NeuroBytes: Development of an Integrative Educational Module Across Neurophysiology and Engineering (Evaluation)

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NeuroBytes: Development of Integrative Educational module across Neurophysiology and Engineering
Abstract

NeuroBytes, electronic neuron simulators developed by NeuroTinker were originally designed to teach students more about neuroscience through the use of hands-on projects. However, this new teaching tool is also well suited for use in other classrooms, such as introductory engineering courses. One issue within these courses is they lack an engaging biomedical engineering project which is suitable for all the students. NeuroBytes are relatively easy to use and require little prior knowledge. This technology bridges the gap between technology and biology or neurophysiology in order to show students the basic principles of biomedical engineering. A total of 15 students and two teachers in a dual credit engineering course, offered by the University of Arizona, participated in this evaluation of NeuroBytes. Teachers first completed a pre-lab survey and then a post-lab survey to determine if there was a need for this kind of tool and whether it was useful in their classroom. Students filled out a post-lab survey only after they had participated in a two-day lab where they were instructed to build a circuit with the provided kits which would respond to light and touch. The goal of the lab was to introduce students to the concepts of biomedical engineering and to show them the connection between the human nervous system and technology.

Introduction

In introductory engineering courses, instructors strive to show their students the various kinds of engineering opportunities that are available to them. However, this task is often difficult to achieve, and certain fields of engineering are only briefly described to students. A solution to this problem is to present students with a hands-on activity to better illustrate the basic principles of that particular field. In one experiment, middle school, high school, and undergraduate students were taught about neural patterns through the use of a four-legged robot called a SlugBug which moved using servo motors and RC circuits [5]. The researchers found that the SlugBug allowed students to explore and utilize the concepts they were being taught. It also allowed them to use their creativity to problem solve. The company NeuroTinker has designed a unique technology-based biomedical teaching tool called NeuroBytes. These electronic neuron simulators are a demonstration of the merging of the technological and biological. The small microprocessors mimic the electrical activity of neurons and allow students to construct functioning circuits which can respond to various stimuli, such as touch and light. With these tools, students can be assigned a task and work through the Engineering Design Process to create a circuit to meet the requirements. Teachers can design various labs for students using NeuroBytes because the circuits can be customized. NeuroBytes are also designed to be used by students coming from various levels of engineering and technology education. No programming or electrical knowledge is required to work with them. Instead, NeuroBytes offer a simple way for students to learn about neural circuitry but also leave room for students to apply their current knowledge.

Due to the cross between neuroscience and technology, NeuroBytes fit perfectly within the realm of biomedical engineering. This interdisciplinary field is often times simply described by instructors in introductory engineering courses because it is hard to demonstrate to a class, let alone provide students with an interesting hands-on project. By providing an interactive project, the NeuroBytes give students the opportunity to learn in a new way and to use their problem-solving skills by themselves or within a group. These projects improve student engagement and increase the retention of the material being taught [6]. Designing more interactive projects for
STEM education is important because it engages the students in the learning process in a different way. This allows students who may be intimidated or unsure about a career in STEM to explore the field in a new way.

The designers of NeuroBytes created NeuroTinker in 2015. Their goal is to provide tools for students to learn about neuroscience through the use of interactive technologies and project-based learning. NeuroTinker has received a grant from the National Science Foundation (NSF) to pursue the development of NeuroBytes in order to use the technology to increase retention rates in the STEM fields [2]. NeuroTinker later partnered with the University of Arizona in phase two of their proposal in order to create different types of NeuroBytes and design new curricula to be used in classrooms [3]. Over the course of its existence, NeuroTinker has gone through several iterations of the NeuroBytes and have expanded their original selection of neurons. They currently have interneurons, motor neurons, touch receptors, and light receptors.

The purpose of this paper is to evaluate the usefulness of NeuroBytes as a tool to introduce students to biomedical engineering. Whether or not they are capable of meeting this goal will be determined by several evaluation questions:

- Are the students engaged in the project?
- Are students more interested in biomedical engineering after the project?
- Do teachers feel that the project helps them in introducing students to biomedical engineering in an effective manner?
- Are NeuroBytes suited to an introductory engineering course? Are they easy to work with? Do they require previous knowledge?

**Background**

NeuroBytes were created in order to mimic the activity of neurons within the body. Neurons are cells that allow us to detect and respond to a stimulus. When a stimulus is detected, neurons work together as a network to pass this signal through the nervous system with the final destination often being the brain. In order to communicate, a neuron first generates an action potential or electrical signal through an ion gradient. When the resting membrane potential becomes more positive, or depolarizes a sufficient amount, the action potential travels down the axon to the synaptic terminals. This then causes the release of neurotransmitters to the next neuron, communicating the original signal. The process repeats itself until it reaches an integration center where the signal can be turned into an appropriate response. These circuits can be very complex and long or can be shorter. Some of the shorter circuits which cause an immediate response are called reflexes. The response to the stimulus is very quick and the signal does not travel all the way up to the brain. An example is a person stepping on a tack and retracting their foot. A quick response is needed in order to avoid further damage to the foot.

NeuroTinker sells the NeuroBytes in kits. One of their most recent kits includes a platform with two motorized wheels, a battery pack, red and blue cables, interneurons, motor neurons, touch receptors, and light receptors. The battery pack is then strapped to the underside of the platform, connected to one or two motor neurons and then the motor neurons are connected to one or both wheels. From there, other neurons can be attached which will send action potentials to the wheels, making them go forwards or backwards.
In 2016 at the University of Wisconsin-Milwaukee, NeuroBytes were introduced to a physiology class of 162 students [1]. The idea was to use this new technology to see if it improved student engagement and retention. One group was given the patella tendon reflex lab designed by NeuroTinker and the control group was given a lab manual based activity to learn about the reflex. Through the usage of a pre and post assessment questionnaire, data was collected that determined the students who used the NeuroBytes better understood the concepts and felt more engaged in the lab.

**Learning Framework**

The idea behind this project was to allow the students to learn how the technology worked on their own, in hopes they would make their own connections to the material and thus be more motivated to learn. The lab was designed within a constructivist framework. Constructivism is a learning theory developed by Jean Piaget which states learning is a more active process where a student uses their prior knowledge and experiences and applies it to problems they encounter inside and outside of a classroom [8]. This type of learning has been used as the basis for many other frameworks. This is especially important in the case of an introductory engineering class where students come from varying levels of experience because they are just starting to learn about engineering. NeuroBytes are also very useful within this framework because they do not require any previous experience but at the same time can hold the interest of people familiar with biology or technology. Some of the students who completed the surveys had programming experience and were curious about the more technical aspects of the NeuroBytes. Whereas other students had little experience with programming or engineering other than the class they were currently taking. These students viewed the NeuroBytes in a more general way and focused less on the specifics. However, both groups of students were able to work together to design their vehicle.

In addition to constructivism, the lab was also designed to be hands-on for all the students. Hands-on and interactive projects have been shown to increase a student’s interest in the material they are being taught. One study at the University of Boulder Colorado found that their Integrated Teaching and Learning (ITL) program for engineering had an 80% retention rate [9]. The idea behind the program was to provide students with more interactive projects and demonstrations. Students in the program said that the activities gave their work meaning and they were able to use their knowledge in practical applications. They even cited the programs unique take on engineering as the reason they selected the university and remained in engineering. Programs similar to this are being implemented throughout universities due to their effectiveness in increasing retention rates and student’s interest in various subjects [10].
Methods

In order to evaluate this technology, a prototype NeuroByte kit was brought to two different high schools, where students were taught briefly about neurons. There was a total of 19 students who worked with the NeuroBytes and all of them completed a survey via SurveyMonkey® to evaluate the technology, eight from one school and eleven from the other. Due to the limited number of kits available for the classrooms, only small groups of students were selected from each high school to work with the NeuroBytes. The teachers were in charge of selecting the students. They chose students who they believed were committed to learning and naturally curious. The lab was conducted across two to three class periods, each about 50 minutes long. The students were given the NeuroBytes and a manual created by NeuroTinker in order to understand how to set up the circuits. The lab and link to the manual is found in appendix A of this paper. Below are the learning outcomes associated with the lab.

Learning Outcomes

- Define and describe the nervous system
- Identify the basic components of a neuron
- Describe how neurons function within the body
- Explain and understand how neurons communicate
- Apply knowledge of the nervous system and neurons to an electronic circuit
- Identify the major components of a circuit and the similarities to the nervous system
- Recognize the differences between neurons and NeuroBytes
- Troubleshoot the circuit by working in teams and understanding how neurons connect and interact

The two teachers were given a six-question pre-lab survey via SurveyMonkey® to determine if they were interested in having a biomedical engineering project for their classroom (see Appendix B). The survey also evaluated if they had noticed any interest in biomedical engineering before the project.

The students were given NeuroByte kits which come with an assortment of sensors. In the kit they had motor neurons, interneurons, touch receptors, and light receptors. In each group there were three to four students. After the students had gone over the manual created by NeuroTinker they were instructed to create a circuit, first without the buggy, to respond to touch and light. Responding to light or touch meant an action potential was fired through the NeuroBytes. The firing of an action potential is indicated by lights, with different colors indicating varying levels of intensity. Students were allowed to use as many or as few NeuroBytes as they wanted to accomplish the task. Each group designed their own circuit to respond to light and touch by discussing and sometimes drawing pictures of what the circuit might look like.

From here, the students were instructed to connect their circuit to the platform in the kit so that the motor on one or both wheels would turn with the detection of a stimulus. Once this task was accomplished, the students combined the light and touch receptors into one circuit, so the vehicle could respond to both stimuli. Like real neurons, the shorter dendrites and terminals (depicted on the face of the NeuroBytes), mean a faster signal transmission. This allows students to set a priority on the stimuli. Touch could be a stronger signal than light or vice versa. One group of
students create a cockroach like vehicle that would reverse if it detected light or touch. The touch signal was prioritized here so the “cockroach” would avoid hitting objects more so than it avoided going into light. The students talked through the various possible designs they could do to accomplish the task. They talked about how the vehicle should respond to the stimuli and which stimulus was most important for their design. The group that decided to create the cockroach-like vehicle decided to make the wheels spin forward in darkness and backward in light. This was the first circuit they created. They connected it to the motor to make sure it produced the desired outcome. For touch, the group assembled the circuit so that the touch receptors were on the edges of the front of the vehicle. They decided that a signal from the touch receptor should make it reverse. They again tested out this addition to make sure it was able to overcome the stimulus of the light and that the wheels spun the correct direction. Once they had constructed this circuit, they placed the buggy on the ground to see how it worked. Students realized after they had tested the vehicle that they had both wheels reversing for one touch. They then rewired the circuit so that only one wheel would reverse if the touch receptor was set off on that side. They did the same to the other side. The wheels were then able to independently respond to the touch receptors on their side of the vehicle. Students accomplished the goal by designing a vehicle which was able to detect and respond to both touch and light.

Both the students and teachers had a ten question post-lab survey in order to determine if the NeuroBytes were a useful tool for teaching students about the basic principles behind biomedical engineering (See Appendix B and C).

Engineering Design Process

When discussing this project with the teachers who were surveyed, they expressed a desire to have a project which allowed their students to work through the Engineering Design Process. This three-step approach to the creation of a product is essential for engineers because it gives them guidelines to follow to ensure they design an effective solution to a problem. The three steps of the engineering design process as defined by the Next Generation Science Standards for high school students are (1) defining the problem, (2) developing possible solutions, and (3) improving designs [4]. Although the students were not explicitly walked through these specifics of the project before the lab, they did work through each them in order to create the final vehicle design.

The students defined the problem by taking the task given to them by the teacher and breaking it down into its basic components so that they could then begin designing a circuit to accomplish those tasks. When moving on to the second step, students mostly utilized verbal communication to discuss solutions. Some groups used a whiteboard to draw out what they wanted but most groups began to construct the circuit using the NeuroBytes to show their peers what they were talking about. Most of the students had no experience with circuits or creating circuit diagrams so they used the tools available to them. Once they had constructed a functioning circuit, they moved on to the final step, improving the design and trying to see if they could use less NeuroBytes to accomplish the same objective. By going through these steps, they worked through the engineering design process. In future labs, teachers could start by defining these steps to guide students through this more hands-on independent project.

Results
There were 19 high school students in total who worked with the kits and all responded to the survey. Eight of the students attended a private school and eleven students attended a public school. Graph 1 and 2 show the demographics for the students who completed the survey. 16% were female and 79% were male.

Based on the pre-lab survey results, both teachers indicated a lack of an interactive biomedical engineering project and thought one would be useful within their classrooms. The private school teacher stated that about 8% of their students were interested in biomedical engineering prior to the experiment, whereas only about 10% were interested from the public school. When asked about neuroscience, the students from the private school had no interest and only 3% of students from the public school. One teacher later stated that some of her students did not realize neuroscience was a field of study they could learn about as high school students or undergraduates.

The post-lab survey filled out by the students in order to determine how they felt about the projects. About 40% of students said that their interest in neuroscience increased after the project and 36% said their interest in biomedical engineering increased after the project. The other respondents reported that their interest in both subjects remained about the same.

66% of respondents said they felt they learned more in this lab compared to others. Three of the respondents said they enjoyed the fact that they learned something about circuitry and neuroscience. 71% of students relayed their experience with NeuroBytes as mostly positive. The
other respondents said they struggled to work with the NeuroBytes. Some reasons cited were that the NeuroBytes seemed to work inconsistently and they felt the manual they were given beforehand did not fully explained how everything worked. The students who enjoyed their experience also stated that they had trouble, but they enjoyed working through the problem within their group. When asked if they discussed the project in terms of biology or technology, the answers were mixed. Six students said they used biological terms and the others said they used a mix of both biological and technological terms (three of the responses did not answer the question).

The post lab survey completed by the teachers indicated that the students did have an increase in their interest in neuroscience because prior to this the students had little exposure to this field. One teacher reported an increase in interest in engineering after the lab and the other teacher felt that the students’ interest remained about the same. Both teachers felt the lab helped fill a hole in their curriculum and taught their students about biomedical engineering. They also felt that the NeuroBytes were a good tool for teaching students about biological and technological concepts in an engaging manner. However, one of the teachers reported some issues with the buggy and faulty NeuroBytes within the kit.

Discussion

Overall, the students had a positive experience with the NeuroBytes and believe they learned more about neuroscience and biomedical engineering. Having a hands-on project seemed to interest the students based on their written responses to the surveys. In addition, the teachers were also pleased with the technology and believed it could fill a hole in their curriculum. They particularly liked that NeuroBytes were customizable and allowed for students to be creative. One of the teachers also noted how the high-tech appearance of the NeuroBytes appealed to the students and they were excited to work with them.

Both teachers and students desired a little more structure out of the project and wanted a more in-depth instructor’s manual to explain the features of the electronic neurons. Also, they noted they had issues with the hardware. This might be due to the fact that prototype kits were used. One teacher wished that the technology was “more durable” because several of the NeuroBytes would stop working after being used a couple of times. Several of students said they were confused about how the excitatory and inhibitory cables worked even after experimenting with them. A majority of the students did not report a huge increase in their interest in neuroscience or engineering but most of the comments about the NeuroBytes were positive. Most of their hesitation seemed to stem from the issue that they did not feel the manual thoroughly explained the NeuroBytes and struggled to understand all of the functions and how to interconnect the systems. However, quite a few of the students did state that although they struggled in the beginning they were able to work together within their group to figure out a solution.

Another issue with the NeuroBytes is the current expense. Due to funds, the school with six participants only had one kit and the other had two, one of which was provided by the University of Arizona. Ideally, one kit should be provided to a group of about three students. This allows for everyone to participate and limits the number of students who would only be able to observe. If more kits were available, more students could have worked on the project and evaluated its usefulness in the classroom.
The purpose of the paper was to determine if NeuroBytes were effective tools for teaching introductory engineering students about biomedical engineering. In order to evaluate this, the surveys aimed to answer several evaluation questions, which can be found in the introduction of this paper. Based on the surveys from both teachers and students, NeuroBytes do seem to be a fitting education tool for an introductory engineering class. Most of the students were engaged in the project and about 36% said they had an increased interest in biomedical engineering. Although, ideally this number could be higher, some of the hesitation may have stemmed from complications encountered in the lab which could be resolved through a more thorough manual. The teachers felt that the NeuroBytes were beneficial to their classroom and expressed interest in working with them again. They also noted that the NeuroBytes were relatively easy to work with and students were able to fully participate after reading over the manual. Based on these findings, NeuroBytes have the potential to be a useful tool in engineering classrooms, provided a more detailed manual can be provided to students.

Conclusion

The preliminary research on NeuroBytes seems promising and could be an effective tool to teach students about the interdisciplinary field of biomedical engineering. Since introductory engineering courses often lack an interactive project for biomedical, this technology offers up a solution. NeuroTinker has created a product which connects biology and technology in a way that has the potential to attract students from various backgrounds. These electronic neuron simulators are designed to show students how neurons function within their body and to provide them with a physical representation of these processes. Often times the activity of neurons is modeled on computers or through animations which are useful but do not allow students to become actively involved. Hands-on projects, such as NeuroBytes, allow students to better engage in their learning process. As seen in previous research, students who are more engaged and more interested in the material being presented to them are more likely to remain within the field. For the STEM field this is vitally important as more students are choosing other fields or even dropping out of college altogether [11].

The implementation of NeuroByte based projects in classrooms could be very useful. By showing the electrical component of neurons to introductory students, it gives them a chance to view the human body and technology in a new light. It allows the students to make more direct connections and show them the fascinating principles of biomedical engineering. The research conducted by NeuroTinker within a physiology classroom revealed that students were quite interested in the idea of a hands-on project which showed them how neurons functioned in a circuit. Similar results were found within the high school classrooms who helped to evaluate the technology in this paper. There was a slight increase in interest in neuroscience and engineering at the conclusion of the project and most students submitted positive statements about their experience. They also offered insight into current issues with the technology, such as a lack of a detailed manual and the need for more written and structured labs. The teachers also reported issues with the durability of the NeuroBytes and having to switch out broken NeuroBytes after a couple of uses.

Teachers also look for a way to teach their students about the Engineering Design Process. The three steps are (1) defining the problem, (2) developing possible solutions, and (3) improving designs. NeuroBytes offer a simple way to introduce students to this idea. The students can be provided with a problem or desired finished product and work together to develop a circuit to
meet these requirements. Naturally, by working with the NeuroBytes students had to design a vehicle, improve the vehicle, and then test it again in order to ensure they had met all the requirements. For students who have never participated in this style of lab, it is a good opportunity to develop their familiarity with this process in a still somewhat structured environment. Since they are already provided with the tools to accomplish their goal, it becomes a matter of focusing on the task at hand and using their problem-solving skills to come up with the best design possible.

By combining the biological and technological, NeuroTinker has provided a useful tool which could be used in many different classes other than neuroscience or even engineering. They have created a physical manifestation of collaboration which should be encouraged within classrooms because it creates an environment where students not only learn from their teacher but also one another. Although the technology still needs some improvements, the interest in NeuroBytes is evident. With some more time, these little electronic neuron simulators can definitely provide classrooms with an engaging interactive project that all students can participate in.

Acknowledgments

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Thank you to NeuroTinker for providing prototype kits to the schools.
References


Appendix A
NeuroBytes Lab: Responding to Light and Touch

Goals of the Lab
In this lab, students will construct circuits, using NeuroBytes, that can detect and respond to changes in light and touch. Students should work in small groups due to the size of the kits. They will begin the lab by making simple circuits to detect light and touch then move on to attaching the circuits to buggies which will then move either toward or away from the stimulus. Students should be allowed to design their own circuits and execute their plan with some direction from the instructor.

Learning Outcomes
- Define and describe the nervous system
- Identify the basic components of a neuron
- Describe how neurons function within the body
- Explain and understand how neurons communicate
- Apply knowledge of the nervous system and neurons to an electronic circuit
- Identify the major components of a circuit and the similarities to the nervous system
- Recognize the differences between neurons and NeuroBytes
- Troubleshoot the circuit by working in teams and understanding how neurons connect and interact

Materials
- NeuroByte kit
- NeuroByte manual: https://www.dropbox.com/sh/5e8q3fkjkph2xlh/AADmZuhb_OAUF9wLv1_rHKX3a?dl=0
- Whiteboard

 Procedures
1. Look over the NeuroByte manual to understand how the NeuroBytes work together and their various functions.
2. Construct a circuit with a light sensor that will fire an action potential when the sensor is moved into light or dark. Repeat this step but use a touch sensor instead.
3. Set up the buggy. The wheels should both receive power through a motor neuron which is connected to the battery pack, or mitochondria. Connect the wheels to the motor neuron, not directly to the battery.
4. Place one of the circuits on to the buggy and connect it to the motor neuron. Make the circuit fire an action potential so that at least one of the wheels turn.
5. Add in the second circuit, also connecting it to the motor neuron. More than one interneuron may need to be added in to make the connection.
6. Make sure the buggy can now respond to both light and touch. Set an objective for the buggy to accomplish. (Ex: The buggy will move away from bright light and touch)
7. Try to improve the original design. Attempt to use less NeuroBytes to accomplish the same tasks.
Appendix B

Pre-lab Teacher Survey Questions

1. What school do you teach at?

2. What is your Gender?
   a) Female
   b) Male
   c) No answer text provided
   d) Prefer not to respond

3. What is your Ethnicity?
   a) Hispanic or Latino
   b) American Indian or Alaska Native
   c) Asian
   d) Black or African American
   e) Native Hawaiian or Other Pacific Islander
   f) White
   g) Prefer not to respond

4. Do you feel that your current lesson plan lacks a hands on biomedical engineering project?
   a) Yes
   b) No
   If no, please describe any past projects

5. What percentage of your students show an interest in biomedical engineering currently? Please enter your answer as a whole number without a percentage sign, or if you are unsure you can type in "NA".

6. What percentage of your students show an interest in neuroscience or biology? Please enter your answer as a whole number without a percentage sign, or if you are unsure you can type in "NA".

Post-lab Teacher Survey

1. What school do you teach at?

2. What is your Gender?
   a) Female
   b) Male
   c) No answer text provided
   d) Prefer not to respond
3. What is your Ethnicity?
   a) Hispanic or Latino
   b) American Indian or Alaska Native
   c) Asian
   d) Black or African American
   e) Native Hawaiian or Other Pacific Islander
   f) White
   g) Prefer not to respond

4. Due to the lab with the NeuroBytes neuron simulators, my student’s interest in neuroscience has
   a) Improved a lot
   b) Improved somewhat
   c) stayed about the same
   d) declined somewhat
   e) declined a lot

5. Due to the lab with the NeuroBytes neuron simulators, my student’s interest in engineering has
   a) Improved a lot
   b) Improved somewhat
   c) stayed about the same
   d) declined somewhat
   e) declined a lot

6. Did working with NeuroBytes help fill a gap in your curriculum? Specifically, did it help you to more effectively teach your students about biomedical engineering and its concepts? Why or why not?
   a) Yes
   b) No

7. In your own words describe your experience with NeuroBytes.

8. How would you improve the NeuroBytes Activity?

9. What was the most difficult part of working with NeuroBytes?
Appendix C

Post-lab Survey for Students

1. What school do you attend?
2. What is your Gender?
   a) Female
   b) Male
   c) No answer text provided
   d) Prefer not to respond

3. What is your Ethnicity?
   a) Hispanic or Latino
   b) American Indian or Alaska Native
   c) Asian
   d) Black or African American
   e) Native Hawaiian or Other Pacific Islander
   f) White
   g) Prefer not to respond

4. Due to the lab with the NeuroBytes neuron simulators, my interest in neuroscience has
   a) Improved a lot
   b) Improved somewhat
   c) stayed about the same
   d) declined somewhat
   e) declined a lot

5. Due to the lab with the NeuroBytes neuron simulators, my interest in engineering has
   a) Improved a lot
   b) Improved somewhat
   c) stayed about the same
   d) declined somewhat
   e) declined a lot

6. What was the most surprising thing you learned during the NeuroBytes activity?

7. In your own words describe your experience with NeuroBytes.

8. What was the most difficult part of working with NeuroBytes? How would you improve the NeuroBytes activity?

9. When discussing the project with fellow students, did you find yourself using terminology rooted in technology or biology?

10. Do you think you learned more or less than usual compared to other labs?