Macro to Micro:
Motivating students in STEAM education through biomimetics

Developed
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From curing cancer and providing energy, to waste disposal and food production, society is confronted with a host of problems that depend on science. Solving these problems is necessarily interdisciplinary, requiring effective teams of biologists, engineers, designers, and a host of diverse fields. How do we train biologists to work collaboratively with such diverse fields to solve problems? How do we communicate the basics of all of these fields to students interested in tackling these problems? How do we excite, inspire, train and retain students from diverse backgrounds to join these efforts? K-12 education is a key time in the development of STEM interest and motivation [1-3]. Recruiting a large and diverse STEM workforce depends on effectively inspiring and motivating students with science early in their education [4, 5].

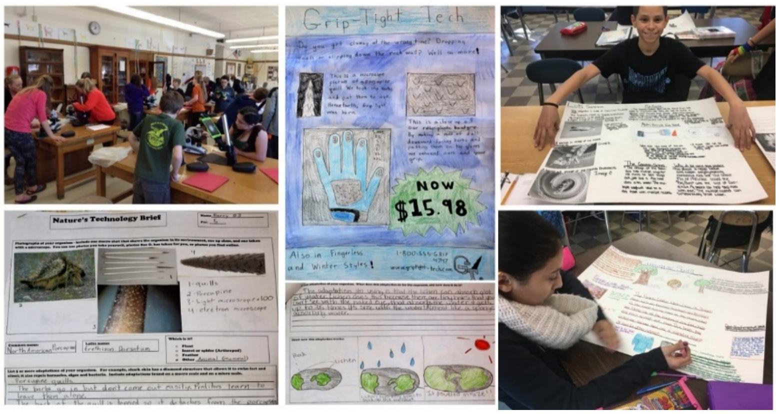
The field of biomimetics offers a framework for immersing students in interdisciplinary research and motivating them to discover, explore and apply scientific concepts, even at young ages. Biomimicry is both a discovery and a problem-solving approach where one seeks to emulate aspects of biological adaptation in their own applications. From gecko-inspired dry adhesives [6] to desalinization technology based on molecules in the cell membrane [7], the biomimetic approach has applications from materials science and robotics to medicine and agriculture [8, 9]. *We have developed a highly effective, evidence-based program – "Macro to Micro" – that immerses K-12 students in biomimetics through microscopy, motivating them to pursue STEM careers while teaching them the basics of biology, engineering, technology and design*.

Macro to Micro works as an approximately 10 to 13-day unit implemented in middle school Life Science classrooms. The unit begins with middle school students receiving a classroom introduction to the field of biomimetics, microscope operation and the scale of the universe. They learn how to draw and are given an orientation to exploring outdoors for biological specimens. Students go on a field trip where they observe, draw, and collect natural specimens (Figure 1). Specimens are brought back to the classroom, where some are viewed under stereo microscopes, and a subset chosen for shipment to a nearby university for remote viewing on a scanning electron microscope or SEM (Figure 2). In the meantime, students engage in a number of additional activities, including literature searches and hypothesis generation about their specimen. Students then interact with a biology graduate student to explore a subset of their specimens on an SEM for 1 class period. The middle school students then choose one micro-trait to focus on in their own biomimetic design and produce a poster displaying the application (Fig 3). *Macro to Micro* has been successfully implemented at five schools, in Ely, MN, Boston, MA, Carver, MA, Beverly, MA, and Kingston, RI in the greater Boston area. Qualitatively, both teacher and student engagement increased as a result of participation. An inner-city Boston middle school student remarked he was motivated

Part 1: Introduction, field work & specimen collection

Part 2: Sample exploration via remote imaging

Part 3: Re-examination, research and designs



to bring up his grades and go into science at MIT; a student in Ely said she was so excited by the project that it was the first one she ever actually completed. One girl saw her specimen on the electron microscope and announced, "*This is why I am going into science*." A quantitative assessment using the science motivation questionnaire [10] revealed that students from two classrooms showed statistically significant improvements in STEM motivation before and after participating in *Macro to Micro*, for instance increasing in their assessment of "*my career will involve science*" and "*learning science makes my life more meaningful.*"

Existing pedagogy research provides support for the high efficacy of *Macro to Micro*. First, recent research has suggested that integration of STEM concepts into instruction can be more motivating for students than teaching concepts in a disciplinary-specific way [11, 12]. Integrated approaches to STEM education have the potential to communicate why the details of specific sub-disciplines (biology, chemistry, engineering, etc) are important to understand. Integration of hands-on technology and engineering experiences often enhance STEM education [13, 14]. In addition, this program effectively integrates art and design into STEM education, consistent with recent calls for "STEAM" [15, 16]. How to design and effectively integrate STEM fields in education, along with art and design, is still an active area of research [17-19], and *Macro to Micro* offers an exciting and promising way forward in the effective integration of STEM fields in middle school instruction. Biomimetics is inherently integrated, not only with respect to subdisciplines within science, engineering and technology, but also with respect to art and design. Second, *Macro to Micro* is problem- [20-22] and inquiry-based [23-26], which are both highly effective methods in science education. Third, *Macro to Micro* involves active outdoor exploration. In K-12 students, outdoor experiences and "field work" can increase self-confidence and motivation to explore biology [27, 28]. Education within natural settings can improve science test scores, problem solving and motivation to learn [29, 30]. In addition, allowing children to "discover" problems in an activity (rather than being assigned them), improves creativity and motivation [31]. Finally, *Macro to Micro* allows students to interact with real scientists (PhD students), often from diverse backgrounds. Such experiences can be quite motivating as they often dispel myths of how scientists "should" look, encouraging students of different ethnicities and gender to continue in science [32].

While STEM education research has a wide range of recommendations for effective K-12 education, we are lagging behind in the development of programs that actually meet all of these criteria. *Macro to Micro* is highly integrative and inquiry-based, while offering opportunities for outdoor exploration and interactions with scientists, all of which no doubt lead to the success of this approach in motivating middle school students to learn science and pursue STEM careers. We are currently seeking financial support to run *Macro to Micro* through the University of Minnesota, where we estimate we would reach at least 1000 middle school students annually for each PhD student coordinating the program.* Over the longer term, we hope to expand *Macro to Micro* to be run through several University hubs across the country, especially at schools with existing expertise and interest in biomimetics, such as Arizona State University, Akron University, Harvard University and University of California at Berkeley. *Macro to Micro* would link graduate programs and imaging centers at these universities to local middle schools to effectively engage students in STEM education by immersing them in biomimetics. This program would additionally benefit the graduate programs and universities involved by strengthening outreach programs and explicitly connecting basic biological research to a range of engineering and design applications.

***Update - Funding was received for a UMN graduate student and instrument time for 2019-2020.**

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