Virtual Reality Enzymes: An Interdisciplinary and International Project Towards an Inquiry-Based Pedagogy

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Abstract Education in Science, Technology, Engineering, and Mathematics is moving towards more inquiry-based and creativity-stimulating pedagogies. Part of a curriculum based on such pedagogies should be challenging learning activities that engage students in investigation. At the same time, it is imperative that such activities are developed and validated in collaboration with the teachers who will incorporate them in their lesson planning. In this project, educators, researchers, and developers from Singapore and the Netherlands are working closely to develop innovative tools that assist biology education. Model-based and virtual reality-enabled solutions are

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being studied through interdisciplinary and international collaboration among the project members from the two countries.

Keywords Virtual reality · Serious games · Biology · Enzymes
Inquiry-based pedagogy

1 Introduction

There is a strong research base providing support for the argument that technology enables the involvement of students in realistic scientific tasks, for example through the use of virtual reality (Cai et al. 2013; Tan and Waugh 2013; Chow and So 2011), simulations (Cai and Goei 2013; Cai et al. 2016; Rutten et al. 2012; Rutten et al. 2015; Shin 2002; van Joolingen and de Jong 2003), external data and laboratories (Cai 2011, 2013; van Joolingen et al. 2005), as well as modelling tools (Blikstein et al. 2005; Louca and Zacharia 2011). These tools allow for the creation of task environments in which realistic and authentic forms of inquiry are possible and within the grasp of students in secondary education. The beneficial effect of such realistic contexts can be linked to the potential of technology to make students' learning experiences more authentic and to increase their exposure, engagement and interaction. Authenticity is considered important because more authentic learning experiences may lead to higher cognitive fidelity, which in turn could contribute to better learning outcomes.

A major goal of science education is to develop students' skills and attitudes towards Science, Technology, Engineering, and Mathematics (STEM), including their views on the nature of science, the role of scientific representations and models, and the processes of scientific inquiry and the creativity involved, as well as students' personal attitudes and possible future careers in science or technology. The construction and evaluation of scientific models (Löhner et al. 2005; Minner et al. 2010) provide a means to offer students experience with scientific research on a small scale and to learn about the model-based nature of scientific knowledge, especially about the relation between models and reality.

In STEM, the learning issue can be defined at two levels. At a domain-generic level, students need to learn about the nature of scientific knowledge and the role of models in representation. Within a specific domain, for example molecular and cell biology that is studied in this project, the relation between models and reality is particularly apparent. It is important that students gain insight into both the explanatory powers of models and their limitations in understanding in this domain, and learn to see the added value of using multiple representations and multiple models.

2 Virtual Reality Enabled Teaching and Learning

Virtual reality (VR) is widely considered to be one of the most viable technology applications for use in education. A large number of research papers has been published over the last few years discussing VR in education (Freina and Ott 2015; Merchant et al. 2014; Chow and So 2011; Cai 2013). This chapter describes a project in which Virtual Reality is applied in molecular biology. The project is a joint effort between Singapore (Nanyang Technological University (NTU), Hwa Chong Institution and River Valley High School) and the Netherlands (Windesheim University of Applied Sciences and Utrecht University). Based on existing work on VR technology development for curriculum-based learning and teaching of molecular biology (Cai 2011, 2013), this interdisciplinary and international project, brings together researchers from the two countries collaborate in developing VR-enabled solutions to be used in innovative lessons for molecular biology. The goal is to promote education research through international partnership conducted to craft pedagogy for VR-enabled learning and teaching, so as to add to the knowledge and evidence already available on VR education, model-based learning, and teachers' competencies in building innovative lessons for VR-enabled learning. The ultimate aim is that students in the classroom will benefit from this research. A previous experimental study by the Singaporean team showed that students do receive benefits from the use of VR technology in molecular learning (Tan and Waugh 2013).

Last but not least, this project is an attempt to bring together educators, researchers, and students using a cross-cultural partnership. The objective is the development of effective and validated pedagogies for inquiry-based learning, as well as skills and attitudes in students for modeling and stimulating relevant for functioning in current complex and rapidly-changing 21st century working environments.

3 Modeling in Enzyme Biology

In the biology domain, textbooks typically depict molecular and cellular processes such as enzyme operation and protein synthesis with iconic representations of macromolecules (Figs. 1 and 2). While this representation enables students to obtain a global view of the processes involved, there are aspects that are neglected despite being important for deeper understanding (Figs. 3 and 4). For instance, apart from the 'lock and key' idea of enzymes that is involved in order for molecules to 'snap' into each other, the molecules themselves are dynamic structures and their movement within the cells adds to the dynamics. Whereas the textbook representation may give rise to the misconception that molecules display purposeful behavior, a representation that incorporates dynamics can give rise to a more accurate 'mechanistic way' of reasoning that is capable of explaining the effects of external factors such as temperature and pH value in the cell (Figs. 5 and 6). This project is interested to develop models and modeling environments in which students can create and play

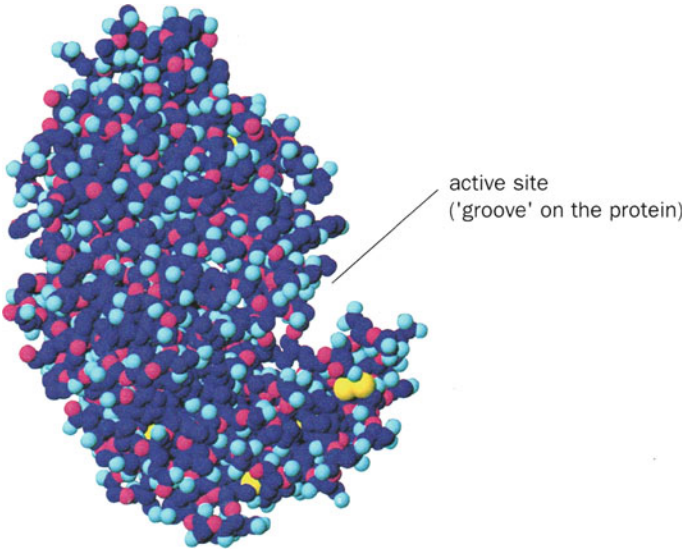

Fig. 1 A three-dimensional model of enzyme pepsin with its active site

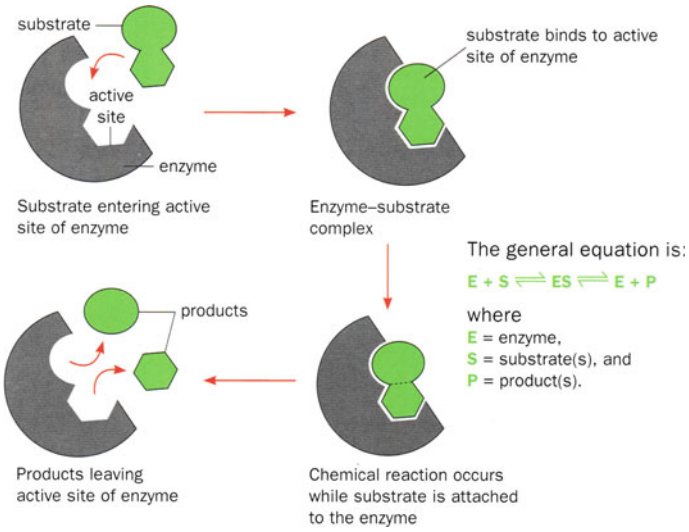

Fig. 2 The mode of action of an enzyme

with such multiple representations and use lesson plans to support learning in these environments. In this way, students can simultaneously learn concepts, processes, and functions within the domain of molecular and cell biology and develop 21st century skills related to the understanding of science and scientific knowledge.

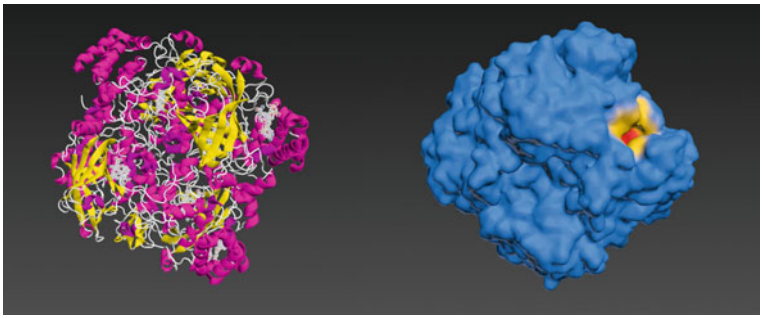

Fig. 3 The three-dimensional remodeling for VR application, 1DGB—human erythrocyte catalase

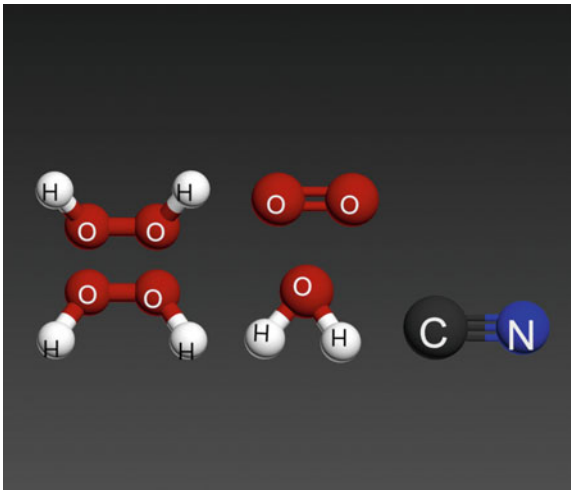

Fig. 4 The three-dimensional models of substrate molecules used in VR application. $2H_2O_2$, O_2, H_2O & CN−

4 VR Technology Enhanced Learning

Figure 7 shows students from the National Institute of Education doing VR enzyme learning in the virtual and augmented reality flipped classroom recently set up in Nanyang Technological University.

In the design, implementation, and evaluation of the modelling activities, teachers often actively involve the use of Lesson Study (Lewis et al. 2006). Lesson study is a collaboration-based teacher professional development approach that originated in Japan (Fernandez and Yoshida 2004). In this approach, teachers collaboratively engage in research inside their classrooms using a design cycle: preparing and designing lessons, performing the designed lessons as research lessons, and evaluating them in order to feed into the next cycle (Cerbin 2011). Teachers collaboratively design

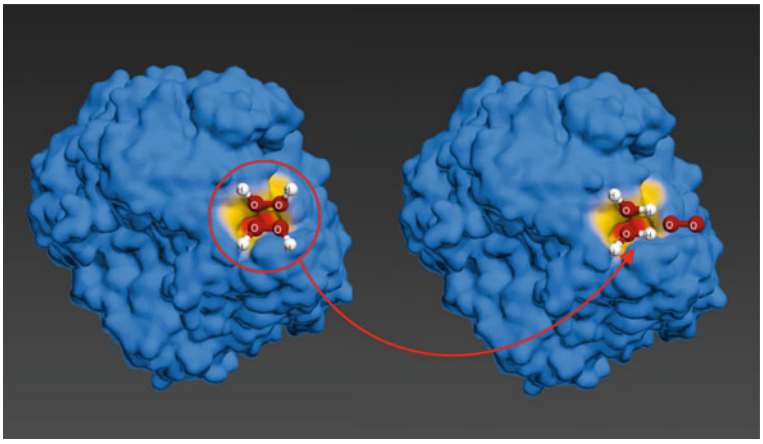

Fig. 5 '*Lock-and-Key*' *Hypothesis* model based interaction in VR Application

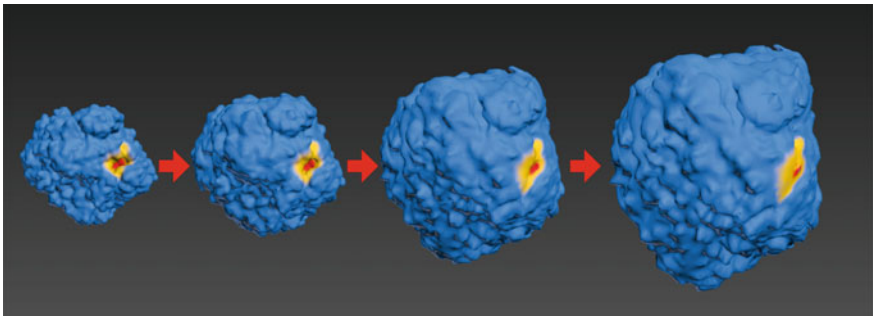

Fig. 6 Enzymes denaturation in VR application. Denaturation is the change in the three-dimensional structure of an enzyme or any other soluble protein, caused by heat or chemicals such as acids or alkalis. Enzymes lose their active sites when they are denatured

one or more research lessons in which they attempt to adjust to the varying educational and instructional needs of their students (Goei 2013). Great thought is devoted to predicting how the students may react. In the Lesson Study cycle, it is crucial for other teachers who are Lesson Study team members to observe the students during the research lesson and pay special attention to their learning activities and behavior. The lesson is evaluated immediately, with the focus being on the learning activity rather than the performance of the teacher who executed the lesson (Becker et al. 2008). Observations are shared, ways of refining and improving the lesson plan are discussed, and a subsequent review of the lesson is planned. In most cases, the adapted research lesson is then used for another class.

The project has now led to a set of lesson scenarios, developed in collaboration with teachers in both countries. The basic idea is to focus on the process of digestion in a story-like manner and have students investigate the factors that influence digestion.

Fig. 7 Interactive learning of molecules modelled

Fig. 8 The poster triggering the exploration of digestion. All the food items are active zones. Gazing at them or pointing to it with the mobile app will trigger a 3D exploration of the digestion of that item

The story starts with a poster of a woman who can choose from a number of available foods. When gazing at a particular kind of food, an animation is started showing the woman eating that food. After that, the student can zoom into the mouth, the stomach or the intestines and see and explore the working of the enzymes, in particular Amylase, which breaks down the starch, present in bread, rice, potatoes etc., to shorter chains of glucose elements. It is visualized that the enzyme will fit on starch, but not on cellulose, which is made up of the same glucose elements, but connected in a different way. Also students can explore how the enzymes behave under different conditions, such as changing temperature and variance in pH (acidity) of the environment (Fig. 8).

In this international collaboration, the Singaporean team has developed the simulations and visualizations for VR-enabled learning and teaching of enzymes whereas the Dutch team has developed the storyline around digestion and will integrate this into molecular biology lesson plans that employ the features of modeling and simulation. They will also validate and fine-tune the lesson plans via Lesson Study. The lesson plans will also be tested out by teachers in Singapore, and by subject matter specialists in the Netherlands.

The VR-enabled solutions draw on the work of the NTU team. They are highly specialized in biology modelling, visualization, interaction and user-interface. With the VR tool, students can deal with two-dimensional (2D) drawings, three-dimensional (3D) graphics of molecular structure, and four-dimensional (3D plus time) simulations of dynamic functions. The pedagogy is based on inquiry-based learning and modeling using the approach of modeling and simulation for learning. Focus in this approach is the integration of the inquiry experiences within the classroom, with the teacher orchestrating students explorations and reasoning. The novelty of the development is its embracing of more general concepts of models across multiple levels and with multiple variables for teaching and learning. The models include simulation and 2D and 3D visualizations. The value of Lesson Study in this process is that the designed pedagogies and lesson plans will take the roles of teachers and students into account. The detailed predictions of student behavior and the classroom observations will provide insight in the reasoning patterns that will be triggered by the 3D visualizations. The Lesson Study stage of this project follows the model designed by De Vries et al. (2016) for the Netherlands. This model entails a structured way for lesson design, selection of case students, prediction of student behavior and lesson observation. Lesson Study is also currently part of professional development initiatives in Singapore schools.

5 Conclusion

This project is timely in its exploration of VR technology in education (especially STEM education), aiming to help pupils achieve better understanding of scientific concepts through model-based simulation for interactive learning. One of the existing challenges for higher education is internationalizing its programs and making students more globally competent. Although teaching is often tailored to local contexts, international collaboration is important for educators as they can grow professionally through exposure to innovative ideas and best practices in other settings. It may be expected that teaching traditions and learner and teacher dispositions are different in the two countries, which would provide all teachers involved with fresh insights about teaching and learning.

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