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Board 320: Integrating Computational Thinking into a Neural Engineering High School Curriculum

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Integrating Computational Thinking into a Neural Engineering High School Curriculum

Abstract

Engineering design and computational thinking are critical to contemporary STEM research. This is reflected in the Next Generation Science Standards, which call for broadly exposing K-12 students to engineering design and computational thinking as core practices. The development and investigation of pathways to successfully integrate these practices in all science disciplines are presently limited. Here, we propose a framework for efficiently connecting computational thinking practices with engineering design, and describe a four week NGSS-congruent module that strategically weaves opportunities for high school life science students to apply engineering design and computational thinking. Analysis of pilot data gathered from five sections of a life science course in a northeastern U.S. urban high school during the 2022-2023 academic academic year will inform the next iteration of the module.

Background and Motivation

The thought processes associated with formulating problems and solutions such that they can be efficiently and effectively carried out by both machine (i.e., computer) and human is known as computational thinking (CT) [1]. While the construct of computational thinking originated in computer science, CT practices like abstraction, pattern recognition, and modeling are recognized to be incorporated in all science, technology, engineering, and math (STEM) disciplines [2], [3] and have revolutionized how scientists and engineers process and analyze vast quantities of data [4], [5].

Despite the fact that CT applies to a wide range of STEM disciplines, most existing K-12 CT education efforts focus on computer science [6] - [8]. This represents a missed opportunity because computer science and programming courses are only offered by 45% of high schools in the United States and are only required by nineteen states [9]. Furthermore, students from minoritized groups that are underrepresented in STEM are less likely to enroll in such courses [10], [11]. Given the ubiquity of computer-based tools and technologies, it is essential that all K-12 students have exposure to CT approaches that underlie modern technology.

Identifying Problems and Opportunities to Broaden CT

Members of the education research community have argued that computational thinking needs to be taught in courses beyond computer science [7], [12], [13]. The National Science Foundation (NSF) has recently promoted the integration of computational thinking into math and science courses, resulting in so-called STEM + computing curricular approaches (STEM + C). However, this CT instruction has been positioned as an add-on, rather than an integral component of disciplinary practice in these efforts [14]. Expanding this work, the NSF's Discovery Research PreK-12 program has encouraged projects that "integrate computing and computational thinking within one or more of the other STEM disciplines as a way to improve teaching and learning in formal education settings" and in projects that "reflect real-world, interdisciplinary thinking in computational and data-enabled science and engineering" [15]. In response, we are developing, implementing, and evaluating resources to support the integration of CT within two STEM disciplines: engineering and biology. We do so by engaging students in engineering design in the context of neural engineering, an emerging and innovative area at the intersection of biology, engineering, and computation [16].

Engineering Design as a Framework for Computational Thinking

Engineering design offers an appealing context for fostering CT in K-12 education because engineering design and CT have many conceptual and practical commonalities like identifying problems, analyzing systems, and creating and testing of artifacts [17], [18]. There is evidence that engineering design can help develop students' CT interests and self-efficacy [19], as well as CT practices [20] - [22], yet engineering design is not commonly used as a basis for enhancing CT in STEM education [6].

Engineering design facilitates opportunities for K-12 students to engage in interdisciplinary thinking. Design provides a real-life context for students to develop and expand scientific, technological, and mathematical knowledge and skills as they make decisions and propose solutions [23]. These affordances are recognized in the framework that guided the construction and composition of the latest science standards – the Next Generation Science Standards (NGSS) – which includes and promotes the integration of engineering and computational thinking [24], [25]. However, the field lacks specific tools to translate these aspirations to educational practices. A decade since the publication of the NGSS, exemplary engineering activities have yet to be identified and published [26].

Here, we propose a framework for explicitly connecting computational thinking practices with engineering design. We consider the three main phases of CT - problem decomposition, abstraction, and algorithmic thinking - and how these map to problem definition, needs finding, and solution generation in engineering design. With these analogs in mind we have developed a crosscutting framework that links NGSS goals with scientific inquiry, CT, and engineering design.

Neural Engineering: Intersection of Life Science, CT, and Engineering

In this project, we are designing a four-week-long CT-intensive high school life science module that revolves around recent developments in neural engineering. Neural engineering, the application of engineering design principles toward solving problems related to the nervous system [27], is critically dependent on computational tools. Neural engineers collect and analyze neuronal data and use these data to characterize disease and injury, control neural prosthetics, etc. CT concepts such as the flow of information, relationships and interactions between system levels, and modeling are fundamental to neural engineering. Thus, neural engineering provides a novel, interdisciplinary, and real-world context to develop high school students' CT.

Project Goals

The project goals are to: (1) Develop and field-test a neural engineering curriculum unit to support CT in high school students; (2) Develop an instructional app to assist students throughout the design process; (3) Investigate how student CT skills and attitudes towards STEM change as they participate in the module. The project addresses several educational research questions:

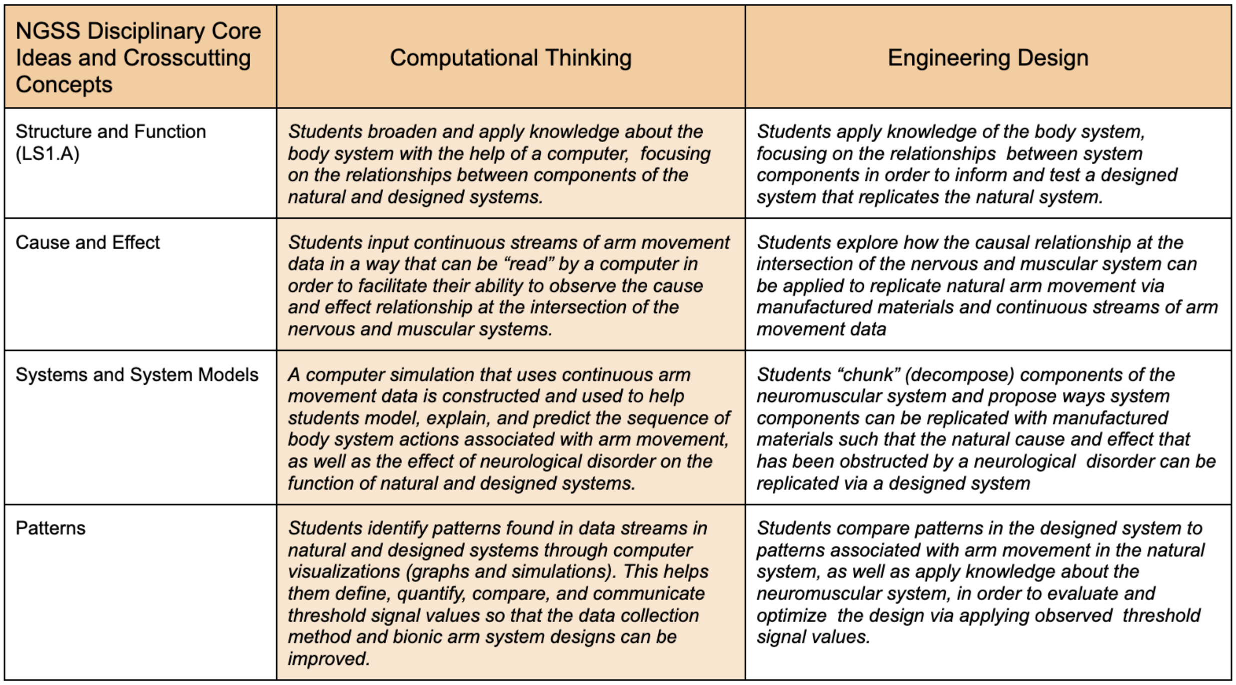
1. How can CT be incorporated into non-computer science STEM disciplines (life science and engineering) at the high school level?
2. How does the process of collecting and analyzing bioelectrical data relate to students' CT? How do students' attitudes towards STEM change over the course of their participation in a CT-intensive biology unit?
3. How to best prepare and support teachers to educate students in CT via engineering design?

The curriculum, instructional app, and associated teacher professional learning (TPL) are being developed by an interdisciplinary team, including experts in neuroscience, biomedical engineering, instructional technology, as well as K-12 science education and research partners. Using design research [28], [29], we are iteratively designing a sustainable and scalable neural engineering curriculum unit with teachers as design partners.

Project Components

Instructional Modules

The instructional modules strategically integrate NGSS life science disciplinary core ideas, engineering practices, and crosscutting concepts associated with computational thinking activities (Table 1). Standards-congruent instructional materials may be more likely to be considered useful to teachers. Accordingly, the instructional materials are designed to fit in mandated high school course content.



NGSS Disciplinary Core Ideas and Crosscutting Concepts	Computational Thinking	Engineering Design
Structure and Function (LS1.A)	*Students broaden and apply knowledge about the body system with the help of a computer, focusing on the relationships between components of the natural and designed systems.*	*Students apply knowledge of the body system, focusing on the relationships between system components in order to inform and test a designed system that replicates the natural system.*
Cause and Effect	*Students input continuous streams of arm movement data in a way that can be "read" by a computer in order to facilitate their ability to observe the cause and effect relationship at the intersection of the nervous and muscular systems.*	*Students explore how the causal relationship at the intersection of the nervous and muscular system can be applied to replicate natural arm movement via manufactured materials and continuous streams of arm movement data*
Systems and System Models	*A computer simulation that uses continuous arm movement data is constructed and used to help students model, explain, and predict the sequence of body system actions associated with arm movement, as well as the effect of neurological disorder on the function of natural and designed systems.*	*Students "chunk" (decompose) components of the neuromuscular system and propose ways system components can be replicated with manufactured materials such that the natural cause and effect that has been obstructed by a neurological disorder can be replicated via a designed system*
Patterns	*Students identify patterns found in data streams in natural and designed systems through computer visualizations (graphs and simulations). This helps them define, quantify, compare, and communicate threshold signal values so that the data collection method and bionic arm system designs can be improved.*	*Students compare patterns in the designed system to patterns associated with arm movement in the natural system, as well as apply knowledge about the neuromuscular system, in order to evaluate and optimize the design via applying observed threshold signal values.*

Table 1: NGSS crosscutting concepts, science and engineering practices, and life science disciplinary core ideas associated with students' computational thinking activities [25]

The design team chose to utilize what is known as an anchoring phenomenon around which learning activities pivot [30]. Anchoring phenomena are observations that are introduced at the beginning of a module to orient and motivate student learning. The anchoring phenomenon for our neural engineering unit is introduced via a short video in which a fellow teen explains why and how she uses a bionic arm. In subsequent activities, students explore components and interactions of the body systems in order to be able to explain how the young woman's bionic arm works, as well as how a similar device could be designed to improve the lives of people with different neurological disorders. Like neural engineers, students use and apply bioelectrical data, as well as physical and simulated models of a simple bionic arm to explore and apply interactions of components of the nervous and muscular systems. Throughout this process, students work with a simplified version of a bioelectric prosthetic: a prefabricated gripper developed by Backyard Brains [31] (Figure 1). The gripper's opening and closing is triggered by bioelectric inputs. Using this device, the students are able to explore how muscular electrical signals can be used to engage a prosthetic and restore some lost lower limb function.

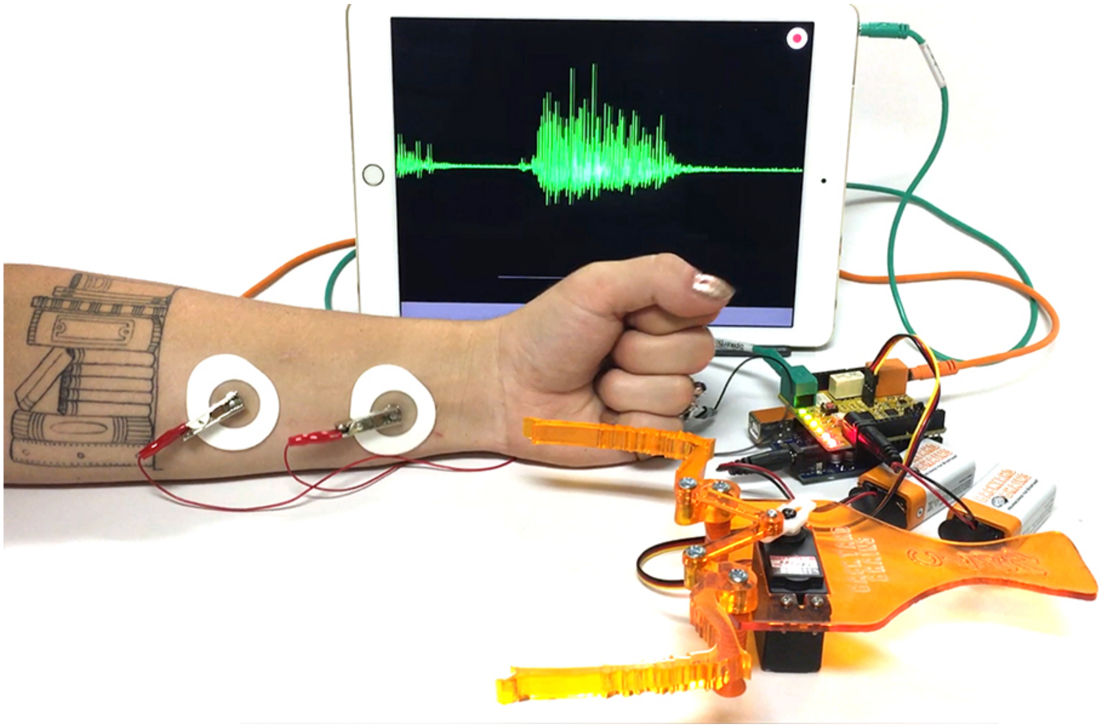


Figure 1: Prefabricated gripper developed by Backyard Brains (image credit: Backyard Brains [31])

In the second module, students apply this knowledge as they improve the design of a bionic arm by considering how the lack of tactile feedback from the prosthetic arm might affect its functionality. Students then engage in the engineering design process where they apply CT practices to decompose the problem, identify appropriate solutions, and develop algorithms to allow the bioelectric gripper to interface with a force sensor, thereby emulating tactile feedback.

Instructional App and Content Management System

An instructional app has been developed to both facilitate and document students' design and CT activities to control the aforementioned gripper (Figure 2). The app employs a block-based programming architecture, allowing students to observe causal relationships, recognize patterns, as well as interactions within natural and designed systems – key concepts embedded in the NGSS [25]. Because the programming is visual and block-based, students are able to apply CT to their bionic arm design without pre-existing programming or syntax knowledge. A web-based content management system was selected, populated, and used to organize the instructional modules and computational tools for students and teachers. This system includes features that enable teachers to modify piloted instructional materials to better serve their students, as well as provide a dynamic digital pathway for teacher input [32].

Figure 2: Instructional app used by students in the unit

Professional Learning

To support teachers as they learn and devise instruction for CT and engineering design, we have designed and implemented a 3-day-long professional learning workshop for high school STEM teachers. During the workshop, teachers were introduced to the instructional modules, app, and content management system. Teachers were also asked to provide feedback on the modules that will inform subsequent improved offerings of this content to other teachers.

Summary and Future Work

This project strives to create instructional tools for teachers to promote their teaching of computational thinking via engineering design. We combine CT with engineering design because the processes of decomposition, abstraction, and algorithmic thinking, which are central facets of CT, are mirrored by the problem identification and solution generation activities that are the hallmarks of engineering design. Additionally, an emphasis on engineering design gives CT problems real-world applicability without the emphasis on computers and programming languages.

Thus far, we have designed the first iteration of a CT-intensive engineering design unit, a teacher professional learning workshop, and a block-based programming app for students. The initial implementation in five sections of life science in an urban northeastern U.S. high school is currently underway, through which we will gather feedback from our teacher partners on the instructional tools, as well conduct assessment of the content and the impact of this instruction on teachers' and students' CT learning. Data analysis is scheduled to be completed before the start of the 2023-2024 academic year. The evaluation process will provide insights on how CT and engineering design can be integrated, as well as inform the revision of these instructional materials.

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