Contextualizing the Learning of Circuits under Biological System: Applying the Yenka Software for Student-Centered Modeling Practices and Self-Assessment

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Abstract: The goal of the project was to introduce a computer-supported modeling activity for biology majors to apply to their understanding of neurons. The activity stressed students' practice of modeling a biological system to learn physics concepts, or vice versa. We introduced an innovative computer-assisted activity to promote the appropriate integration of physical models that could motivate students to see the relevance of physics to a biological system for self-assessment purpose during the learning process. Students manipulated the values of circuit elements experimentally using Yenka software, which allows easy access to simulated science laboratory activities, in order to highlight underlying concepts. The learning activity was tailored for life sciences majors taking introductory biology in their freshman year (n_b = 164). We leveraged students' prior knowledge of the underlying mechanism that drives sensory or motor action (e.g., vision or muscle reflex) and applied that understanding in constructing the circuit simulation on Yenka software. Three electrical models were provided on Yenka for students to manipulate in order to simulate the *equilibrium potential*, *membrane potential*, and *action potential* in neurons. Based on response to an end-of-session question, more than three-fourths of the life sciences majors (75.6%) perceived the modeling activity to be at least 'somewhat helpful' for their learning experience. This study is important because it presents a computer-assisted technology used in teaching/learning physics or biological phenomena in class and in the laboratory. It supplements conventional instruction of neuron or circuits with simulations, computer modeling, experimental data processing, and analysis of graphics obtained during the activity. Educational implications are discussed.

Keywords: computer-supported modeling, Yenka program, neuron, circuit, simulation

1. Introduction

Models and modeling practices are crucial in scientific reasoning and inquiry and are often used as simplified representations for describing or visualizing micro- and macro-level phenomena (Cheng & Brown, 2015; Gilbert, 2006). In addition, appropriate integration of physical models motivates students to see the relevance of physics to biological systems. In view of this, a project to introduce a computer-supported modeling activity for biology majors to apply to their understanding of neuron and circuits was proposed, where the practice of modeling a biological system to learn physics concepts or vice versa is stressed. This project investigates students' perceptions toward practicing their interdisciplinary modeling knowledge with the assistance of computer technology, using a student-centered assessment approach. To achieve this goal, the laboratory activity is designed in a way so students can connect with their prior knowledge of biological phenomena. In other words, the biology or physics concepts were not linearly introduced from a textbook but were included in the computer-assisted modeling activities as it became necessary to understand the target phenomenon. Concepts are believed to be retained better by learners in this way (Gilbert, 2006). In addition, it brings out the important task of a scientist to create models, so that students not only acquire declarative knowledge but the procedural knowledge through model-building.

Science concepts are usually represented as simplified models to help people perceive the world. We used Namdar and Shen's definition (2015) of model—"a human construct used to describe, explain, predict, and communicate with others a referent such as a natural phenomenon, an event, or an entity." (p.994) scientific models can be found in the form of diagrams, physical replicas, mathematical representations, analogies, and computer simulations. (NGSS Lead States, 2013). We adopted the computer simulation as our means of constructing scientific models. An innovative computer-assisted activity was introduced in this study to promote the appropriate integration of physical models that could motivate students to see the relevance of physics to biological system. Students' prior knowledge of the underlying mechanism that drives biological senses and action (e.g., vision or muscle reflex) was leveraged and applied to the construction of scientific models.

Without a proper scaffolding process in constructing models, however, students often encounter problems during the modeling process because it is believed to associate with more sophisticated reasoning (e.g., intentional integration and establishment of connections among data, causal-effect relationships, transfer between dynamic and static representations, etc.) (Gobert & Clemen, 1999). Educators agree that careful scaffolding and context-oriented modeling is essential to guide students to use relevant explanations and models to account for phenomenon in their daily lives (Gilbert, 2006; Krell, Reinisch, & Krüger, 2015). Computer-assisted learning tools are thus introduced to facilitate the scaffolding processes; while the contextualization of physical models of a biological system provides context-oriented modeling, and also avoids students perceiving textbook models as isolated, non-transferrable facts. One of the purposes of adopting a computer-assisted modeling practice is to allow the classroom instructors to shift away from rote memorization of scientific principles.

In this study, we aimed to create a scaffolding activity in which students could behave as scientists and approach phenomena as scientists approach them by modeling biological systems and applying that in understanding the physical models on the computer-assisted learning environment. The modeling practice is not only applied in the biology lab but also contextualized in understanding the phenomenon. We will focus on the discussion of adopting neuron models by constructing circuits in this study.

2. Methods

2.1 Computer-Assisted Modeling—The Yenka Software

Yenka is a modeling and simulation software platform for mathematics and sciences education. It allows students to build circuits using a set of basic electrical components (see Figure 1). Notice that the background image with channel proteins embedded on neuron membrane were either retrieved from the textbook *Principles of Biology* (Nature Education, 2014) or created by instructor. An electrochemical gradient governs the movement of ions across the membrane of a neuron. The electrical properties of neurons can be readily modeled by an electrical circuit. The concept of the electrical potential in a physical science textbook was introduced in the context of the driving force behind the electrons.

Students manipulated parameters associated with the Yenka models, with possible predictions beforehand. For instance, the resistances in the equilibrium potential model represented concentrations of the ions (see Figure 1). Students could change the inside and outside concentrations to see how this affected the equilibrium potential. They could make a plot of the ratio of the inside to outside concentration versus equilibrium potential and then draw conclusions. Another example is for the membrane potential. The parameters were the equilibrium potentials of the two ions represented by batteries and the permeabilities of the two ions represented by resistances. Students manipulated these and saw the effect on the membrane potential. For instance, students could choose a scenario where the leakage channels of potassium were blocked by one-half by a certain venom and see the effect on the membrane potential. The students collected data to see how the membrane potential varied with each parameter. These could be plotted, discussed and subsequent conclusions could be drawn. The main purpose of all these activities for us was for students to query the models to get a deeper knowledge of the underlying biological phenomenon. The Yenka models could be applied with different objectives, such as a way to design an artificial neuron.

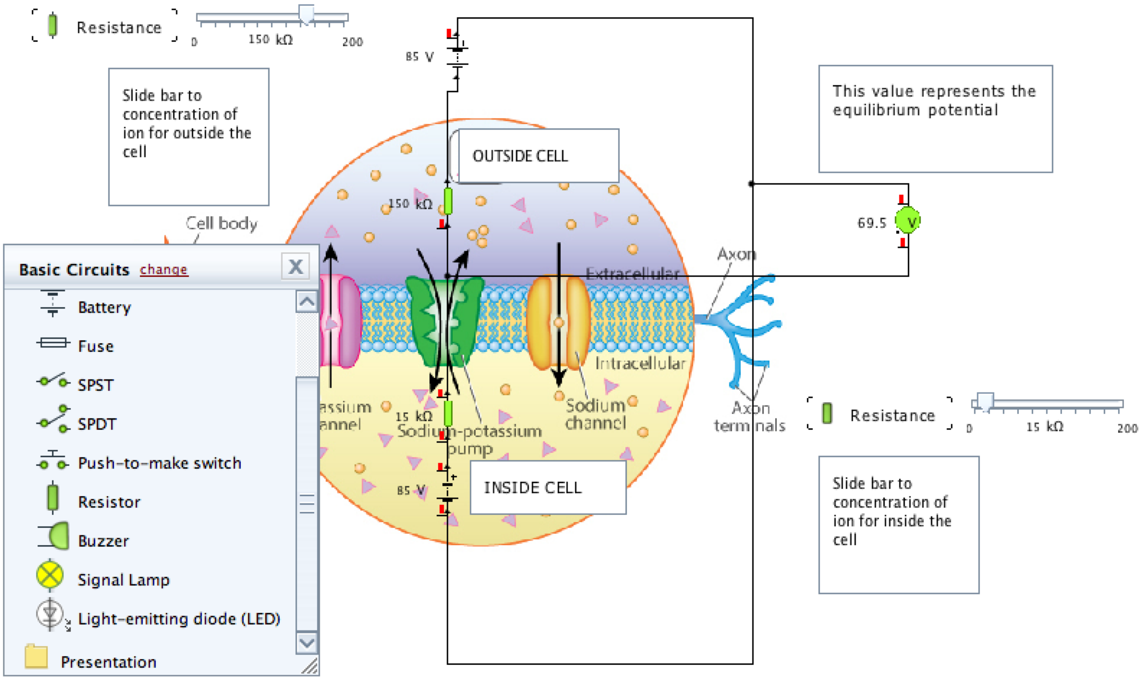

Figure 1. The figure shows some basic components for constructing basic circuits enlisted in the pop-up window entitled "Basic Circuits."

Borrowing the analogous concept of electrical potential in a circuit context and the nervous system, the instructors were able to provide the context-oriented learning environment in order for learners to understand the three different kinds of potential under discussion—equilibrium potential, membrane potential, and action potential.

2.1.1 Equilibrium Potential

The equilibrium potential of an ion is when the diffusion and electrical gradients acting on that ion species are balanced. No net movement of that ion across the membrane is detected. In the Yenka software, the computer simulation is set up as in Figure 1, where the concentration of the designated ion is represented as the resistance inside and outside of the cell without the sodium pump involved. When both of the ion concentrations, inside and outside of the membrane, equal each other the equilibrium potential is 0 mV, meaning that there is no potential difference across the membrane, thus, no net movement of an ion of its kind in the neuron.

To scaffold the scientific modeling process, guiding questions were posed to direct their interaction with the Yenka software. Some representative questions to scaffold the understanding of equilibrium potential are provided below:

Example question #1: Manipulate the concentrations of potassium inside and outside of your Yenka model for equilibrium potential as shown in Table 1 and record the resulting equilibrium potential. Plot and insert an Excel chart representing K+ equilibrium potential as your Y axis (dependent variable) and the inside/outside K+ concentration ratio as your X axis (independent variable).

Table 1: Effect of the K+ concentration inside and outside a neuron on K+ equilibrium potential.

Concentration of K+ INSIDE (mM)	Concentration of K+ OUTSIDE (mM)			
	10	100	1,000	10,000
10				
100				
1,000				
10,000				

Example question #2: What is the actual concentration of potassium inside and outside a neuron for a human? What is the resulting equilibrium potential?

In example question #1, students were asked to manipulate the concentration of ions and to present their data graphically, while question #2 asked students to find and use the actual ion concentrations found in neurons. The immediate application of simulated results helped connect the physical models with the biological systems.

2.1.2 Membrane Potential

The membrane potential of a neuron indicates the difference in electric potential inside and outside the cell. It is different from the equilibrium potential because it is a cumulative effect of all ions that are permeable to the membrane instead of "one particular ion." Two important features for the establishment of a membrane potential are the *ion-specific leakage channels* (passive action) and Na^+/ K^+ pump (active action). Specifically, when neurons are not sending signals, the membrane potential is said to be at *resting membrane potential* (or *resting potential*). The resting membrane potential is about -70mV for humans, where interior is more negative than exterior. It is the result of the fact that there are more K^+ leakage channels than Na^+ ones. So, the resting potential is closer to the equilibrium potential of K^+.

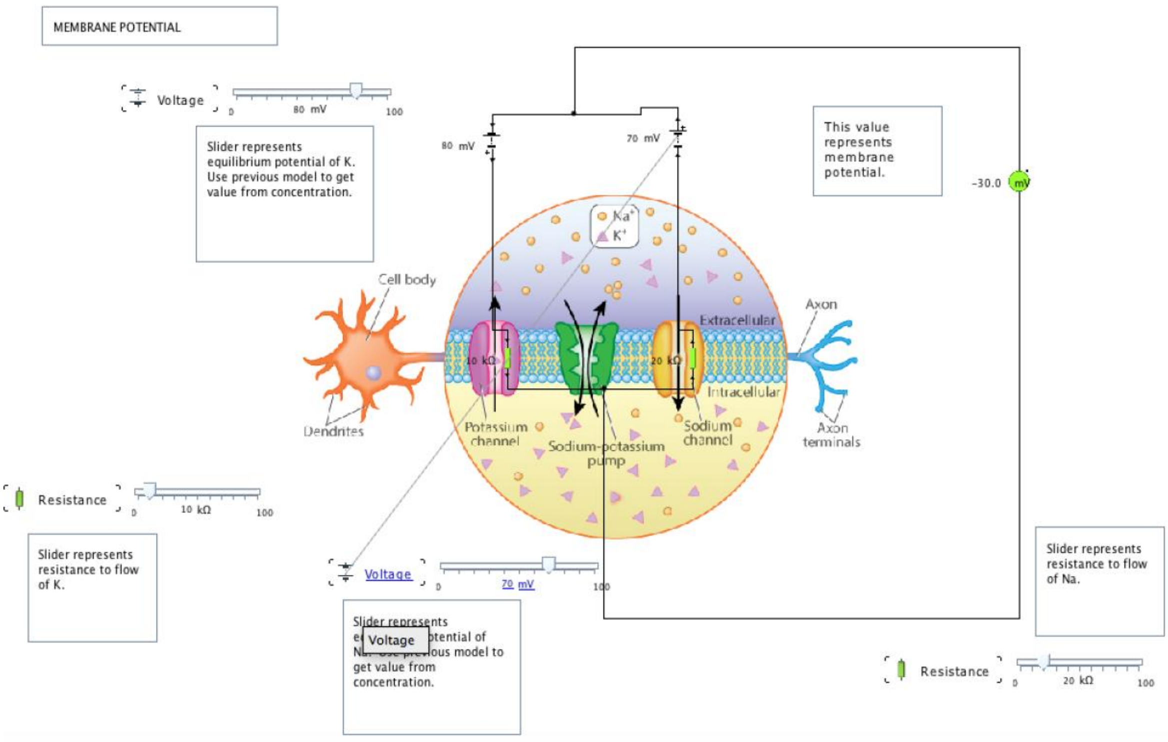

Figure 2. The circuits models the membrane potential of the neuron in Yenka software.

In the Yenka software, the computer simulation was set up as in Figure 2. In addition to using the resistance as the representation of the flow of ions, students were able to change the value of *equilibrium potential* by adjusting the “Voltage” slider. The value is derived from the computer simulation model of the previous activity (e.g., Example question 1 in 2.1.1).

Some representative questions to scaffold the understanding of membrane potential are provided below:

- Manipulate the permeability of the membrane such that it is equally permeable to sodium and potassium. What is the resulting membrane potential?

Table 2. Effect of the relative permeability of the membrane to sodium and potassium on the membrane potential

	Membrane permeability to **potassium**		
Membrane permeability to **sodium**	High	Medium	Low
High			
Medium			
Low			

- Manipulate the permeability of sodium and potassium channels such that the resting membrane potential is equal to -70mV. Calculate the corresponding ratio of sodium/potassium permeabilities.

2.1.3 Action Potential

Action Potential is one of the two types of changes in neuron’s membrane potential. It is triggered when voltage reaches threshold with the onset of depolarization and then hyperpolarization. Depolarization indicates the opening of Na^+ gated channels, while hyperpolarization indicates the opening of K^+ gated channels. (see Figure 3a).

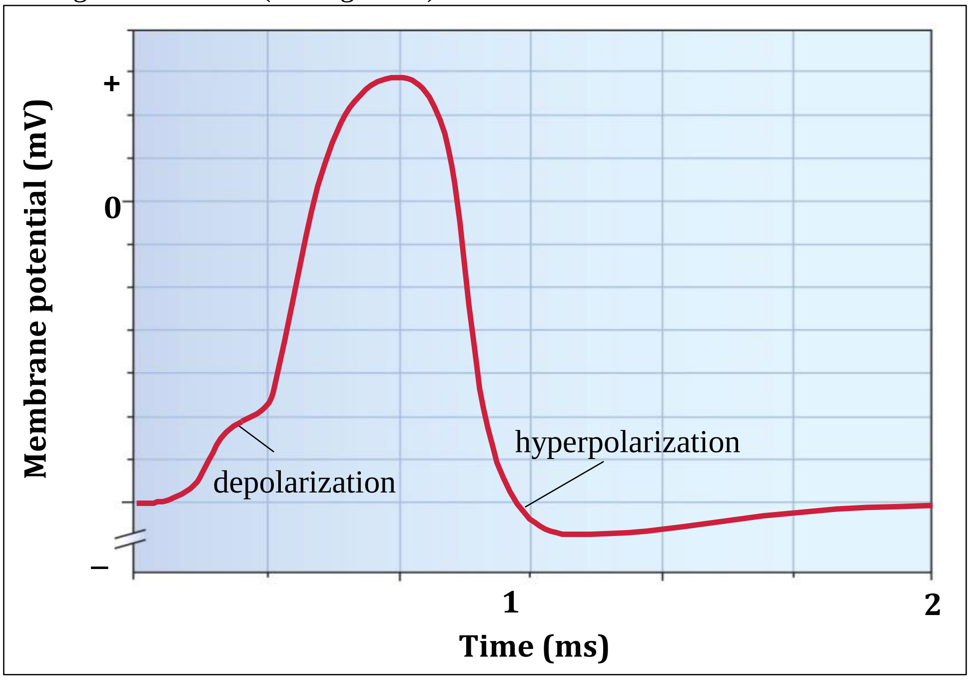

Figure 3a. The change of membrane potential in an all-or-none action potential with the progression of time (ms).

In the Yenka software, the computer simulation was set up as shown on Figure 3b. In this setting, a new feature was introduced for students to observe simultaneous graph plotting while they turn on and off the switches that represent the voltage-gated sodium/potassium channels.

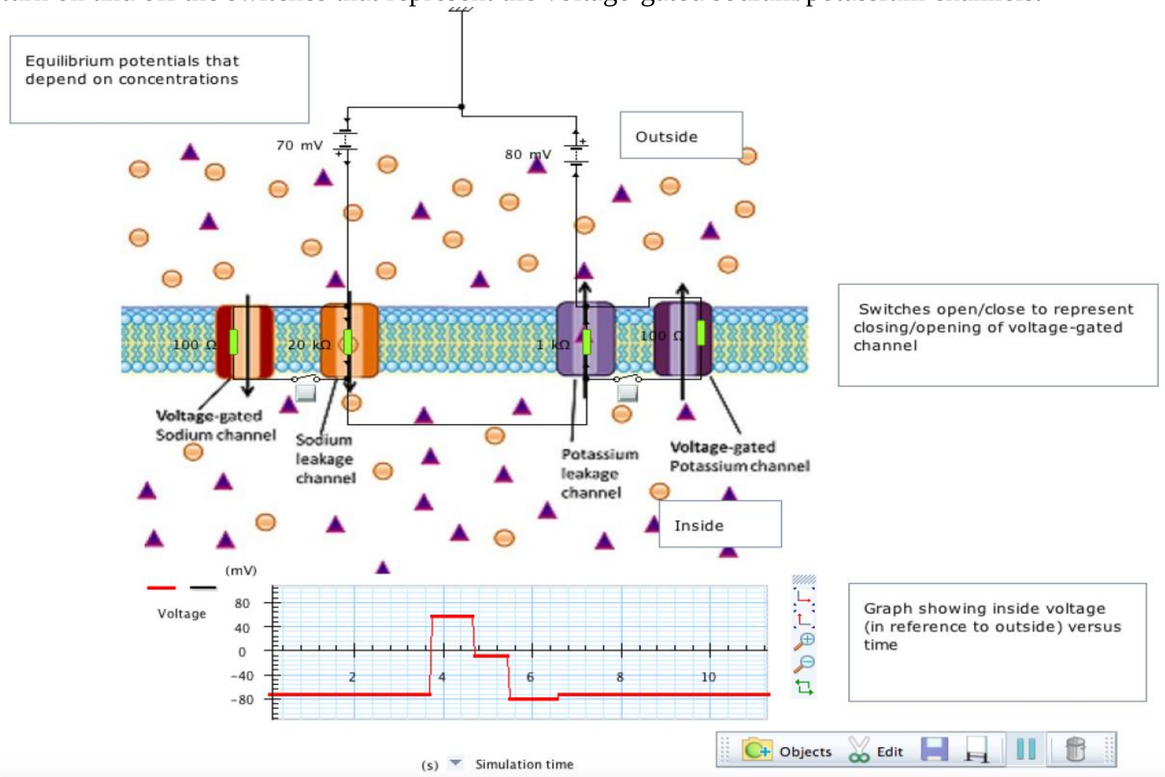

Figure 3b. The circuit simulation model that replicates the action potential of the neuron in Yenka software.

The following question was provided to scaffold the application of the circuit model in order to replicate the action potential using the Yenka software:

Open and close voltage-gated sodium and potassium channels by following the order in which they open and close during an action potential. You can record the voltage changes over time by clicking Yenka/edit/pause. Insert a screenshot of your Yenka model. Note that the x-axis in an actual action potential is represented in ms; however, in the simulation seconds were used. The depolarization and hyperpolarization was correctly represented by the Yenka simulation plot, however, the plateau around the fifth second is due to the delayed closure of voltage-gated sodium channel.

2.2 Participants

The learning activity was tailored for life sciences majors in a small college in the Southeastern United States of America. The students were taking introductory biology in their freshman year (n_b = 164). In one class meeting students discussed and presented analogies of neuron physiologies, and the next session was spent on the Yenka activity.

2.3 Data Collection and Analysis

We administered 10 questions related to neuron concepts as pretest and posttest. To determine whether students' performance on both tests were significantly different after Yenka activity, we applied paired samples T-test to analyze the data. Students' perceptions toward the three Yenka activities were collected by an end-of-session 5-level Likert-Scale question: What do you think about the "Yenka Models of neuron physiology" activity in the lab? (e.g., extremely helpful, very helpful, moderately helpful, somewhat helpful, and not helpful).

3. Results and Discussion

There was a significant difference in the scores for pretest (*M* = 3.30, *SD* = 1.501) and posttest (*M* = 4.54, *SD* = 2.067), $t(152) = -4.691$, $p = .000$. The preliminary result indicated that the students understanding of neuron was better after the learning activities in class. However, we did not have the performance of a control group as baseline data to see whether students' achievement was better than previous year. The percentage for students' perceived helpfulness for Yenka activities was: extremely helpful (16.5%), very helpful (14%), moderately helpful (18.9%), somewhat helpful (14%), and not helpful (24.4%).

More than three-fourth of the participants perceived the student-centered modeling practices on Yenka software to be at least 'somewhat helpful' for them to learn different potential concepts. This finding is substantial in the following ways. First, because students not only actively engaged in modeling practices, but also continuously carrying out the self-assessment about their understanding of neuron model on Yenka by manipulating the parameters. However, there was still approximately a quarter of students who found Yenka activity to be 'not helpful' for their learning. This finding could be due to several reasons: First, because the modeling activity was introduced late in the semester, not enough time was allotted for students to fully explore the Yenka activity in the laboratory. Besides, one of the sessions encountered technical difficulty when opening Yenka software, so even less time was designated for that particular group to participate in Yenka in a meaningful way. Even with time constraints, in order to receive constructive feedback to their model modification, more professional training for instructors to take advantage of modeling practices was recommended.

Second, even though we guided students with step-by-step scaffolding questions during the neuron modeling practices, some students were still not able to appreciate the inclusion of a model during learning processes. Since this process was mainly done through the worksheet in this study, we recommend that more in-time face-to-face scaffolding process could be adopted by instructors. In this way, more structured personal communications as means of scaffolding processes can be introduced and incorporated during students' Yenka activity in order to supplement the relatively passive scaffolding (i.e., written responses on the worksheet).

Third, the participants in this study had not been introduced to physical sciences concepts related to circuits. We plan to revisit the neuron concepts longitudinally when these freshman life science majors take physics class in the third year as a spiral curriculum design. In this very first exposure to the modeling practice, brief introduction of how the unfamiliar physical sciences terminologies are used in nervous system should be provided prior to Yenka activity. For instance, *potential, voltage, resistance, and concentration gradient of ions*, etc, might not be readily comprehensible by life sciences majors. This might supplement the application of such concepts in understanding neuron. Future research should be done on more careful curriculum design to foster such interdisciplinary collaboration and understanding.

Because the student participants in this study had not taken the physics course, explicit contextualization of each concept on the Yenka model as well as how such understanding could be applied to understand biological systems would be highly recommended. Such conduct would gradually foster the habit of mind to think and create models beyond disciplinary constraints, as most of the real life problems transcend well-defined disciplines.

The study is important because it presents the computer-assisted technology used in teaching/learning physics or biological phenomena in class and in the laboratory. The scaffolding processes in the form of guiding questions were provided as reference for other educators who wish to adopt the learning of neurons with computer simulations. It supplements conventional instruction of neuron or circuits with simulations, computer modeling, experimental data processing, and analysis of graphics obtained during the activity.

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