A New Open-Source Web Application with Animations to Support Learning of Neuron-to-Neuron Signaling

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Abstract

Pesticides and their associated modes of action serve as real-world examples of chemical toxicity, stimulating student interest and supporting their understanding of nervous system function and cell signaling. An open-source web application called “Neuron-to-Neuron Normal and Toxic Actions” hosts narrated animations of pesticide toxic actions and exists as a resource for instructors of advanced secondary or undergraduate biology courses. This article describes the features of the web application, reports student feedback on the animations, and details a cooperative learning procedure for instructors to use the web application in online learning environments or in-person classroom settings with technology support.

Key Words: pesticides; toxicology; cellular biology; neurobiology; neurons; cell signaling; nervous system; jigsaw technique; cooperative learning; web application; animations.

Methods

North Carolina State University’s Digital Education and Learning Technology Applications (DELTA) provided financial and technical support for the creation of a web application and animations to compare and contrast normal neuron-to-neuron signaling and modes of toxic action for various insecticides. The iterative animation development process involved an instructional designer, an educational media designer, and a multimedia designer from DELTA, as well as two university faculty with pesticide toxicology expertise. Professional voice actors provided voice-overs for the animations using transcriptions developed by faculty.

The learning objectives for the animations are as follows:
• Diagram and describe the function of the neuron and its parts (dendrites, axon, and cell body).
• Diagram the steps of signal transmission at the axon and synapse.
• Distinguish normal transmission from transmission under pyrethroid, organophosphate, neonicotinoid, and DDT toxic action.

The web application content consists of four major sections. The Overview section introduces students to the neuron structure and communication between neurons. The Axon section provides an overview of normal signal transmission along the axon, as

Including a discussion of pesticide modes of action in advanced secondary or undergraduate courses, particularly courses on cellular biology, toxicology, and neurobiology, can support students’ understanding of nervous system function and cell signaling. An open-source web application called “Neuron-to-Neuron Normal and Toxic Actions” hosts narrated animations, with full transcriptions, and exists as a resource for instructors looking to incorporate pesticide toxic actions in their courses: https://go.distance.ncsu.edu/neurons-toxicaction/. The availability of this web application fulfills the need for high-quality, accessible digital resources.

Introduction

Pesticides have important societal functions not only in the production of food but also in the control of disease vectors (such as mosquitoes) and the prevention of infestations of homes and buildings (Krieger, 2010). The properties that make pesticides effective in mitigating pests also make them hazardous to human health. Pesticides can be categorized according to their use, whether they control weeds (herbicides), insects (insecticides), or plant fungal diseases (fungicides). Specifically, pesticides that target insects often act on the insect nervous system. Because of the similarities between human and insect nervous systems, insecticides may result in human toxicities (Hodgson, 2010).

Like many human therapeutic drugs, insecticides act specifically, often targeting a single site within the insect nervous system. When an insecticide binds to this target site, it produces a toxic action by interfering with normal cell signaling. The binding of the insecticide to the target site and the resulting toxicity are referred to as the insecticide’s mode of action. The mode of action is the defining characteristic of any pesticide (Hodgson & Cope, 2015).
well as more detailed animations for each stage of signal transmission. The pyrethroid toxicity subsection depicts two sites of toxic action for this chemical class at the axon—inhbrition of sodium/potassium ATPases and prolonged opening of the sodium channel. The Synapse section provides an overview of normal signal transmission at the synapse, as well as more detailed animations for neurotransmitter-based signal transmission. Subsections for organophosphate toxicity and neonicotinoid toxicity illustrate toxic action as the result of acetylcholinesterase inhibition and overstimulation of ion channels, respectively. The Axon + Synapse section includes a DDT subsection highlighting the pesticide’s toxic actions at both the axon (i.e., inhibition of sodium/potassium ATPases) and synapse (i.e., interference with calcium ions).

Several features of the web application aid student use and learning. In the upper left-hand corner, a “You are here” inset map orients students to where the sections and animations are set (i.e., axon or synapse). Several conventions are used to differentiate normal from toxic actions. Different colors and voices are used to note normal functions (i.e., green and female) and toxic actions (i.e., red and male). For each specific toxic action, a smaller window appears below the animation of the toxic action with the corresponding animation of the normal function. This feature allows students to toggle between toxic and normal actions and supports their learning of how to distinguish between the two (Figure 1). To improve accessibility, full transcriptions are available in the upper right-hand corner of each animation.

**Discussion**

The web application and animations have been successfully implemented in two offerings of an advanced undergraduate/graduate-level course. Student feedback was overwhelmingly positive about the animation design and the extent to which the animations helped them meet the learning objectives. The vast majority of students agreed that the animations clearly conveyed normal cell signaling (95%) and toxic actions (84%), helped them to effectively compare normal and toxic actions (89%), and improved their understanding of the modes of action for the various insecticides (95%). Student feedback supports the broader use of the web application and its animations.

The web application organizes the content into several types of categories (axon vs. synapse functions, normal functions vs. toxic actions, different types of toxicities). This organization supports the application of the cooperative learning model, particularly the “jigsaw” technique (Aronson, 1978), to help students master the concepts through work in small groups. Research has shown that the jigsaw technique enhances conceptual understanding, accountability, social skills, and learning interests in science education (Doymus, 2008; Eikle, 2005; Tarhan et al., 2013). The jigsaw technique makes each group member responsible for one part of the learning materials essential for complete understanding. The procedure below describes how the jigsaw technique might be implemented with this web application. It can be conducted in either in-person classroom settings with technology support or online environments with tools such as Zoom for whole-class and small-group meetings.

1. Ask all students to learn the Overview section to develop a basic understanding of the neuron structure and neuron-to-neuron communication.
2. Assign jigsaw groups of 3–4 students with the initial goal of learning the axon and synapse normal functions.
   a. Assign 1–2 students within each jigsaw group to learn the axon normal functions and 1–2 students to learn the synapse normal functions using the animations.

**Figure 1.** Screenshot of the Pyrethroid Toxicity subsection of the web application. View online for a color version of this figure.
b. Form expert groups by pulling 1–2 students from each jigsaw group to join other students who learned the same content. Ask the expert groups to prepare a presentation for teaching what they learned using screenshots from the animations.

c. Students go back to their jigsaw groups and teach other students about the axon or synapse normal functions. Ask the jigsaw groups to identify classroom or household items to demonstrate their understanding of those functions.

3. Repeat the jigsaw technique for learning the toxic actions.

a. Assign each student in the jigsaw group to learn one type of toxicity using the animations. For groups of three students, the organophosphate and neonicotinoid toxicities, both affecting synapse functions, can be assigned to one student.

b. Form expert groups by pulling one student from each jigsaw group to join other students who learned the same toxicity. Again, the expert groups will prepare presentations for teaching the toxicity using animation screenshots.

c. Students go back to their jigsaw groups and teach other students about the toxic actions they learned. The jigsaw groups need to compare the toxic actions with the normal functions and use the same classroom or household items they selected to represent their understandings.

○ Conclusion

The “Neuron-to-Neuron Normal and Toxic Actions” web application is an open-source, high-quality resource available to biology instructors. This resource presents an opportunity for instructors to incorporate real-world examples of chemical toxicity to support their students’ understanding of nervous system function and cell signaling. Furthermore, the web application format lends itself to use in both online learning environments and in-person classroom settings with technology support.

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