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Neuroscience and Engineering: Interdisciplinary STEAM Curriculum at a Girls' Middle School (Work in Progress)

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Background

To support students' meaningful learning, the *Framework for K-12 Science Education* emphasizes the importance of incorporating engineering practices in science instruction [1]. Students who are more actively engaged in engineering design will be better equipped to participate in and contribute to addressing societal and environmental challenges in the present and future. Additionally, the underrepresentation of females in the areas of science, technology, engineering, and mathematics (STEM) has been well documented [2]. It is crucial for girls who aspire to STEM careers to have access to learning environments that engage them in scientific and mathematical practices and that support a growth mindset. Including an art component with the integration of science, technology, engineering, and mathematics (STEAM) engages students in authentic problem-solving through creative design experiences [3].

Objectives

In partnership with a National Science Foundation (NSF) funded Research Experience for Teachers (RET) program at the University of Washington's Center for Sensorimotor Neural Engineering (CSNE), the author, a middle school science teacher, designed and implemented a two-week, project-based neural engineering STEAM unit. The unit was designed to provide multiple access points for student engagement through the inclusion of a range of high interest topics: neuroscience, circuitry, coding, engineering design, art, and ethics. The unit's effectiveness in teaching science and engineering skills and affecting attitudes was evaluated through the use of student surveys.

Program Description

The interdisciplinary STEAM curriculum unit titled "Sensory Substitution" examined the real-world problem of sensory impairment. The unit engaged 5th-8th grade students at an all girls middle school in engineering design and was implemented over a nine-day period. Each day's lesson lasted 2 hours, with a total of 18 hours for the entire unit. Forty-seven students participated in the STEAM project over two years.

The unit consisted of lessons in neuroscience, sensory impairment, ethics, circuitry, programming Arduino microcontrollers, and the engineering design process. Students then spent the last three days of the unit engaging in the creative process of planning, building, and testing a model of a device that substituted one sense with another (see Appendix A for an outline of the lessons).

Two neuroscience lessons involved the discussion of sensory inputs, processing through the central nervous system, and motor outputs. Since the class was multi-grade, 7th and 8th grade students had the opportunity to mentor 5th and 6th grade students in their understanding of the neurobiology concepts as the human body is covered in the 6th grade science curriculum. Videos and articles were used to explain the problem of sensory impairment, explore current research in the area of neural engineering and sensory substitution, and showcase devices such as closed-loop prosthetic arms currently being tested and used.

One lesson was devoted to considering ethical issues related to neural engineering. This was done through class discussions of assumptions made about user needs, and through a TED Talk video about what is “normal” for persons with disabilities. The assumptions about user needs and possible harmful effects of engineering devices were considered throughout the unit, and students were required to reflect on these questions as they presented their sensory substitution device to the school community.

The concepts of circuitry were introduced through hands-on experiences using Snap Circuits® and breadboards, as well as online animations and videos. Students learned about connecting and programming the Arduino microcontroller through a series of scaffolded activities which included some offline learning and modifying of existing code. Students then discussed the different aspects of the engineering design process and used a design notebook to document their ideas, questions, and modifications while building a model of their sensory substitution device. Art was incorporated into different parts of the curriculum, from decorating prosthetic fingers as a consideration of the importance of aesthetics to the user, to the final slideshow to communicate the process of building their Arduino-controlled model.

To evaluate the effectiveness of this interdisciplinary Sensory Substitution curriculum, student self-assessments were administered. In the pilot year, only general questions were asked at the end of the unit (Appendix B). Students were able to self-assess their ability to perform a certain skill as “Yes,” “I’m getting there,” or “Not Yet.” In the second year, students self-assessed their change in skill level in building circuits, programming an Arduino, communicating neuroscience concepts, engaging the engineering design process, and considering ethics at the end of the unit (Appendix C). Students rated their ability to perform a certain skill on a 5-point Likert scale, with the lowest value being “Hardly at all” and the highest value being “Very well.” Additionally, students in the second year self-assessed their attitudes about problem-solving, ethics, and STEAM careers before and after the unit (Appendix D). A 5-point Likert scale was used with responses ranging from “Strongly Disagree” to “Strongly Agree.” These questions were adapted from the Friday Institute survey designed to assess middle school student attitudes toward STEM [4]. Additionally, open-ended questions asked students to reflect on their most memorable experience in the unit and how they might apply the skills they learned in the future.

Results/Evaluation

A total of 47 students participated in the Sensory Substitution unit over two years. However, only 44 students (19 students from Year One and 25 students from Year Two) completed the surveys.

General Evaluation of Student Learning

From the general questions asked at the end of the unit in both years (44 responses), 93% of the students answered "Yes" or "I'm getting there" when self-assessing their ability to make connections between neural pathways and electronic circuits (Figure 1). Ninety-five percent of students answered "Yes" or "I'm getting there" when self-assessing their ability to create and modify an Arduino-controlled circuit (Figure 2), and 100% reported competency or developing competency in independently solving problems and asking for help when needed (Figure 3).

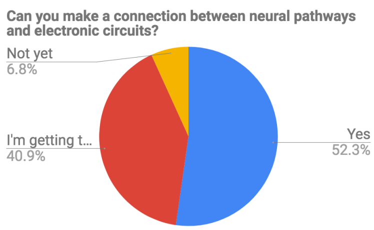


Figure 1. Student-assessed competency in connecting neural pathways and electronic circuits.

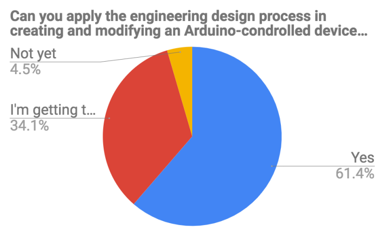


Figure 2. Student-assessed competency in creating and modifying an Arduino-controlled circuit.

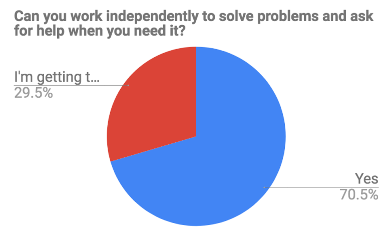


Figure 3. Student-assessed competency in solving problems and asking for help.

Students Gain Skills in Several Disciplines

Results from the second year of curriculum implementation showed students gaining skills in explaining basic neuroscience and circuitry, building an Arduino-controlled circuit, describing the engineering design process, and considering ethical issues (Figure 4). The greatest acquisition of skills occurred in the areas of building a circuit on a breadboard and programming an Arduino to control the circuit.

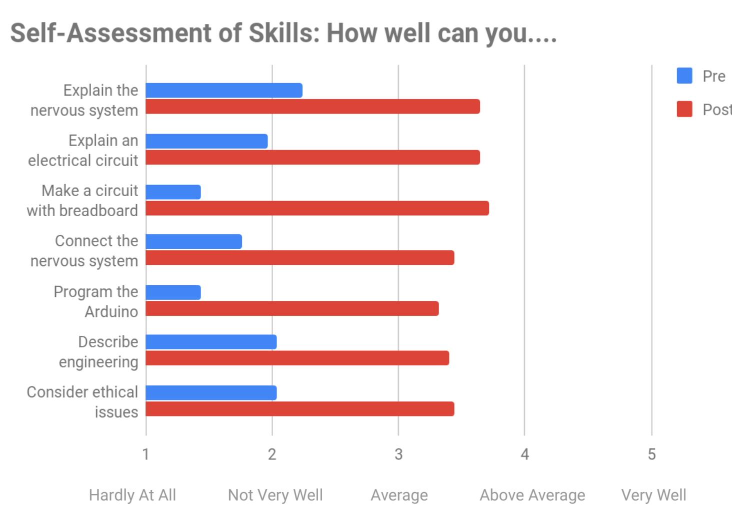
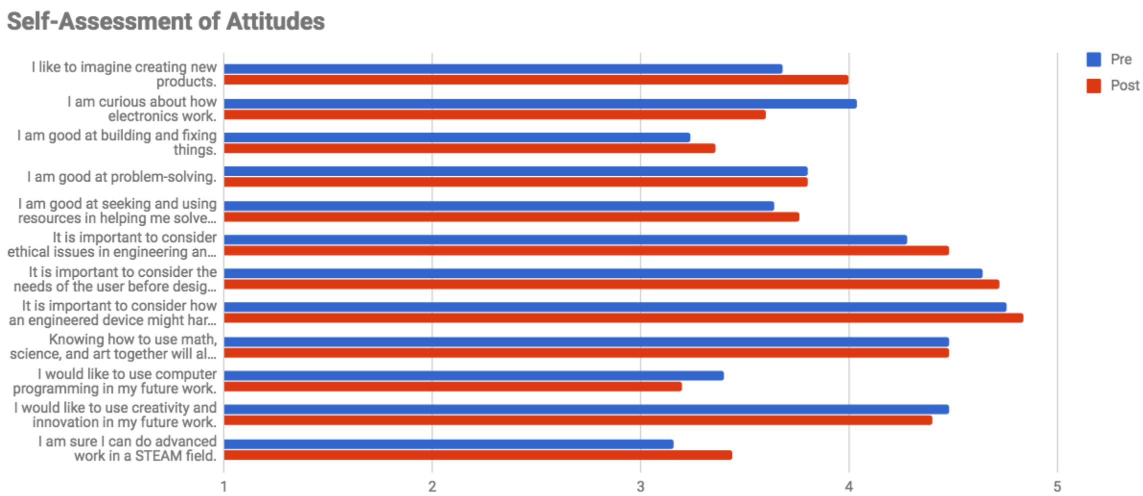


Figure 4. Means of student-assessed skills before and after unit (n=25).

Student Attitudes Remain Relatively Unchanged

Students started with a high rating for most of their attitudes about their abilities and their future in STEAM-related tasks and careers (Figure 5). These attitudes remained high at the end of the unit, with slight to no change in attitude for all questions. Students decreased in their curiosity about how electronics work (M=-0.44, SD=1.04), and there was a slight decrease in the number of students who would like to use computer programming in their future work (M=-0.20, SD=0.87). Students increased their attitudes towards imagining creating new products (M=+0.32, SD=0.80) and doing advanced work in a STEAM field (M=+0.28, SD=0.89).



Strongly Disagree Disagree Neither Disagree Nor Agree Agree Strongly Agree

Figure 5. Means of student-assessed attitudes towards STEAM before and after unit (n=25).

Ethics and Arduinos as Highlights of the Unit

Eleven of 25 students reported that the TED Talk on how disabilities are viewed was the most memorable activity from the unit (Figure 6). Additionally, students gained the skill of connecting and programming Arduinos, and 17 of 25 students saw this as an important skill to use in the future (Figure 7).

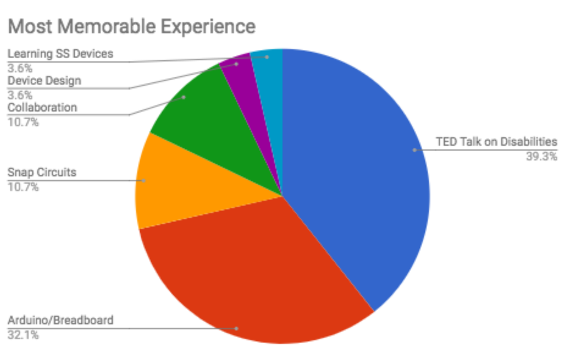


Figure 6. Student-reported most memorable activity.

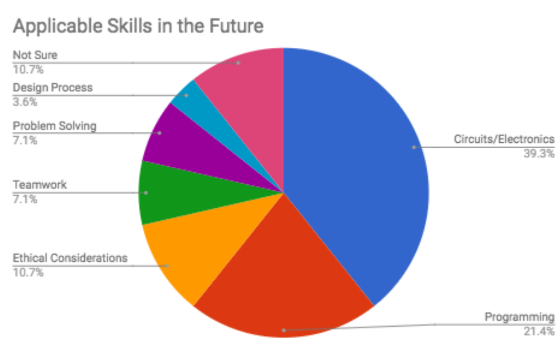


Figure 7. Student-reported future skill application.

Conclusion

Students at an all-girls middle school benefited from engaging in the interdisciplinary Sensory Substitution unit. They acquired skills in the areas of neuroscience, ethics, engineering, circuitry, and programming. The largest gains were made in learning about programming Arduino microcontrollers and in using breadboards to construct functioning circuits. Students saw the applicability of these skills in the future. One of the more favored activities was watching videos involving ethical considerations. This highlights how students are attracted to the humanistic aspect of the work done in science and engineering; they enjoyed discussing the benefits and potential harm from engineering a device designed for a person with a sensory impairment.

At the school where this STEAM curriculum was implemented, there is a constant focus on providing authentic learning experiences for its students and providing many opportunities for creativity, design, and problem-solving. This resulted in a ceiling effect on many of the attitudes towards STEAM. Students even decreased in their curiosity about how electronics work, likely due to having learned about electronics and how circuits are constructed through this unit. However, students reported growing confidence in doing advanced work in a STEAM field and creating new products. These results suggest that educators can implement more interdisciplinary units to provide opportunities for all students to engage in creative design processes while considering ethics in science and engineering. As women are still underrepresented in STEM careers, providing opportunities for girls to engage in this type of interdisciplinary learning is crucial to helping girls develop skills they can use, and maintain interest, in future STEM careers.

Future Plans

Following the second implementation, the curriculum was revised to improve the unit. The next step is to make the unit available for broad dissemination to pre-college science and engineering educators through publication on websites, presentations at educational conferences, and other professional development workshops. The goal of the dissemination is to help K-12 teachers incorporate neural engineering design into their science instruction to support students' meaningful learning; this will reach and engage more students in designing creative solutions to real-world challenges.

References

[1] National Research Council. *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, DC: The National Academies Press, 2012.

[2] C. Hill, C. Corbett, A. St. Rose, & American Association of University Women. *Why So Few?: Women in Science, Technology, Engineering, and Mathematics*. Washington, D.C: AAUW, 2010.

[3] J. Miller, & G. Knezek. "STEAM for student engagement," In R. McBride & M. Searson (Eds.), *Proceedings of SITE 2013--Society for Information Technology & Teacher Education International Conference*. New Orleans, Louisiana: Association for the Advancement of Computing in Education (AACE), 2013. pp. 3288-3298.

[4] Friday Institute for Educational Innovation. *Student Attitudes toward STEM Survey-Middle and High School Students*, Raleigh, NC: Author, 2012.

Acknowledgments

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Appendix A - Overview of Lessons

Day	**Topic**	**Activity**
1	Introduction to Neuroscience Introduction to Sensory Substitution	If you lost your _____ sense…. Robot hand stimulated with muscle Nervous System Diagrams David Eagleman TED Talk
2	Assistive Devices vs. Neuroprostheses Introduction to Circuits	Videos about assistive devices and neuroprostheses Exploring circuits online Snap circuit exploration
3	Circuits	Breadboard introduction Creating prosthetic finger
4	Neuroethics Circuits - inputs and outputs	Stella Young TED Talk Snap Circuits to manipulate outputs based on inputs
5	Introduce Arduinos	Examine prosthetic finger and discuss modifications Parts of Arduino Using Blink program and various outputs
6	Engineering Design Process Arduino - using sensors to control output	Define problem, criteria, constraints Write if/then statements to program into Arduino based on device design Using sensors to control output
7	Engineering Design Process	Design and modify Sensory Substitution Device
8	Communicating the Design	Continue modifying device Create presentation to showcase design process and device
9	Presenting the Design	Finish presentation Share project with larger audience Surveys

Appendix B - General Self-Assessment Questions (Year One and Year Two)

Responses for the following questions included "Yes," "I'm getting there," and "Not yet"

- Can you make a connection between neural pathways and electronic circuits?
- Can you apply the engineering design process in creating and modifying an Arduino-controlled device that helps substitute an impaired sense?
- Can you consider the end-users and the ethics involved in designing and implementing the sensory substitution device?
- Can you work independently to solve problems and ask for help when you need it?

Appendix C - Questions in Self-Assessment of Skills (Year Two)

Responses for the following questions were on a 5-point Likert scale, with choices of "Hardly at all," "Not well," "Average," "Above average," and "Very well."

- How well could you explain the basic structure and function of the nervous system... [BEFORE/AFTER the unit?]
- How well could you identify the basic components of an electrical circuit and explain how they should be arranged... [BEFORE/AFTER the unit?]
- How well could you explain the structure of a breadboard and how to arrange components on a breadboard to make a functioning circuit... [BEFORE/AFTER the unit?]
- How well could you explain the similarities between the nervous system and electrical circuits... [BEFORE/AFTER the unit?]
- How well could you connect an Arduino to a breadboard and program the Arduino to vary output based on different input levels... [BEFORE/AFTER the unit?]
- How well could you describe the steps involved in the engineering design process... [BEFORE/AFTER the unit?]
- How often or deeply did you consider the ethical issues when brainstorming to solve a problem for the intended user of an engineered device... [BEFORE/AFTER the unit?]

Appendix D - Questions in Self-Assessment of Attitudes (Year Two)

Responses for the following questions were on a 5-point Likert scale, with choices of "Strongly disagree," "Disagree," "Neither disagree nor agree," "Agree," and "Strongly agree."

- I like to imagine creating new products.
- I am curious about how electronics work.
- I am good at building and fixing things.
- I am good at problem-solving.
- I am good at seeking and using resources (like researching and asking questions) in helping me solve problems.
- It is important to consider ethical issues in engineering and problem-solving.
- It is important to consider the needs of the user before designing a device or product.
- It is important to consider how an engineered device might harm the people who might use it.
- Knowing how to use math, science, and art together will allow me to invent useful things.
- I would like to use computer programming in my future work.
- I would like to use creativity and innovation in my future work.
- I am sure I can do advanced work in a STEAM field.