Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #48362

BOARD # 327: Biomimicry as an authentic anchor: Giving teacher the tools to adapt an interdisciplinary middle school curriculum (DRK12)

Geling Xu, Tufts Center for Engineering Education and Outreach

Geling Xu is a Ph.D. student in STEM Education at Tufts University and a research assistant at Tufts Center for Engineering Education and Outreach. She is interested in K-12 STEM Education, AI Education, MakerSpace, LEGO Education, and curriculum design.

Dr. Kristen B Wendell, Tufts University

Kristen Wendell is Associate Professor of Mechanical Engineering and Education at Tufts University. Her research at the Center for Engineering Education and Outreach explores curriculum and pedagogy that support all learners in discourse and design practices for engineering knowledge construction.

Ms. Tyrine Jamella Pangan, Tufts University

Tyrine Jamella Pangan is a STEM Education PhD student at Tufts University and a Graduate Research Assistant at the Tufts University Center for Engineering Education and Outreach (CEEO). She is interested in integrating social and emotional learning (SEL) in engineering, specifically within the elementary school context. Tyrine hopes to explore how Transformative SEL can be implemented to cultivate socially responsible engineers.

Debra Bernstein
William Church
Dr. Ethan E Danahy, Tufts University

Dr. Ethan Danahy is a Research Associate Professor at the Center for Engineering Education and Outreach (CEEO) with secondary appointment in the Department of Computer Science within the School of Engineering at Tufts University. Having received his graduate degrees in Computer Science and Electrical Engineering from Tufts University, he continues research in the design, implementation, and evaluation of different educational technologies. With particular attention to engaging students in the STEAM content areas, he focuses his investigations on enhancing creativity and innovation, supporting better documentation, and encouraging collaborative learning.

Biomimicry as an authentic anchor: Giving teacher the tools to adapt an interdisciplinary middle school curriculum (DRK12)

Introduction

Although many middle schools teach science, technology, engineering, and mathematics (STEM) in separate classes, education policymakers realize that integrating STEM learning is beneficial for students (e.g., Achieve, 2013; NRC, 2014). When effectively implemented, integrated approaches can help cultivate creative thinking, support problem-solving, and develop students' interests while supporting knowledge gains (Guzey et al., 2022).

In recognition of the importance of integrated STEM yet the difficulty of implementing it effectively in classrooms, the community has called for research on how to support better-integrated learning (English, 2016; Kelley & Knowles, 2016). The Biomimicry as an Authentic Anchor project, funded by the DRK12 program of the NSF Division of Research on Learning, takes up this call by designing and researching a professional development model that supports middle school science and engineering teachers to adapt, plan, and enact design-based integrated STEM units focused on biomimicry. Biomimicry, the application of a structure-function relationship from an organism or ecosystem in the design of a human-created system, represents a *professionally authentic* approach to integrated STEM learning. Using biology as the basis for engineering design and problem-solving mirrors the practice of professional engineers and roboticists. When teachers customize biomimetic challenges for their particular classes, biomimicry can also be a personally authentic learning experience for students. In our research, we are exploring how middle-school STEM teachers adapt biomimicry curriculum materials to meet the needs of their school, classroom, and students.

Theoretical Framework

Our research on professional development for STEM teachers is grounded in prior research and theory on teachers as designers. Studies have shown that when teachers are supported to take on the role of designer, they develop a deeper understanding of curricula, build their sense of ownership, and make changes in instructional planning (Cviko et al., 2014; Penuel & Gallagher, 2009). In addition, engaging teachers as designers can increase the frequency and effectiveness of teachers implementing technology activities (Cviko et al., 2014).

Activity theory also provides a framework for our exploration of teachers' curricular decisions.(Engeström, 1987) Activity theory is based on the idea that human actions occur within systems that are mediated by material and conceptual tools and shaped by rules, communities, and cultural practices related to the division of labor. Each activity system consists of six elements. The first two elements are the human *subject*(s) and their goal, which is called the *object*. The other four elements influence how the subject achieves the object. They are *tools*, *division of labor*, *community*, and *rules*. The six elements together shape the way actions unfold within the system and produce the system's *outcome* (Engeström, 1987). Educational researchers have used activity theory in many contexts; for example, a recent study shows how chemistry instructors make different choices about how to deploy teaching assistants in their classrooms (Karch et al., 2024). In our study, activity theory provided a way to analyze similarities and differences between teachers' curricular decisions and the influences on those decisions. Our research question is: *How do middle school STEM teachers make curriculum choices when implementing interdisciplinary biomimetic design activities?*

Method

This is a descriptive case study (Merriam, 1998) of seven middle school STEM teachers from six different U.S. school districts – five in New England and one in the Midwest. The teachers all attended our biomimicry teachers' multi-day professional development (PD) workshop. During the PD, teachers first used resources provided by the project to conduct a structure/function analysis of plants and animals that are well adapted for the action required by a specific design challenge (flinging, grasping, or digging). Then they used what they learned to create a prototype in response to the design challenge. We provided motors, batteries, Hummingbird robotics kits, and Tinkercad software for prototyping. After engaging with the design challenges, de-brief discussions, and project resources, the teachers were supported in developing their biomimicry design curriculum. During their curriculum enactment, we took field notes during two to three observations in each classroom in the New England area and received short video recordings of student presentations from the Midwestern classrooms. We also interviewed all teachers about their curriculum choices and collected their lesson artifacts and student work.

To guide our data analysis, we created a set of eight descriptors adapted from the elements of the activity system triangle (see Table 1). We omitted *subject* and *division of labor* from activity system theory because these elements did not reveal differences across teachers. Next, with evidence from field notes, interview transcripts, and lesson plans, we wrote a very brief memo describing each of the eight descriptors for each of the seven classrooms. After displaying these 56 descriptors in matrix form, we looked across classrooms to find the commonalities and differences between their activity system elements. Then we made Table 1 and wrote narrative memos about how and why they developed different design challenges for their students' biomimicry.

Findings

Across the seven teachers in our study, several common themes emerged in their curriculum development process. All teachers adhered to the core requirement of integrating biomimetic design into their classes, recognizing the research team as part of their teaching community, and utilizing at least some of the learning materials from the PD. However, the outcomes of their curriculum designs were shaped by varying school or district requirements, the specific needs of their students, and personal preferences regarding tools and learning goals.

Three teachers—Eli, Ryan, and Taylor—had to adapt biomimetic design to fit within mandatory topics from their districts. This influenced their curriculum goals and design challenges. For example, Eli incorporated a weather-related theme into a biomimetic design challenge by having students build a weather rescue robot inspired by flinging organisms. Ryan and Taylor, who taught separate classes at the same school, adapted biomimetics into lessons on evolution and space flight, respectively, integrating bio-inspired designs like a seed collector and a Mars landing rocket.

In contrast, four teachers who had more flexibility in their curriculum development chose topics based on personal interest, familiarity, and class constraints.

As an engineering teacher, Sydney had the whole semester to teach biomimicry topics and wanted to prepare her students for high school CTE on biomedical engineering. She also wanted to help students build VEX robotics skills. As a result, she tasked students with using VEX materials to build an assistive grabber device with bio-inspiration from grasping organisms.

Jamie preferred to give students the opportunity to define a specific design problem, so her curriculum involved open-ended robot design to help someone with disabilities. The main design challenge in her class was to build a device to help in daily life with bio-inspiration from flinging or grasping organisms. She only had a portion of a semester to teach this topic, so she chose to use the tools both she and students were familiar with. Her students learned how to use Hummingbird robotic kits in a previous class, so she provided Hummingbird motors and batteries as tools for her students.

Kelly is an experienced former science teacher teaching biomimicry in her 6th grade STEAM class, which doesn't have any required topics or standards, so she had a lot of space to test her ideas. Because of her experience with NGSS standards, she wanted to emphasize science and engineering practices during biomimicry experiences, specifically the engineering practices of identifying and meeting design criteria. She designed a protective helmet design challenge where students could practice structure/function analysis (for the function of energy absorption), identify the criteria for a helmet, and brainstorm designs. To provide students a hands-on opportunity, she added another design challenge - medical packaging with bio-inspiration from a student-chosen organism. For this challenge, she adapted an existing curriculum unit on medical packaging. She emphasized the skills of structure/function analysis and setting and meeting criteria over spending time on new tools. She chose craft materials, motors, and batteries as tools for the design challenge.

Blair, like Sydney, wanted to prepare their students for high school CTE biomedical engineering pathway. Different from Sydney's focus on the grasping function, she asked students to build a supply delivery device with bio-inspiration from flinging organisms. With two quarters to teach this biomimicry curriculum, she wanted to provide students with opportunities to use different tools, so she asked students to use motors and batteries, Hummingbird robotic kits, and Tinkercad.

Overall Project Outcomes

In the first year of curriculum enactments for the Biomimicry as an Authentic Anchor project, over 300 middle-school students in seven different school districts have solved biomimetic design challenges as a part of their STEM courses. Although their teachers differed in the specific topics and tools they used, all design challenges were shaped by the need to balance district mandates with the flexibility to explore biomimetic concepts. Teachers' choices reflected their understanding of students' prior knowledge, the time available for instruction, and their own expertise in design and engineering. These variations highlight the impact of both external factors such as school requirements and personal teaching goals on the outcomes of the curriculum implementation.

Teacher:	Eli	Ryan	Taylor	Jamie	Kelly	Blair	Sydney
Rule: Timeframe	Section at end of semester	Portion of a semester	Portion of a semester	Portion of a semester	Half of a semester	Full course (1 quarter)	Full course (1 semester)
Rule: Required topics	Include weather	Include evolution; different topic from Taylor	Include flight/space; different topic from Ryan	Accessible design	Meet the NGSS engineering standards	Prepare for H.S. CTE biomed. eng. pathway; integrate bio & eng	Prepare for H.S. CTE on biomed. eng.
Community	6th grade science students with Hummingbird robotics experience	7th/8th grade students who also have Taylor as an engineering teacher	7th/8th grade students who also have Ryan as a science teacher	7th grade students with Humming-bird robotics experience	6th grade students new to STEAM class	7th grade students in enrichment block; Co-teacher	8th grade students new to VEX robotics; teacher partner for FIRST LEGO League
Tools (physical)	Craft materials						
	Motors and batteries	Humming-bird robotic kits	Tinkercad; Humming-bird robotic kits	Motor and batteries; Humming-bird robotic kits	Motors and batteries	Motors and batteries; Hummingbird robotic kits; Tinkercad	VEX robot sets
Tools (curricular)	Learning materials from PD						
	Existing weather curriculum	Existing science curriculum	Existing PLTW curriculum				Existing VEX curriculum
Object (goal as curriculum developer)	Connect biomimetic design to weather curriculum	Connect biomimetic design to the science of evolution	Connect biomimetic design to a PLTW flight/space unit	Connect biomimicry to digital literacy; disability assistive robot	Meet the NGSS engineering standards through biomimicry	Develop a biomimicry curriculum teaches both biology and engineering	Develop biomimicry course; build VEX skills; value s/f analysis
Outcome: Warm-up	None	None	None	None	Protective helmet	Windswept transport	Windswept transport
Outcome: Main design challenge(s)	Weather rescue robot with bio-inspiration from flinging functions.	Seed collector robot with bio-inspiration from student-chosen animal	Mars landing rocket with bio-inspiration from grasping organisms	Device to help in daily life with bio-inspiration from flinging or grasping organisms	Medical packaging with bio-inspiration from student-chosen organism	Supply delivery device with bio-inspiration from flinging organisms	Assistive grabber device with bio-inspiration from grasping organisms

Table 1. Curriculum choices and other activity system elements for middle-school STEM teachers implementing biomimetic design

Conclusion

We analyzed the curricular decisions of seven middle school STEM teachers who were implementing biomimetic design challenges in their classrooms. Guided by activity system theory, we found that different rules for timeframe and required topics, different pre-existing curricular and physical tools, and different teacher goals were consequential to the different teachers' biomimicry implementations. These findings suggest the flexibility afforded by biomimicry as a design challenge framework. In future work, we plan to analyze students' learning outcomes and the relationship between teachers' curriculum choice-making and students' learning outcomes.

References

Achieve, Inc. (2013). Next Generation Science Standards. Achieve, Inc.

Cviko, A., McKenney, S. & Voogt, J. (2014). Teacher roles in designing technology-rich learning activities for early literacy. *Computers & Education*, 72, 68-79.

English, L. (2016). STEM education K-12: Perspective on integration. *International Journal of STEM Education, 3*(3). DOI 10.1186/s40594-016-0036-1

Guzey, S. & Li, Weiling. (2022). Engagement and Science Achievement in the Context of Integrated STEM Education: A Longitudinal Study. *Journal of Science Education and Technology.* 32. 10.1007/s10956-022-10023-y.

Merriam, S.B. (1998) Qualitative Research and Case Study Applications in Education. Jossey-Bass Publishers, San Francisco.

National Research Council. (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. National Academies Press.

National Research Council (2012). *A framework for K-12 science education: Practices, cross-cutting concepts, and core ideas*. Washington DC: National Academies Press.

Karch, J. M., Mashhour, S., Koss, M. P., & Caspari-Gnann, I. (2024). Expansive learning in the learning assistant model: how instructors' goals lead to differences in implementation and development of LAs' practices. International Journal of STEM Education, 11(1), 37–25. https://doi.org/10.1186/s40594-024-00496-1

Kelley, T.R. & Knowles, J.G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education, 3*(11). DOI 10.1186/s40594-016-0046-z

Engeström, Y. (1987). Learning by Expanding: An Activity-Theoretical Approach to Developmental Research. Helsinki, Finland: Orienta-Konsultit.

Penuel, W.R., & Gallagher, L.P. (2009) Preparing Teachers to Design Instruction for Deep Understanding in Middle School Earth Science, Journal of the Learning Sciences, 18(4), 461-508. https://doi.org/10.1080/10508400903191904

Penuel, W.R., Roschelle, J., & Shechtman, N., (2007). Designing formative assessment software with teachers: An analysis of the co-design process. Research and Practice in Technology Enhanced Learning, 2(1), 51-74.

Acknowledgments

This material is based upon work supported by the National Science Foundation (NSF) under Grant No. 2300433. We are also grateful to the teachers who joined this research.