Development of a Prototype Biochemistry Virtual Laboratory: Reflections on the Instructional Design

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Abstract

This paper describes and critically evaluates the instructional design process for the development of a prototype biochemistry virtual laboratory for teaching and learning for medical students. The designing strategy was essentially based on the ADDIE model. However, many innovative ideas and practical tips are discussed in this paper to illustrate the importance of case specific adaptations. For example, factors such as intended learning outcomes, learning pedagogy and learner's reactions will be considered. In particular, our research findings emphasize the importance of students' feedback of virtual lab design during the evaluation stage, which provides valuable insights for the instructional designers.

Keywords: eLearning Instructional Design; Virtual Lab; Virtual Learning; Biochemistry Education

I. INTRODUCTION

As an experimental science, biochemistry is a practical science which needs more hands-on activities. Many great scientists indicate that successful laboratory generally breeds more success (Bynum 2012) because laboratory exercises can facilitate and stimulate biochemistry concept learning. However, some major issues hinder the efficiency of teaching and learning in lab scenarios. To begin with, wet lab work will not be cost effective due to higher cost of equipment, dedicated preparation by technical staff and unpredictability of time management. To follow uniform assays, dry lab can hardly mimic perfect lab experiences and varieties. In this way, they can hardly resolve learning problems independently. Further, if students are not well instructed in lab safety measures, they could be more prone to danger. Thus, on one hand, teachers want to design more lab based learning activities for students to get more familiar with lab equipment to achieve learning outcomes. On the other hand, due to strict control of lab use, concern of lab safety and high cost of lab maintenance (Bakar and Zaman 2006), chances are slim for teachers to implement lab-based learning activities for students to practice experimental skills in real lab.

The virtual simulation offers a possible solution to support the real lab practice. It can not only potentially display details for abstract concepts, but also provide simulated interactive lab work for teaching and learning. In the health science education, virtual laboratories can simulate real-lab scenarios in an engaging and intuitive environment to help students acquire new knowledge and skills through learning by interactions. Studies shows that virtual lab promotes students to master lab skills by doing more virtual practice (Raineri 2001, Maldarelli, Hartmann et al. 2009, Bean, Fridovich-Keil et al. 2011). Setting up the virtual environment is not simply building virtual objects for display, it also involves pedagogical considerations including students' attentions, learners reactions, collaborative design and so on (Hansen 2008). Hence, it is essential for instructional designers to consider more factors when designing and developing virtual objects for teaching and learning.

This paper presents an exemplar process involved when designing and developing a virtual lab for biochemistry teaching and learning. Following the ADDIE instructional design models, the instructional designers of this project adopts constructivism instructional model for building up virtual lab and organize students to participate in implementation and evaluations to improve the designs. Reflections in this paper could provide a practical guide for more efficient virtual lab instructional design.

II. METHOD

A. Student's academic background

The development of the prototype biochemistry virtual laboratory was intended for the clinical biochemistry teaching of the year one to three undergraduate medical students. The students were enrolled in a six-year medical degree (MBBS) program. Approximately 75% of the intakes undertook the local public examination for the Diploma of Secondary Education (DSE), while the others studied either in the International Baccalaureate Diploma Program (IBDP) or the Advanced levels General Certificate of Education. Minority was admitted as graduate students.

B. HKU's medical program

The teaching and learning themes at the HKU medical school adapts a holistic, discipline integrated system block approach. For example, the year one students study in an integrated art and science of medicine (IASM) block, while year two and three students enter into human system blocks where disciplines of basic sciences as well as other humanity and basic clinical skill studies are carried out through nine blocks, such as the respiratory system block, cardiovascular system block, etc.

The medical program also takes a hybrid approach where Problem-Based Learning (PBL) and traditional class teaching

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are integrated. The cohort is divided into PBL groups of around 11 students per group. Teaching takes place in multiple of formats, including whole class lectures, practical sessions, clinical sessions and PBL sessions. The basic science teaching in Biochemistry is in part carried out as practical sessions. Typically, five PBL groups are together for a practical session of three-hour duration. Therefore, such session is repeated four times to cover the entire cohort.

The development of the prototype biochemistry virtual laboratory was intended to be used during the practical session, which means it was designed to blend in and complement the real-time practical sessions.

A cohort of 220 year two medical students was involved in our research study. Our study obtained clearance from the human ethic committee and consents were sought from all participating students of this study.

C. *The ADDIE model*

The ADDIE model (Molenda 2003) was implemented in this project for the instructional design. In brief, five phases were followed in the process to ensure the quality and efficiency of the overall system development.

1. Analysis

At the begin of development, the instructional designer needed to gain understanding of the various learning theories and associated instructional design strategy to implement instructional solution in creating appropriate learning environment (Mergel 1998). Those learning theories such as behaviorism, constructivism, and cognitivism help shape and define the outcome of instructional materials (Ertmer and Newby 1993). Biochemistry virtual lab requires students to actively construct their own understanding and apply their knowledge into practice. As constructivism learning can promote interactive, collaborative and problem-based learning, allowing instructional designers to simulate and assume authentic roles in the real environment (Ruey 2010), constructivism instructional design framework was used to guide virtual lab design. To implement constructivism online course, a set of instructional principles guided the constructivism instructional design as follows (Savery and Duffy 1995):

- Anchor all learning activities to a larger task or problem.
- Support the learner in developing ownership for the overall problem or task.
- Design an authentic task.
- Design the task and the learning environment to reflect the complexity of the environment they should be able to function in at the end of learning.
- Give the learner ownership of the process used to develop a solution.
- Design the learning environment to support and challenge the learner's thinking.
- Encourage testing ideas against alternative views and alternative contexts.
- Provide opportunity for and support reflection on both the content learned and the learning.

2. Design

Under the constructivism instructional design framework, the instructional designer purposefully chose the technical tools to design the virtual lab. The inclusion criteria of the technical tools should be constructively promoting students to interact, discuss and collaborate with each other. Second Life was chosen as the virtual design platform. Launched in June 2003, Second Life is one of the most popular virtual world platforms in use today, with an emphasis on social interaction, reaching millions of users up to now (Boulos, Hetherington et al. 2007). It is not only widely accepted as social networks, but also currently the most mature and popular multi-user interactive virtual world platform being used in education (Warburton 2009), especially for medical and health sciences education areas (Boulos, Hetherington et al. 2007). To enhance more interactive teaching and learning, google presentation suite and video clips were also integrated into the Second Life to supplement knowledge building.

3. Development

During this phase, storyboards were drafted by lecturers of biochemistry. According to the stories boards, the instructional designer created flow charts with Microsoft Excel to indicate the data flow. Based on the storyboards and flow charts, initial architecture of the virtual lab were drawn. Then according to the instructions, photographers took photos of the real lab and equipment to send the designers for editing. With Photoshop CS6 software, all the pictures were edited as texture of the equipment. Simple equipment modeling work was done in Second Life while more complicate equipment was done with 3D MAX software. Video clips and google presentation materials were separately edited for contents display and were finally integrated into virtual lab by instructional designers.

4. Implementation

The virtual lab is delivered to students in blended learning model. Generally speaking, blended learning is an education program to combine face-to-face learning with computer-mediated activities. Unlike distance learning emphasizing self-paced learning in synchronous and low fidelity environment (Graham 2006), blended learning shares advantages of both the face-to-face instruction and virtual learning environment. It provides a way for educators to use virtual tools to better serve for teaching and learning purpose, especially the adoption of constructivism learning theory. With blended learning method, people learn by active construction of ideas and building of skills through exploration, experimentation, receiving feedback, and adapting themselves accordingly. Students will be engaged in activities which focus on real world, authentic tasks and collaboration (Sharpe, Benfield et al. 2006). Thus blended learning can foster constructivism learning.

During the implementation stages, blended learning demonstration classes were organized to let students experience the virtual lab system. Students were given handbooks of virtual lab and related learning activities instructions. Facilitators guided them to conduct virtual lab activities and technical staff stood by to deal with hardware and software issues of the virtual lab use.

5. Evaluation

The evaluation consisted of formative and summative evaluations. Formative evaluations were covered in each stage of the ADDIE process in the project. Regular meetings were held for course lecturers, instructional designers and programmers to assess project progress and quality. Summative evaluation was conducted after demonstration classes. During the demonstration classes, the observers carefully followed five teams in each class to record their class performance in a standard observation form. The observation notes were shared in Google Drive to make conclusion. After class, students were given a week to complete open minded questions about their perceptions of virtual lab. Their feedbacks were coded for analysis by the whole project team. Instructional designers would propose the next stage upgrading version according the students feedback

III. RESULTS AND DISCUSSIONS

A. Virtual Lab Room.

The purpose of the practical was to facilitate the students to become familiar with the separation patterns of plasma lipoproteins using gel electrophoresis. The wet lab set-up displayed in virtual prepared students to be much more perceptive of the real lab practice.

Two lab areas were designed to carry out virtual learning. One area is for audio tour where students get familiar with general lab equipment and instructions. The other area is the experiment specific lab bench where students can carry out some self-learning related to their lab session.

Figure 1. Virtual Lab Room

Once logging into the system, students can be directed to the virtual lab, where they can do audio tour under the instructions. In these virtual rooms, equipment of gloves, micropipetts, pipette filler, 10ml pipette, box of blue & yellow pipette tips, marker pen, graph paper, paper towel, a rack of test tubes, a 96-well plate, spectrophotometer and MultiSkan spectrophotometer were displayed. Next to each of the major equipment, interactive screen was embedded with Google presentation. Audio recordings of introduction to this equipment automatically display when an avatar approaches it. At the virtual lab bench, experiment specific equipment was displayed, in our particular setting, students would be required to carry out a procedure in virtual for the separation of plasma lipoproteins using gel electrophoresis.

Based on the class observations and student feedbacks, it demonstrated that the design of virtual lab enhanced their learning motivations. They were quite inspired by the virtual lab design as they could conduct some work which cannot be done in the real world. The visualization of the real lab on the computer could encourage them to try and even create the virtual experiments with their avatars. Based on constructivism learning model, this virtual lab were more interactive and collaborative, seemingly suitable for social learning and PBL group work. Furthermore, students could design their avatar in different images and control them to chat and work with others while doing the similar tasks, which would benefit those who might be shy in the real world.

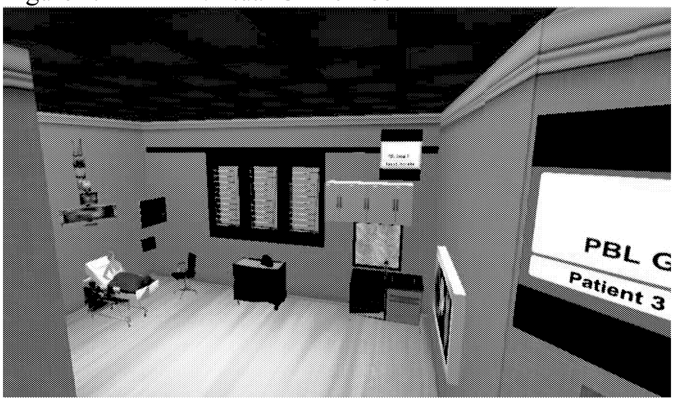
Explicit learning model is the heart of learning process, which will influence the design of a learning environment and ultimately its effectiveness (Piccoli, Ahmad et al. 2001). Failure to adopt appropriate learning model would easily lead to the inability to different learning environments, conflicting the initial design purposes (Leidner and Jarvenpaa 1995). Class observation indicates that students' interests in learning were largely aroused in virtual laboratory, with more interactions and better performances in presentation of PBL case study. The virtual laboratory enables the users to interact and socialize with each other through collaborative work (Gorini, Gaggioli et al. 2008), so constructivism instructional design promotes students to actively learn by interactions and collaborations. Constructivism virtual lab encouraged the students to treat learning as social knowledge constructions (Jonassen 1994). However, students complained that while the equipment in the virtual lab were similar to the real ones, it was still hard for them to find the right parts to control them. Most of them indicated that there were limited opportunities to interaction in the virtual lab as too few animations were designed to support the virtual operations. Avatar could just go around to see the equipment and took very limited simple actions. Ideally, they wished to have more interactions with the virtual lab. From their feedback, instructional designers realized that constructivist learning model could be a framework to guide virtual laboratory. However, in this virtual lab, a lot of virtual objects lacked interactive functions, which hindered the full penetration of constructivism design. Therefore, the designers were informed to be more mindful to specifically improve this part in the upgraded version.

B. Virtual Clinic Room.

For the medical students, one of the ideal contextualization to enhance the basic science learning is to use a clinical scenario. The virtual clinics were made close to the real clinic environment, helping students to get familiar with real clinical practice.

The use of the patients in the virtual clinic was aligned with the use of the virtual lab. Students in one class formed five learning teams. Each team was assigned with one virtual patient for analysis. Virtual patients were placed in the clinic rooms with patient records displayed in the room. The surrounding pieces of equipment showed relevant examination results and index. As a team, members would first obtained the relevant patient records from the virtual clinic, gather the relevant results from the virtual lab, discuss and generate their reports with collaborative work via Google Presentation. Finally, students would make a class presentation using the Google Presentation for their analysis as a team.

Figure 2. Virtual Clinic Room



According to the open minded questions, students were generally attracted by the virtual clinic rooms. But with the trials of virtual lab, they indicated poor instructional design of clinic rooms, as the layout of the different rooms made them totally lost due to unclear route instructions. They stressed the importance of clear navigation and instructions, as their learning experiences could be greatly affected by it. Indeed, the instructional designers did not carefully plan the locations of the five clinical rooms. Consequently, some students could not find the right clinical room for virtual patient diagnosis due to the lack of a proper navigation map, which wasted a lot of time. In addition, some were not clear about how they could control the avatars, equipment, and other virtual tools, making them frustrated during the learning process. Their passions toward using the virtual lab had declined due to these unclear instructions.

In the virtual clinical rooms, students also indicated some technical problems. They found some bugs in the animations while using virtual equipment. The solutions of pictures and virtual modeling were rough to some students. Google presentation was not working because of network issues. Besides, due to higher capacity and specification requirement of the computer hardware, students with lower capacity laptops could hardly run the virtual lab. Most of those who suffered technical issues indicated that such disadvantages disturbed their learning.

Overall, students felt that more careful considerations should be placed towards adopting virtual technologies so that more attentions could be channeled towards improving the details of design and development to satisfy the learning objectives. Interestingly, their feedbacks echoed with some of the educational philosophies in the literature. For instance, Piccoli et al (Piccoli, Ahmad et al. 2001) had indicated that technologies should be suitable to support specific theoretical models. Failure to adopt technologies with quality, reliability and easy accessibility would affect students' effective reactions to the learning experience (Hiltz 1994). It is very important to consider how technology can serve the learning objectives before construction of an instructional design. It is not advised to exploit the use of technology without prior consideration of the learning outcomes. Essentially, rather than indulge in the more technological inputs, instructional designers need to think carefully about how to leverage appropriate technology design to serve learning outcomes, eliminating negative experience from technology and instruction issues.

C. Discussion Room

The purpose of the virtual discussion room was meant to provide a virtual space where presentations of results obtained from the study can be on display. It would be a place where post-lab discussions can take place either while towards the end of the class session, or after the class session.

Figure 3. Virtual Discussion Room

The discussion rooms were originally designed for students to collaboratively discuss and work out a presentation on virtual patient's diagnostic report. The instructional designers intended to build this place to promote virtual social interactions. However, as expected, students complaint the most for this part as they failed to appreciate the usefulness of designing this place for presentation. Apart from the fascinating appearance of the amphitheatre, the place lacked functional purpose for teaching and learning. They even did not use it for discussion and presentation. Thus, students' perceptions in this virtual space disconnected with the original ideas of the design. On reflection, it is essential for the instructional designers to be much more critical regarding whether or not a particular design could serve the learning purpose.

The focuses of the intended learning outcomes of the biochemistry practical session for the medical students are generally very different to those of the undergraduate science students. For example, emphasis of contextualization, data analysis of results in terms of reliability and sensitivity are more important than technical trouble shooting such as fine tuning of assays to obtain maximum yields. The instructional designers therefore should not under estimate the efforts required towards the construction of peripheral components to the laboratory, namely the virtual clinic and the discussion rooms. Such designs in term, boosted the students' attention in class, which is the basis for learning efficacy. The unnecessary superfluous designs are not only without added value, but may even be disturbing to the core learning process.

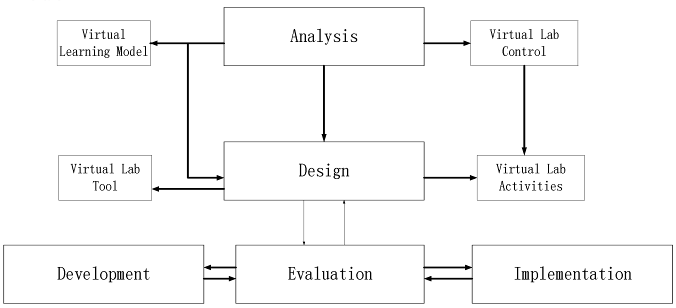
IV. CONCLUSIONS

This virtual lab instructional design takes advantages of ADDIE design model to emphasize the importance of integration of learning theories, intended learning outcomes and students reactions into technical design and development. From the stages of analysis to evaluation, a lot of reflections could be concluded for the future virtual lab instructional design. Here are a few important points to consider:

- Define virtual learning theoretical framework.
- Adopt appropriate virtual technologies to serve learning outcomes.
- Design more interactive virtual lab activities based on the learning model.
- Accumulative evaluations of instructional design must be performed during development and implementation stage.

The instructional design framework of virtual lab could adapt the following workflow:

Figure 4. ADDIE Virtual Lab Instructional Design Model



In this report, we shared our experiences with the design and development of the virtual laboratory to facilitate medical students' learning. Our lessons learnt along the way should serve to provide more insights for others who are in the process of tailor design their virtual component as part of course revamping in the modern era. Of course, there were some limitations encountered in this research project design. Firstly, the qualitative data collected from a small number from only one faculty cannot be generalized. Secondly, their feedback toward instructional design were not tested yet, without certain validity. However, our input should serve to strengthen the evidence-based educational research on a greater perspective.

In general, when deploying a blended learning solution with a virtual lab or any other virtual technologies, it is essential to consider how the virtual technology can help achieve learning outcomes. The adoptions of technical tools should fit learning pedagogy and learner's reactions toward these virtual tools have to be carefully monitored. Students' feedback would provide meaningful insights for instructional designers to upgrade systems. The reflective tips and feedback obtained from this study will be further tested in the continual second phase of study.

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