Developing an Interactive 3D Learning Experience to Help Students Understand Key Regulatory Processes Associated with Glycolysis

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Abstract

Recent recommendations for undergraduate biology instruction emphasize teaching foundational biological principles and helping students transfer these principles to more complex biological phenomena. These curricular endeavors can be facilitated by the incorporation of interactive visualization materials. The following research project was developed to explore whether a visual interactive didactic tool could be developed to improve learning outcomes for undergraduate biology students on the topic of allosteric regulation within the context of glycolysis. The results of this research could be beneficial for improving the development of interactive applications for science education.

Introduction & Purpose

Complex topics such as cellular respiration are often introduced before students have a solid understanding of foundational biological principles. This lack of understanding can hinder the development of critical thinking abilities needed for integrating increasingly complex scientific information as students continue their studies. Using glycolysis as the context, the purpose of this research project was to improve learning outcomes for introductory biology students studying cellular respiration by fostering foundational knowledge about enzymatic regulation. A 2D animation and a dynamic interactive application that allowed for real-time exploration of proteins and molecules were created. Content was presented in a manner that allowed students to build on prior information and transfer concepts to the specific context of glycolysis. Materials were made accessible to students as an online module.

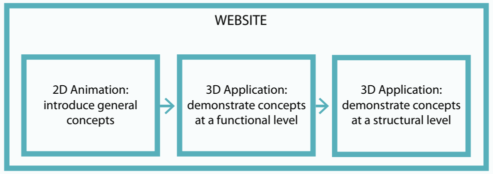

Figure 1: scaffolded knowledge building of biological principles

Materials & Methods

Overall Process

Glycolytic enzymes with resolved structures were first aggregated from the Protein Data Bank and modified in the Visual Molecular Dynamics (VMD) software. Enzyme models were then exported to Pixologic ZBrush where they were retopologized for efficiency of geometry and performance (see figure 3). Enzymes and substrates were animated in Autodesk 3ds Max. The user interface elements were created in Adobe Illustrator. All assets were imported into Unity and scripted for interactivity. Finally, lighting and materials were applied within the Unity environment. The completed application was built out on the WebGL platform in order to be accessed online. For the 2D animation, all elements were created within Adobe Illustrator. Adobe After Effects was used for compositing and the finished animation was encoded with Adobe Media Encoder for deployment and integration into the online module.

Figure 2: project work flow

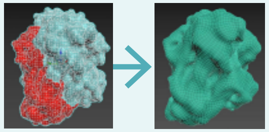

Figure 3: optimizing enzyme model geometry

Application Design and Delivery

There were two primary scenes in the application:

Functional level scene (see figure 4): Students were able to control the amount of adenosine triphosphate (ATP) in the environment and observe the effects on enzymatic activity. By manipulating this value, allosteric enzymes were either activated or deactivated. User interface elements were implemented strategically to help scaffold student understanding of this process. Students were then encouraged to click on the third enzyme, phosphofructokinase, to observe allosteric regulation at the structural level.

Structural level scene (see figure 5): The final scene allowed students to interact with and observe the regulatory mechanisms of phosphofructokinase (PFK). Students could again manipulate the levels of ATP in the system and observe the effects on PFK. At this level, direct structural changes due to allosteric interactions can be observed in PFK. Students also had access to background information and guidance to help them deconstruct and understand their experience with this part of the application. The finished application and 2D animation were optimized and exported for web delivery (see figures 6 and 7). The landing page contains a brief introduction along with the 2D animation. The next page hosts the interactive application.

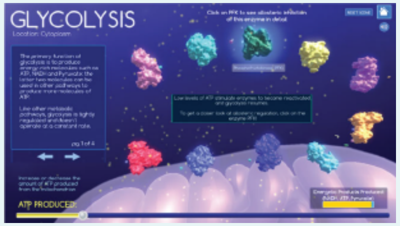

Figure 4: functional overview of feedback inhibition in glycolysis

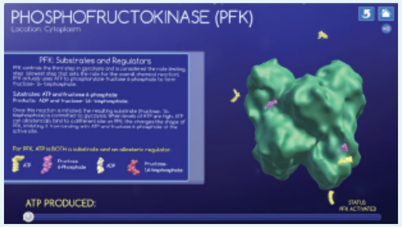

Figure 5: structural overview of allosteric regulation in PFK

Figure 6: website landing page and selected animation screenshots

Figure 7: website page hosting interactive application

Results

A pretest-posttest design method was used during an introductory biology course at the University of Illinois at Chicago in Spring 2017. 16 students completed the pretest and 12 completed the posttest. Both tests were worth 5 points. A decrease of 1.38 points was observed for the average score on the posttest. Due to the lack of control with this research study and the small sample sizes, it is not possible to draw meaningful conclusions from these preliminary quantitative results. Qualitative results aggregated from the posttest reveal an overall positive experience with the interactive application (see figure 8 below).

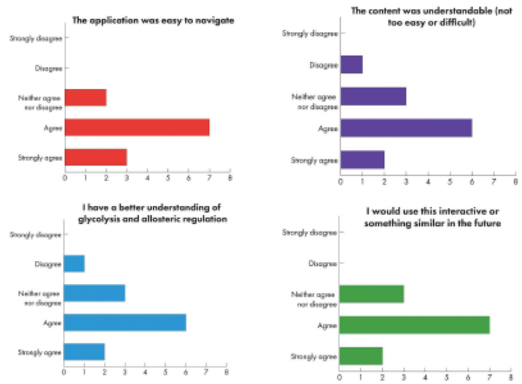

Figure 8: student qualitative feedback for the interactive application

Discussion

This project sought to combine effective teaching pedagogies with a novel interactive visual presentation in order to foster deeper understanding of allosteric regulation and glycolysis. When combined with interactivity, visualizations allow students to explore spatial and causal relationships in a dynamic and constructive manner, helping students build connections and integrate information. Future directions will focus on improving the overall design and conducting a more rigorous and accurate analysis of the application's efficacy.

References

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