INTRODUCTION

Teaching signaling pathways in the undergraduate classroom can be challenging as students try to learn content through memorization, failing to grasp core concepts that would facilitate long-term retention and connection across multiple topics (1). Here, we describe a constructivist approach to introduce signal transduction. Constructivism is an underlying theory behind the American Association for the Advancement of Science (AAAS)’s Vision and Change in Biology Education: A Call to Action that has been applied to the teaching subdisciplines of biology, including botany, ecology, and medicine (2–5). Constructivism is a theory that is based on the idea that learning occurs through authentic experiences (6). Constructivism is a student-centered approach that contrasts with objectivism, a teacher-centered theory based on the principle that knowledge can be imposed on a learner. The basis of constructivism is that learners build meaning and therefore understanding through structured experience. Depth of learning is based on the extent to which the experience facilitates active use of the information obtained (7, 8).

Signal transduction is often taught by presenting specific pathways as examples of how signal transduction occurs. However, this approach ignores the diversity of signaling molecules and mechanisms present in biology and fails to help students understand how signaling mechanisms are integrated across pathways. The objective of our activity is to help students understand important signal transduction concepts that are independent of specific pathways, providing students with an understanding of general signaling mechanisms.

In this activity, students are first presented with a list of molecular building blocks that comprise signaling pathways and are then asked to diagram their own signaling pathway. This activity complements other methods used to teach concepts in signal transduction, such as visualization methods like animations (9, 10). The activity uses active learning and specifically engages higher order thinking skills such as creation, synthesis, and application (11). This approach fostered student engagement with the material, and pushed them to think past signal transduction examples that were presented in class.

PROCEDURE

The activity was implemented at Hendrix College, Hastings College, and High Point University in accordance with IRB and informed consent protocols.

Lower-level cell biology courses

The constructivist signaling activity was piloted with an introductory level course (~45 students) at Hendrix College and implemented twice in a sophomore-level Cell Biology course (19 to 24 students) at Hastings College. Students were given a brief 20-minute lecture on signal transduction where major concepts were emphasized (Supplemental Table 1 outlines the material covered).

Students were provided with a list of building blocks that comprise cell signaling pathways: signal molecules, receptors, intracellular signaling molecules, effectors, second messengers, and cellular responses or final targets (Supplemental Table 2). Using the list of components, students worked together to diagram their own signaling pathways by selecting components of pathways and matching them together. They developed a 250- to 500-word narrative to describe how the signal was transduced from the receptor to response (for student examples, see Supplemental Figures 1 and 2). In small groups of two to four, students compared their signaling pathways and looked for overlap and divergence while the instructor provided feedback as they walked around. Following in-class
discussion, students turned in their assignments and received written feedback.

Helpful tip for implementation

- Demonstrate the activity for students on the board so they understand that they do not have to synthesize a specific pathway in biology as long as their mechanism is complete. For example, a G-protein coupled receptor could not be used in the absence of a G-protein, but a GPCR could be used with any of the signal transduction building blocks they prefer.

Variations

A variation of this learning activity was implemented in an upper-level Cell Biology course (nine students) at High Point University. After a discussion on the discrete components of signaling pathways and examples, students were divided into groups and searched the literature using tools like PubMed or Web of Science. They picked an example of a cell signaling pathway and identified all of its parts or components. Once they had identified their paper, students were allowed ~30 minutes to come up with a diagram that represented the signaling pathway discussed in the paper and its different components—the signaling molecule, the receptor, the intracellular signaling molecules, etc. Next, the class discussed their answers with the instructor. Volunteer students were asked to draw their diagrams on the board to facilitate discussion, allowing the instructor to give feedback during the process.

Safety issues

None.

CONCLUSION

Cellular signaling is a challenging concept for students to understand, and they often struggle to grasp how key ideas like phosphorylation and molecular interactions result in altered cellular behavior if they are presented with a “catalogue-of-pathways” (1). We describe a signaling activity that uses constructivism to help students understand the foundational concepts of cellular signaling that are applicable to all pathways.

Overall, students at each of the three institutions reported that the exercise helped them understand how signal transduction occurred. In our first implementation, students were only provided with general signaling pathway components as indicated in the leftmost column of Supplemental Table 2. After receiving feedback from students in the first implementation that indicated that starting the activity was challenging (Supplemental Table 3b), we altered our instruction to include more explicit components of signaling pathways that students could use and also demonstrated how to build a signaling pathway and complete the activity. Following the second implementation, students reported that synthesizing their own pathway was challenging, but that drawing a pathway of their own design improved their learning. Several students did mention that they preferred to learn through more traditional approaches that did not include group work. To address these concerns, we recommend being transparent and explicit about why a constructivist approach and working with others is beneficial, as indicated in the instructor guide.

A strength of the exercise was the feedback students provided, which suggested they were engaged with the material. Several students included feedback suggesting additional approaches and ideas for other implementations. It was recommended the instructor provide part of the signaling pathway (i.e., a signal or response) and then require students to provide the remaining part of the mechanism. Others suggested that the instructor provide examples of different receptors and messengers and then have students do follow-up research to investigate how these examples apply in well-documented biological systems. Such responses indicate they were thinking about how signal transduction pathways are integrated. In this implementation, faculty primarily provided feedback through verbal conversations with students as they developed their pathways and through written feedback on assignments, but additional feedback could be facilitated using a written self-reflection assignment.

We found that using a constructivist approach to teaching signal transduction encouraged students to “think beyond the pathway.” The technique is easily implemented in lower and upper level cell biology classes and can be altered to include a discussion of pathway regulation or signal scaffolding. Importantly, the technique encouraged students to practice higher-order thinking skills, including synthesis, in an accessible way that fostered creativity.

SUPPLEMENTAL MATERIALS

- Appendix 1. Supplemental Table 1: Lecture outline of signaling information covered as introductory information.
- Appendix 2. Supplemental Table 2: List of molecular building blocks students could choose to use in their pathways.
- Appendix 3. Supplemental Figures 1 and 2: Examples of student work.
- Appendix 4. Supplemental Table 3: Student feedback from three pilot institutions.
- Appendix 5. Supplemental instructor guide: instructional handout with instructor guide for implementation.

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