Examining Design Features of a Research Experience for Teachers in Mechanobiology towards Promoting K-12 STEM Integration

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Abstract: Learning in real-world contexts and problem-solving using interdisciplinary perspectives is essential in education. In this case study, we engaged ten local teachers in a summer research experience with sustained school year professional development, and investigated how specific design features could support teachers in STEM integration. We found the teachers gained essential skills needed for success (e.g., obtaining disciplinary knowledge needed to make explicit connections across STEM fields) but some challenges remained (e.g., in designing relevant and authentic lesson plans based on their experience). This study provides an in-depth analysis of how specific design features can promote the goals of STEM integration, which in turn can increase student interest in STEM pursuits.

Introduction

K-12 STEM curriculum has traditionally focused on individual disciplines; yet, increasingly complex challenges confronting society require learning in real-world contexts and problem-solving across disciplines (NRC, 2014). While learning in discrete subject areas is still valuable, multi-faceted perspectives allow for more nuanced understandings of phenomena (Gardner & Tillotson, 2018). Therefore, K-12 educators have been called to integrate science, technology, engineering, and mathematics (STEM) into their practice (NRC, 2014). Since this requires teachers build knowledge and skills in all four domains, there is a need for professional development (PD) that supports gains in content and pedagogical content knowledge specific to STEM integration (Acar & Büyüksahin, 2021).

One way to address this need is through Research Experiences for Teachers (RET), which help push the development of curricula that integrate engineering into the STEM disciplines (e.g., Klein-Gardner et al., 2012). RETs provide opportunities for teachers to gain firsthand experience in conducting real-world STEM research and often incorporate the development of new curricula (based on the research experience) for the classroom. However, RET programs vary widely in their design features and more research into how design choices impact teacher experience is needed (Enderle et al., 2014). In this study, we examine the impact of an RET focused on the emerging field of *mechanobiology*. We define mechanobiology as an interdisciplinary field (including biology, engineering, chemistry, physics) that looks at how biological systems (cells, tissues, organs) sense, respond to, and generate physical forces. This field can lead to advancements in constructing engineered tissues and organs, repairing and regenerating damaged tissue, and providing therapy for diseases. Thus, mechanobiology is an ideal focus for an RET aimed at promoting a genuine understanding of STEM integration. We were guided by the following research questions: 1) To what extent did the design features of the RET help teachers prepare for STEM integration in their classroom? 2) What key challenges emerged that hindered success of program goals?

Methods

Context and participants

Our case study takes a noncomparative, qualitative approach. Ten local teachers (Table 1) participated in a summer research experience (Table 2) at an interdisciplinary science and technology center in the northeastern United States. Teachers engaged in mechanobiology research and then worked together to design STEM integrated curricula based on their experiences.

Table 1
Teacher Characteristics

Teacher Pseudonym	Cohort #/Year	Years Taught	Courses Taught	Grade level
David	1/2022	1	Biology, Anatomy & Physiology	10-12
Amy	1/2022	36	Biology, Algebra	9-10

Reggie	1/2022	10	Biology, AP Biology	9-12
Isaac	1 /2022	14	Biology, AP Biology	9-12
Kathy	2/2023	15	Integrated Science, Physics, Anatomy	10-11
Emily	2/2023	1	Biology	10
Henry	2/2023	16	Biology, Survey of Science	8
Nick	2/2023	7	Engineering, CTE Engineering	9
Jana	2/2023	4	Biology, Environmental Science	9-12
Alex	2/2023	20	Algebra, Life Sciences	7

Table 2
Research Experience Design and Goals

PD Design Features	Needs for STEM Integration
Mechanobiology 101– week 1 crash course introducing teachers to disciplinary knowledge, tools, and practices in the field through various activities (e.g., hands-on labs, lectures/lab tours with experts, workshops)	Support teachers in skill-building, conceptual understanding, and how these connect across disciplines (English, 2016)
Authentic Research Experience in Mechanobiology– weeks 2-7 (Mondays-Thursdays) teachers separate into research groups with their mentors and gain firsthand experience working in their research labs	Support teachers in gaining firsthand experiences of integrated STEM research and learning (Ryu et al., 2019)
Weekly Working Groups– week 2-7 Fridays teachers regroup to reflect, discuss, and evaluate their research experience; engage in pedagogical seminars to support inquiry-based lesson in mechanobiology; work collaboratively to design a lesson plan aligned with standards	Support teachers by dedicating time to brainstorm and design STEM-integrated curricula together (Brown & Bogiages, 2017)
Foster Engagement with Industry and Academic Experts– teachers tour and connect with academic experts, local industry and outreach organizations (i.e., biotechnology startups; outreach facilities that provide free, industry-informed curricula and job training in the STEM workforce for students)	Support the formation of an interdisciplinary community of learning and practice (Hardre et al., 2013; Kelley et al., 2016)
Sustained PD and Teacher Networking– reconvening quarterly during the academic year; continue to revise and improve upon mechanobiology curricula and provide support in implementing and publishing in TeachEngineering.org	Continue to support teachers as they navigate bringing multiple domains into their teaching (Dare et al., 2018)

Data sources and analysis
We evaluated the following data sources for evidence of teachers linking program design features to goals and supports needed for STEM integration: transcriptions of meeting recordings, observational field notes, and teacher artifacts (i.e., presentation slide decks, lesson plans). We used a constant comparative method of analysis to identify emergent themes (Glaser, 2008). Interrater reliability and member checking with participants to ensure accuracy and validity of these findings is forthcoming (Creswell, 2013).

Results

Lab work "opened eyes" to the nature of real-world research
When teachers reflected on the everyday routines of their lab experiences, most emphasized how the experience "really opened [their] eyes [to] how integrated the labs were". For example, Kathy noticed that even though her lab group was "in the engineering [school], they all have their specialties…I have biology background while [Mentor 1] is more physics and [Mentor 2] is more chemistry. So we were able to work together and I get to see…even though they may have different interests, they need each other in order to move forward". Likewise, in Amy's research experience conducting computational modeling research, she observed that "when you're doing computational models…you're just doing modeling of things. They actually have to go into other people's wet labs and show them these models [and revise them] based on what their data is…I'm [with] my coworkers in the office and there's always somebody there that you can ask questions...So we have people in industry, we have a couple engineers." Additionally, Emily noted that "I've definitely seen more interconnections between biology and engineering and physics and chemistry, more than I knew before… I think a big takeaway is trying to bring more of the Excel and data analysis into the classroom because that'll be good to learn…not only just in science." Nick added, "This program is allowing me to teach the intersection of engineering, chemistry, biology, and materials science, all kind of under a physics wrapper…it's one of those things that's been on my list of things…but until this summer, I didn't have the dedicated time." These excerpts highlight how naturally an authentic research experience in mechanobiology can contribute to teachers' appreciation for and knowledge of interdisciplinary nature of real-world research and can provide motivation to bring those aspects back to school.

Established foundational disciplinary knowledge in teaching STEM integration

Importantly, teachers expressed intent and/or an ability to make STEM connections explicit in their curriculum. For example, Nick noted that this program has given him "the ability now to talk to other departments with a baseline level of knowledge to be like, 'Hey, so I'm doing this. Does this fit into what you guys are doing?'" When Isaac presented his mechanobiology lesson to cohort 2, he shared that "participating in the RET gave [him] an awareness of mechanobiology" around him, and this prompted him to incorporate materials science in his lessons. Furthermore, in developing her mechanobiology lesson modeling a cell adhesion system, Jana discussed how the RET "taught me to look at the world in all of the different lenses that we see here to get a better picture…[using] the lens of physics or the lens of engineering, not just biology." Thus, disciplinary knowledge gained during the program gave teachers the ability to make STEM connections more explicit.

Working collaboratively to design a hands-on mechanobiology lesson

Teachers had substantial time during working groups and in their research labs to brainstorm ideas and co-design lessons with mentors and other experts. They noted this aspect was critical in developing a lesson plan. For example, Isaac advised cohort 2 teachers to "ask <u>everyone</u> in your lab for their ideas", and he further discussed how his mentor helped him think through and test out various ideas. Further, during her final presentation, Jana mentioned how talking to a postdoctoral researcher helped her conceive her lesson plan on cellular adhesion because the researcher mentioned how myosin (a contractile protein in cells) reminded her of Velcro. Moreover, there were multiple instances of encouragement (e.g., "That's a cool lab right there that you just described!") and opportunities for feedback about lesson plan ideas during the summer program. This demonstrates that the collaborative atmosphere was overall generative, encouraging, and contributed to helping teachers succeed.

Teachers as a bridge between two worlds

When Amy presented on her experience implementing her mechanobiology lesson in class with cohort 2, she reflected that she felt as if she were "a bridge between students, who don't know this world exists." David added that they felt they "have been able to provide insights to students that they hadn't before" because prior to the program they did not "know this world." Nick also noted that "I think you need to let people know that this stuff exists...And [this program has] provided us with a deep and large, wide view of some amazing stuff. So now all of us get to go back to our students and be like 'Here's these big things, I'm telling you, you can do this. And partially because if I can do this, you can do this.'" Jana responded to Nick with "Yeah, I agree with you knowing that it exists, but also being able to see yourself succeeding…Because a lot of the times I think my students can't." Next Henry added that "I like that [in this research institution], when you look around the buildings, you see the contributions of everyone. And that's what I think students need to see…Everyone does science. It's not just one group." These excerpts demonstrate that this experience can lead teachers to bring true insight into what people, careers, and research in mechanobiology are like back to their students.

Teachers "feel like students" again and lesson design can be a daunting task

In working groups teachers expressed some apprehension about learning new research and skills. Reggie stated, "It's sometimes a little stressful [in lab]…I'm not on their level...Those guys are great at what they do, but I don't think like that. And I haven't really felt like that since high school." Henry reflected similarly when he said that "I felt like a student again, I wanted to know what the right answer [was]." He further explained that being put back in that position where he was struggling was important for him to experience again as a teacher. Nick also emphasized that "there's a limit of comprehension…I can read this stuff. Doesn't mean I'm going to comprehend this stuff." He then described how important the workshop on how to read a scientific article (during Mechanobiology 101) was to help scaffold his learning. Thus, gaining disciplinary knowledge is an ongoing process that involves a substantial time commitment and a level of comfort with "feeling like a student" again.

Furthermore, in designing lesson plans, teachers often iterated through multiple ideas, while trying to simultaneously consider how it would fit into their curriculum and align with required standards at their respective schools, before ultimately deciding what to build out into a final product. This was a clear challenge for some and resulted in lesson plans that did not include all the features they had set out to include. For example, Isaac mentioned that he had a "hard time coming up with a solid idea for a lab." At the start of the program, he shared that he'd "like the lesson...to be less of a metaphor and more of a genuine lab experience…rather than working with a model system." He also expressed wanting to show his students "the applied aspects of what we're doing, but …I see it as basic research. So how do I show [students] the applied aspects in a hands-on way?" Ultimately, Isaac developed a lab with his mentor where students perform compression testing using Jell-O as a model of liver elasticity in health and disease. This shows that translating and simplifying complex, interdisciplinary STEM research in innovative ways is a salient challenge.

Discussion

Here we examined teachers' perspectives on an RET in mechanobiology to reveal how specific design features could support STEM integration. Through their experience as mechanobiology researchers, teachers were able to appreciate and gain firsthand insight into the interdisciplinary nature and diversity of people and career paths in real-world research. The program also provided teachers with the time and resources needed to learn key concepts in mechanobiology, which in turn allowed them the opportunity to make explicit connections across STEM fields in their teaching. In addition, building in opportunities for collaboration with colleagues and experts on lesson design was critical in teachers' ability to create a hands-on lesson plan by the end of the summer program. However, challenges arose at times in teachers' ability to grapple with the complexity of the subject matter and in designing a lesson plan that was relevant and authentic for their students.

Our work contributes to understanding the specific features of teacher learning environments that support STEM integration. For example, establishing foundational knowledge in mechanobiology and forming a professional learning community likely contributed to teachers' self-efficacy and confidence in teaching STEM-integrated concepts (Hardre et al., 2013; Kelley et al., 2016). Additionally, the challenge of "feeling like a student" again can help teachers better understand students' difficulty when enacting inquiry-based learning in STEM (Wenglinsky & Silverstein, 2006). The "double burden" of creating a lesson plan alongside conducting research seemed partially alleviated by time spent brainstorming with expert mechanobiologists (Darling-Hammond et al., 2017; Ryu et al., 2019). Overall, this study is important because it provides an analysis of the specific design features that can lead to achieving the goals of STEM integration (NRC, 2014; English, 2016). Our future research will continue to follow this population of teachers longitudinally and the student impacts of the RET program. Ultimately, this work will contribute to increasing the relevance, authenticity, and interest in K-12 curriculum that conveys the importance of interdisciplinary enterprises in solving important societal issues (NRC, 2014).

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Acknowledgments

This research is funded by the Center for Engineering MechanoBiology (National Science Foundation 15-48571).