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Curriculum Choices for Middle-School Biomimetic Design Activities

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Abstract: In this comparative case study, we used activity theory to explain how and why different middle-school STEM teachers from the same professional development community made different curricular adaptation choices for biomimetic design activities. Analysis of teacher interviews, classroom observations, and lesson artifacts revealed that teachers' choices for biomimicry activities were particularly influenced by confidence with and access to particular *tools* and by *rules* related to learning goals and time constraints.

Introduction

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 since using biology as the basis for problem-solving mirrors a practice used by professional designers (Vanderbilt, 2012). When teachers customize biomimetic challenges for their students, biomimicry can also be a personally authentic learning experience. We explore middle-school STEM teacher adaptation of biomimicry curriculum materials.

Theoretical approach

In developing and studying professional development (PD) for STEM teachers, we draw from theory on teachers as designers. Supporting teachers as designers can help teachers develop a deeper understanding of the curriculum, increase a sense of ownership, and lead to changes in instructional planning (Cviko et al., 2014; Penuel & Gallagher, 2009). Engaging teachers as designers may also increase how often teachers implement technology activities and their effectiveness (Cviko et al., 2014). It can help increase uptake and potentially the extent to which innovation persists (Penuel et al., 2007). Our work is also guided by activity theory (Engeström, 1987, 1999, 2001) as a framework for examining what elements influence teachers' curricular decisions. 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, 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 (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 an analytical lens to answer our research question: How do middle school STEM teachers make curriculum choices when implementing biomimetic design activities?

Methodological approach

This is a comparative case study of two middle school STEM teachers from two different school districts in the New England area. These teachers both attended and were highly engaged in our multi-day PD workshop. After the PD, both teachers successfully implemented biomimicry topics in their respective classrooms. We selected them as focal cases because although they engaged with the same PD content, they made different choices in their tools, topics, and student activities. We were curious about the factors influencing teachers' choices.

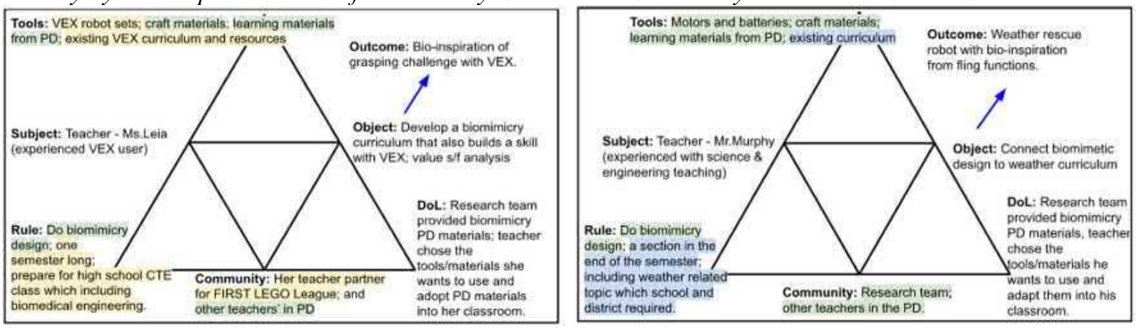
During the PD, teachers first used resources provided by the project to conduct a structure/function (s/f) analysis of plants and animals that are well adapted for the action required by a specific design challenge (flinging, grasping, or digging). They then used what they learned to create a prototype of a design solution, using motors, batteries, Hummingbird robotics kits, and Tinkercad software. After solving three design challenges, de-briefing in group discussion, and exploring project resources, teachers were supported in developing their own biomimicry design curriculum. During their curriculum enactment in the following academic year, we recorded video/audio and took field notes during two observations in each teacher's classroom. We collected lesson plans, class instructional materials (e.g., slides, worksheets), and students' artifacts. We also interviewed both teachers about their curriculum choices. For data analysis, we were guided by the six elements of the activity system triangle. We reviewed each data source and listed all the evidence it provided under those six categories. Then, we compared the similarities and differences between the two teachers, constructed the activity system triangle, and wrote narrative memos about how and why they developed different design challenges for students' biomimicry.

Preliminary findings

Our analysis (see Figure 1) showed that first, *rules* related to learning goals and time constraints shaped the structure and focus of the teachers' curriculum design. Second, although teachers had access to and training on the same *tools*, their choices were influenced by their confidence with particular tools and whether those tools were already in their classrooms. Finally, different *community* members inspired each teacher.

Figure 1

Activity System Representation of Biomimicry Curriculum Choices by Two Middle School STEM Teachers



Green highlighting indicates common elements from PD; blue and yellow indicate elements differing by the teacher.

During the time he planned to implement biomimicry, Mr. Murphy was also required by his district to address science standards on weather. With limited flexibility, he chose to connect biomimetic design to his existing weather curriculum. He developed a design challenge that asked students to design biomimetic devices that could fling small weather instruments into tornadoes, hurricanes, or blizzards to support scientists studying those weather phenomena. He gave his students the choice of prototyping with motors and batteries, Hummingbird kits, or Tinkercad, since they were already familiar with these tools. However, because he had a tight schedule for running this activity, most of his students chose to use the motors and batteries, which they perceived to be the easiest to use. Overall, Mr. Murphy's approach supported him in connecting science standards to biomimicry.

Ms. Leia, on the other hand, had more flexibility to choose the teaching context without specific school or district requirements. She had prior experience with VEX robotics, and saw the similarities between VEX and the Hummingbird kits used in PD. Because Ms. Leia wants to prepare her students for high school careers and technical education (CTE) standards, she chose to combine biomimicry with biomedical engineering to design a semester-long curriculum that also develops students' VEX skills. Her curriculum included three design challenges: airborne transport focusing on learning how to do s/f analysis; an assistive-tech grasping device design challenge maintaining an emphasis on s/f analysis but also developing VEX skills; and a final design challenge allowing open-ended biomimicry. Ms. Leia believed s/f analysis is important for biomimicry learning, so she prioritized s/f analysis in her class compared to Mr. Murphy. She was also influenced by a conversation about s/f analysis with other teachers at the PD and by her FIRST LEGO League partner.

Conclusion

In this study, analysis of curricular decisions according to the six elements of an activity system revealed that different rules, tools, and communities were consequential to the different teachers' biomimicry implementations. Through the analysis of the activity system, we can see that biomimicry afforded the teachers the flexibility to develop their own curriculum based on tools and rules that they were comfortable with. This in turn provided multiple points of entry to encourage integrated learning in their classrooms. While the teachers used biomimicry and the related PD resources differently and developed various outcomes, they were engaged and empowered to create authentic learning experiences for their students. This kind of integrated learning is crucial for students because STEM integrates concepts and practices from multiple disciplines. Overall, Mr. Murphy and Ms. Leia gained the confidence to implement integrated learning through biomimicry in their own classrooms.

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