The combined effects of physical and virtual models in learning cellular biology

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Physical models have long been used in science education for visualization of complex cellular structure and dynamics during face-to-face lecture (F2F). Recent advancement of technology has enabled us to create virtual models and to share knowledge remotely. This study aims to find out whether physical and virtual models work synergistically to enhance student engagement in learning an undergraduate Life Sciences module. Three independent experiments were conducted to assess learning effectiveness on three biology concepts through four learning approaches: video with virtual model only, video with integration of virtual and physical model demonstration, F2F lecture using virtual model only, F2F lecture using virtual and physical models. Participants were randomly assigned to different groups each with one learning approach. Data collected through pre- and post-tests revealed that significant improvement in learning scientific concepts occurred in one of three controlled experiments when the video contains both virtual and physical models, while no obvious difference found in the other two experiments. This data suggests that well-prepared digital media alone may convey scientific information well and additional physical models do not aid in information acquisition. However, feedback survey on student learning experience showed that all participants preferred to learn from physical models. In all three experiments, students consistently voted that the physical models attracted their attention and enhanced their interests. They made better mind maps and raised more questions. These hint that a combination of digital media with physical models might improve engagement and promote higher order thinking.

Background

The rapid development of technology has greatly transformed teaching and learning. Educators use video clips, animations and web-based learning to help visualizing challenging concepts and to cater for different learning needs (Brame, 2016, Yellepeddi & Roberson, 2016; Mayer, 2002). On the other hand, students have become more proactive in searching for these technological aids for deep learning. This is evident in the rise of educational content on video-sharing platforms such as YouTube, Vimeo and Dailymotion (Abdelouarit, Sbihi, & Aknin, 2015). The benefits of instructional video have been widely studied and recognised (Barford & Weston, 1997; Mayer, 2002; Girod, Bell, & Mishra, 2007; Targamadzė & Petrauskienė, 2010). Yellepeddi and Roberson (2016) reported that the implementation of educational videos in the classroom mitigated the complexity of pharmacological content and improved student's learning through the use of visual instructional aids. It also alleviates student's difficulty in understanding abstract and hard-to visualize concepts. These positive outcomes are often directly linked to cognitive load, student engagement and active learning (Brame, 2016).

Creation and selection of multimedia presentation are guided by a theoretical framework- Cognitive Theory of multimedia learning (CTML) (Day et al., 2006; Mayer, 2002). Most educational tools aim to decrease two cognitive loads, namely the intrinsic load which corresponds to the inherent difficulty of the topic and the extraneous load which are information that do not contribute to the learning outcome (Brame, 2016). There are nine ways to reduce cognitive load in multimedia learning and visual aid is an important tool for the purpose (Mayer & Moreno, 2003). Another central idea that revolves around the design of educational videos is the level of student engagement (Brame, 2016). Two working definitions are namely emotional and behavioral engagement. Emotional engagement reveals the affective reactions of the student with regards to the information that was presented. These feelings can be described as interest, anxiety, happiness and many more. Behavioral engagement on the other hand is defined as behaviors that reflect positive attitudes towards learning. Some of these behaviors include persistence, attention, questioning and effort, which are often indicators for the level of student engagement (Fredricks et al., 2004).

Physical models have long been used in science education and the advantages have been widely recognised (Harrison & Treagust, 1998; Azer and Azer, 2016; Bryce, et al. 2016; Krell & Krüger, 2016). However, there is rarely corroboration for the effectiveness of using a combination of video and physical models in both e-learning and face-to-face learning (Harris, 2009). Therefore, it is instrumental to find the values of physical models in the technology-enhanced learning environment, and hopefully the data generated from this research would enrich our technological pedagogical content knowledge (Koehler & Mishra, 2009).

Methods

Physical models, virtual models and video preparation

Three physical models: spindle apparatus, chromatin and mitochondrion were created and used to teach students in non-life science majors about three biology concepts: cell division (Expt 1), chromatin remodelling (Expt 2), and glucose metabolism (Expt 3), respectively. All models were designed to show dynamic process through their movable components and created using crafting materials. The building components were colour-coded to enhance their visual effects and attractiveness. Virtual models were created in PowerPoint (PPt) files with images to show the structures and animations to explain the dynamics. These PPt files were used for both video recordings and face-to-face (F2F) lectures. All instructional materials were designed for students with minimal prior biological background and aligned with learning objectives of a General Biology course (LSM1301).

Participants and experiments

Participants were mainly recruited via three platforms: a NUS internal website in Integrated Virtual Learning Environment (IVLE), a public website known as 1our.today and Facebook. The participants must not major in any biology-related field such as Life Sciences, Medicine, Nursing and Pharmacy and should not have taken any general biology module in order to minimize the bias in their biology background knowledge prior to experiments. They were from various faculties, such as engineering, computing science, arts and social sciences, business, etc.

Three independent experiments related to the three key biology concepts were conducted to investigate the effectiveness of combination effects of physical models and virtual models in both e-learning and F2F learning environments. In each experiment, participants were randomly assigned into 4 groups, receiving four different treatments (Table 1). In the E-learning environment, students watched the videos only. In the F2F learning environment, instructors gave live lectures using PPt file and physical models. The duration of presentation and scientific content were controlled to be the same for each treatment.

Table 1: Four groups in each experiment and their respective instructional materials and methods

	Instruction without Physical Model	Instruction with Physical Model
Video (E-Learning)	Recorded PPt presentation without using physical model (VO: Video Only)	Pre-recorded demonstration of physical model is embedded into the recorded PPt presentation (VM: Video + Model)
F2F presentation	Live PPt presentation without using the physical model (F2FO: F2F Only)	Live PPt presentation with the physical model (F2FM: F2F+Model)

Data collection and analysis

Data was collected through a pre and post-test followed by a survey using a 5-point Likert scale. Multiple choice questions in the pre and post-test were the same, but randomized to assess basic understanding of concepts. Questions in the survey were used to get their feedback on their learning experiences. Mind map drawing was only used in Expt 1 and 2, and questions raised by students were only collected and analysed in Expt 3. Student's preference on various components in educational tools was compared to evaluate its effectiveness. Data analysis was conducted via the two tailed student T-test at $\alpha = 0.05$.

Results and discussion

Structures and their dynamic changes during cellular processes are critical in understanding the mechanisms of life. However, it is notoriously difficult for students to understand geometric and topological changes of molecular complexity. Therefore, physical and virtual models are often used to help students visualize the structural and conformational changes. However, little research has been carried out to investigate relative benefits of traditional physical models versus computer-generated structures for student learning and comprehension. It is not known whether a synergistic effect can result from using both physical and virtual models in complementary ways in the classroom or in an e-learning environment. Nevertheless, a common theme from very limited research is that different types of structural models can be used to illustrate different concepts (Integrating Research and Education, n.d.). In order to gain technological pedagogical content knowledge (Harris et al, 2009) and improve students learning experiences in the blended learning mode, we built three different biology models, representing very different three concepts in Cell Biology (cell division, Expt 1), Epigenetics chromatin remodelling, Expt 2), and physiology (glucose breakdown, Expt 3). Virtual structures and dynamics were showed in PPt files using images and animations. The effectiveness was compared in both e-learning and F2F learning environments. Learning outcomes evaluated by pre-and post-tests showed clearly that all the instruction had improved students' understanding of the scientific concepts (Figure 1).

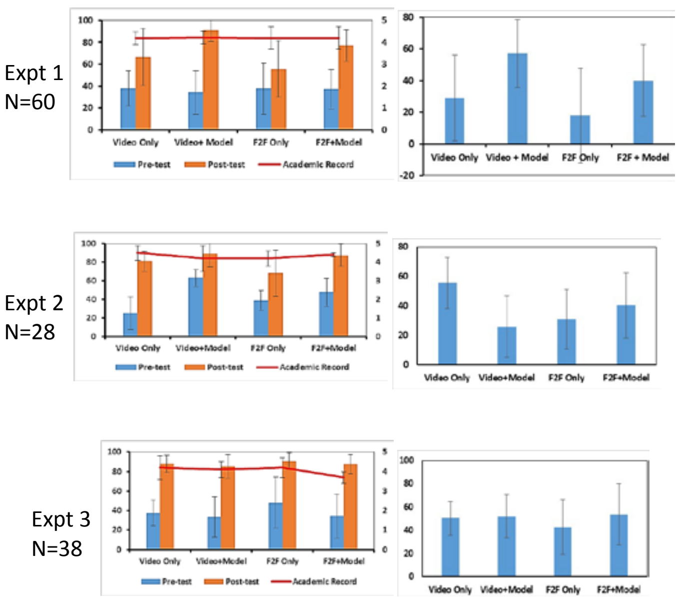

Figure 1: Comparison of learning outcomes using pre- and post-test scores

Three independent experiments were carried out to teach three biology concepts. In each experiment, participants in one of four groups were taught via one of four methods, namely video only, video with integration of demonstration of physical model (Video+Model), face-to-face lecturing without physical models (F2F only), and F2F lecturing with physical models (F2F+Model). Learning outcomes were evaluated with pre-and post-tests. The bars (mean ± S.D.) in the left column indicate percentage of pre-and post-test scores, the red line (mean ± S.D.) corresponding to the right Y axis indicates the average Cumulative Average Point (CAP) in the group. CAP is used to measure academic performance by grade points on a 5-point scale in NUS, being used as bench mark information of participants' academic capacity. The bars (mean ± S.D.) in the right column of the figure represents the net increase of test scores (post-test score minus pre-test score). The * indicates significant difference between test groups.

In Expt 1, participants (n=60) achieved the best post-test scores after learning through the combination of video and model (VM) among the four groups. It may suggest that the scientific concepts were best learnt through the integration of physical model demonstration into video file. The post-test score was significantly higher than the pre-test, and the mean net increase of test score was the highest among all tested groups. However, there was no significant difference in learning outcomes among all the four groups in Expt 2 (n=28) and 3 (n=38). Although the mean increase of test score after learning through video only (VO) was significantly higher than it after learning through VM in Expt 2, it is worth noting that the pre-test score in VO group is much higher. Therefore, the mean increase of test score may not be meaningful for comparison in the case.

It is complex to try to explain the variation of the learning outcomes among different experiments when a combination of virtual (images and animations) and physical models is used. One possible explanation based on participants' feedback is the seamless integration of the physical model into the presentation in Expt 1. Written feedback from students may partially explain the results. *"The 3D physical model and animations are most useful because they help me "see" what is happening. Static images in the PowerPoint are unable to do the same!" "'The model complemented the already well-done slides and yet did not seem redundant. I am not an auditory learner so speech does not capture much of my interest. However, when speech is synchronized with the animation and the model, it really helps digesting the information."* However, the learning outcome may also be theme related as mentioned above, and affected by other factors.

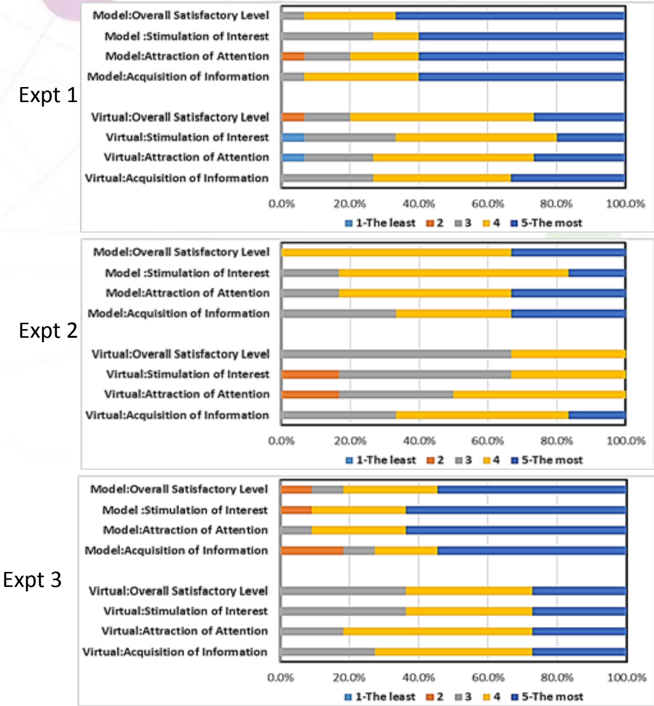

Figure 2: Survey on the virtual models and physical models using a 5-point Likert scale

Although the physical models did not always bring out significant improvement on learning scientific concept, survey on students' learning experiences and preferences were very consistent. Participants in the all experiments reported that the physical models were much better for stimulating interests, attracting attention, and acquiring information than the virtual models used in both video presentation and F2F presentation (Fig 2). The percentages of participants giving the highest rating for physical models were larger than the percentages for virtual models. This is an important finding because the ability to capture the students' interest and attention is an important criterion of an effective educational tool (Donnelly, Harvey, & O'Rourke, 2010).

Previous studies revealed that students prefer to use tactile tools to solve higher-level thinking questions instead of computer imageries. In addition, differences of student learning with a combination of hand-held models and computer imaging programs were not found in typical course assessments as compared with computer imagery alone, while differences can be identified by interviews and highly-challenging questions (Harris et al. 2009). This may suggest that our pre-and post-test may be unable to reveal all learning differences when virtual and physical models were used in different scenarios. We did note that the quality and completeness of mind maps created by students who had been taught with a combination of virtual and physical models were much better than those created by students who were taught with virtual models only in Expt 1 and 2. In Expt 3, we also noted that students asked more questions when the physical model was used as compared with virtual models alone (data not shown). Taken together, our finding may hint that a combination of physical and virtual models may function better to attract students' attention and engage deep learning. In future, we may explore students learning efficiency when they are invited to create models and play with models

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