. 10. TCs (9 of 11) and graduate students (4 of 4) interviewed about the project.	1. Physics students met with instructors to discuss quantum physics topics that could work for a STEM Night activity. 2. Physics students met with TCs for 1 hour to teach TCs the content. 3. Physics students and TCs met for 2 hours to co-construct an activity for STEM Night. 4. Instructors gave feedback on activity idea. 5. Activity implemented by both TCs and graduate students multiple times over a 2-hour Family STEM Night that was attended by approximately 600 people. 6. TCs and physics students submitted written reflections on the project.

Note. P^4 = Physics & Preservice Teachers Partnership Project; QuEST = the Quantum Physics for Elementary STEM project; TCs = teaching candidates.

teamed with TCs to co-construct and enact an activity for a local elementary school's Family STEM Night. STEM Night activities were not constrained by the state standards, so this was a great opportunity to get elementary students excited about areas of science they might not have the chance to cover in school. This freedom meant that in the QuEST project, our four student groups (see Table 1 for details) could each create a quantum physics-based activity using concepts from the physics majors' course. Quantum physics-based STEM activities for K–5 students might at first glance seem surprising. Traditional STEM teaching starts with classical physics and moves on to quantum physics much later in a student's education. However, the weirdness of quantum physics could be a way to breed enthusiasm for physics from an early age. Teleportation and seeing through walls is the stuff of comic books, but also the stuff of quantum physics. Young children are often capable of engaging in science more deeply than we give them credit for (Duschl, Schweingruber, & Shouse, 2007). Therefore, we opted to ignore the dichotomy between classical and quantum physics and expose younger children to these exciting ideas that may encourage their future pursuit of STEM subjects.

Data collection and analysis

To ascertain what the students saw as the affordances and constraints of these pilot projects, the data collected consisted of student self-reports. For P^4, the 11 consenting TCs and four physics graduate students wrote reflective papers on their experiences. Except for two of the TCs, all students also participated in a 1-hour semistructured interview with the first author to further elaborate on their experiences. For QuEST, the eight TCs and 24 physics majors wrote a reflective paper. We analyzed data in an emergent fashion (Charmaz, 2006), paying particular attention to the affordances and constraints of the projects. The findings that follow are largely summaries of student descriptions of these affordances and constraints, with direct quotations included when they are particularly illustrative of a specific finding.

Student outcomes of P^4

All of the TCs and physics graduate students in this study found P^4 to be beneficial in terms of providing them with new skills, knowledge, and/or perspectives. During their work with P^4, TCs confirmed that working with the graduate students helped them increase their content knowledge and saw the graduate students as experts. Related to the increase in content knowledge, TCs also commented that they better understand how to implement physical science lessons in the classroom. Prior to P^4, one TC stated that she felt comfortable teaching elementary-level life sciences, but could not see how to teach physics topics, as they can be so abstract. However, after P^4, she exclaimed, "I realized that there's definitely a lot you can do in physics and it's interesting, and it's easy to do hands-on experiments with physics!" TCs also saw the collaborative benefits of P^4. In terms of their future careers as teachers, TCs saw value in seeking out experts in other fields to enrich their content knowledge or teaching; five TCs commented that they would invite experts to work with their future classrooms.

A rather unexpected outcome of P^4 for the TCs was that it reminded them how difficult learning a new science topic can be and how teaching strategies can help or hinder that learning. For example, one TC found her graduate student's instruction to be lacking strategies that would have supported learning, stating that while the graduate student was struggling to explain the content, this TC sat silent and hoped the graduate student would figure out how to scaffold instruction. Consequently, this TC stated that she would be more aware of silences from her students and use them as cues to provide more supports. Similarly, other TCs used this experience as impetus to find multiple ways to present concepts to students.

Participating in P^4 provided two of the four graduate students their first opportunity to plan and teach a lesson. As such, they saw it as an opportunity for professional development and highlighted several benefits, including learning about best practices, seeing the advantages of active techniques, and realizing the importance of lesson planning for effective teaching. The graduate students also gained an appreciation for the challenge of communicating complex ideas to a nonscience audience, reflecting that this was a skill they would need regardless of their future career. Two of the graduate students commented that, for this reason, they would like to see P^4 implemented universitywide.

Last, the graduate students shared that they now understand how complex high-quality science teaching really is. One graduate student stated, "You take for granted how much time it takes to plan . . . and I think that takes a lot of thought . . . [as to] how you plan and how you communicate." He described the difficulties particular to planning lessons that include experiments (guided inquiry) because he was used to very "linear" (confirmatory inquiry) lessons. As he put it, "Doing a lesson plan that's based off of an experiment is much harder because you don't know how the experiment will go."

Notwithstanding the benefits of P^4, students also identified some problematic aspects. Both sets of students found 1 month to be insufficient to find time to meet with everyone and complete all components of the project. Specifically, all of the TCs stated that they would have liked to practice teaching their lesson to their graduate student, whereas the graduate students shared that they would have liked more time to plan their lessons and to learn about inquiry-based instruction more fully.

In addition, because elementary standards are aligned to classical physics, the graduate students found that the content knowledge the TCs needed did not align with topics from their quantum physics-based course. Even so, three of the four graduate students said that finding ways to explain content to TCs helped them reinforce basic physics concepts.

Student outcomes of QuEST

As with P^4, TCs and physics students found QuEST to be beneficial overall. The most common benefit TCs reported was increased confidence to teach science. Despite the complex quantum physics content covered, one TC shared that:

> I should not let science intimidate me. Even though something can seem overwhelming with terminology and concepts I do not understand, the material can always be broken down to a simpler explanation. This will help me with my future years of teaching.

Relatedly, TCs also noted QuEST showed them that elementary children *can* grasp complex scientific topics when properly engaged and that as teachers they are capable of crafting this engaging instruction.

Last, TCs appreciated collaborating with students from outside of their major. Different perspectives on science helped them see how working effectively with people with different viewpoints will be central to their careers because "as future teachers we are going to be working with different people all the time like parents, other teachers, and staff." Working with those outside of education allowed TCs to reinforce their pedagogical knowledge: "It [QuEST] caused me to have to explain how lesson planning and working with kids goes, which helped me to deeper understand these things. I did not realize how much I knew about how children learn."

Sixteen of the 24 physics undergraduate students reported that QuEST helped them reinforce their own physics content knowledge. One stated, "Being required to explain the concept to someone . . . helped me understand it better . . . I had to make sure I had it all straight in my own mind in order to explain it." Another commented, "Putting effort into explaining something simply enough that someone without a scientific background could readily understand is a great way to gain a deeper understanding of the subject yourself." They experienced the usual difficulties with translating complex concepts, and saw how much content knowledge they take for granted that others may not have. As a result, it was clear to the physics students how the communication skills used in QuEST would be applicable to future careers.

The physics students also recognized the impact of TC expertise on the success of their outreach activities: "[The] synergy between our physics content knowledge and their elementary education training made for the best explanation." Following QuEST, six physics students noted that they would now give more consideration to going into secondary teaching, whereas five others stated that QuEST had solidified their goal of an educational career. And while the majority of physics students did not foresee a career in education, eight students stated that they enjoyed working with the elementary students and could possibly continue teaching in some capacity outside of their formal jobs.

Finally, four of the physics students enjoyed QuEST because they formed closer relationships with their physics classmates. As a result of this project, they created exam study groups, felt more comfortable asking each other questions, and were generally more engaged in the course. One student characterized this as a "family" feeling, while another said:

> The absolute greatest strength with this project was the interactions with my fellow classmates. This assignment made me feel closer with the entire group. I've never been in a class where the sense of community was as strong as with this class.

Although we anticipated positive collaborative relationships, this unexpected outcome was a great encouragement for future projects.

Given the numerous affordances described by all students, we certainly intend to implement QuEST again. However, before we do so, both sets of students identified constraints that we must attend to. As with P^4, both groups of students cited time as an issue. Large groups made scheduling meetings difficult, and all students would have appreciated more time to work on QuEST. The date of the STEM Night early in the semester meant students only had approximately 1 month to complete the project. Both sets of students struggled with their roles and responsibilities, with some unsure who was responsible for completing different project components. This lack of clarity caused uncomfortable moments and frustration for two groups. Finally, three physics students felt that quantum physics is too abstract to distill down to activities suitably engaging for a Family STEM Night. One student lamented, "We didn't have something showy and exciting like dry ice or robots."

Future directions and conclusions

Taking the outcomes of P[4] and QuEST into account, we have identified components we intend to retain in future iterations of the projects and changes we plan to make. These should be seen as key components for those who would like to create similar partnership projects at their institution.

Of the project components we intend to preserve, certainly the interdisciplinary nature of the projects was highly beneficial to all student groups involved. Depending on the project and major, students were able to reinforce content or pedagogical knowledge, refine communication skills and make professional connections with others. We also believe the authentic outcome of both projects (working with elementary students) to be valuable, as it forced all students to think through the content and presentation carefully to appropriately and correctly teach the ultimate consumers.

Concerning changes needed for P[4] and QuEST to be successful in the future, first and foremost, we now realize that both projects require more than a month's effort. For P[4], we envision including more time to work with the graduate students on pedagogical skills and more time for both TCs and graduate students to practice teaching to their peers so all involved will receive timely, targeted feedback. For QuEST we envision including more time for TCs and physics students to work together, in smaller groups, to facilitate easier scheduling. As a result, we are considering a different venue for the final product of QuEST such as a STEM club, which provides more flexibility with scheduling later during the semester.

A second issue we wish to address in both projects is that of the content to be taught/presented. In P[4], because of the nature of the elementary science centers' need to be tied to state science standards, they will always focus on concepts from classical rather than quantum physics. In future iterations, we will be explicit with the graduate students about the limited overlap with their coursework, and instead frame P[4] as an opportunity to practice the communication and collaboration skills that are so highly sought after by employers. As for QuEST, we do believe that some foundational topics in quantum physics *can* be taught simplistically to elementary students, and we will thus continue to tie the project to the content of the physics undergraduates' course. However, we will provide additional help to the physics students prior to their meeting with TCs, as they narrow down possible topics, and discuss interactive and fun ways to present them.

Although this article focuses on collaborations between physics courses and an elementary science methods course, we believe that both the P[4] and QuEST models could similarly be implemented in Earth and life sciences courses. Because elementary teachers must teach all branches of science and generally feel unprepared in every area (Trygstad, 2013), partnerships between elementary TCs and all hard science courses would be incredibly beneficial. Likewise, we believe that such partnerships would be advantageous for students from across the hard sciences in terms of reinforcing content and improving their soft skills.

Finally, we have found that engaging in interdisciplinary collaborations is beneficial for instructors as well as students. Although researchers have noted that "interactions between faculty in the science departments and education departments . . . have high activation energy" (Seethaler, Czworkowski, Remmel, Sawrey, & Souviney, 2013, p. 54), the positive impacts of our interdisciplinary work mirrored those found by Zitzewitz, Moyer, Otto, and Everett (2010). Our collaborations have enriched our respective instructional skills, tapped into expertise we each lack, and elevated our focus on meeting students' needs in our classes. Therefore, we would encourage instructors to try their hand at interdisciplinary collaborations such as P[4] and QuEST, to benefit not only their students, but also their own professional development. ■

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