TECHNOLOGY-ENHANCED LEARNING IN A TEACHER EDUCATION UNIVERSITY: DESIGN AND DEVELOPMENT OF INNOVATIVE ONLINE EXPERIMENTS AND RELATED COURSEWARE FOR STEM EDUCATION

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Abstract

In many disciplines of science and engineering education, online (or called remote-controlled) experiments are recently emerging as another important exemplar of technology-enhanced learning because it can support not only e-learning for engaging students with authentic experiments but also break through the spatial and temporal constraints of conducting experiments. In the last two years, we have formulated an innovative low-cost and open-source approach for developing online experiments. Through the Internet, students can readily set and control the Arduino-based platform for conducting the experiments in their smart phones, tablets or computers at anytime and anywhere by using a web browser without installing any bulky and/or proprietary plugins. We also purposely integrate a kind of pedagogy called Prediction-Observation-Explanation into a number of online science experiments, rendering some self-contained courseware for students’ self-regulated learning.

Two online experiments and related courseware have been developed and refined, namely (1) Lighting technology and (2) Landfill gas production. The first one aims to develop learners’ in-depth understanding of the energy efficiency of different lighting devices and their characteristics through real-time hands-on scientific investigation activities. Students will find out the several physical properties of each of the four types of lamps and students will also need to compare of relative performance of different lamps for making the best consumer choice. For the second online experiment, it is featured with a long-time automatic collection of data for observing and analyzing the changes in gas levels and pH level throughout the fermentation process with 4 sets of different methane inducers. This experiment will develop students’ habit for monitoring the changes (methane level, carbon dioxide level, pH) in the landfill gas production process over a long period of time and help them get an in-depth understanding of the landfill gas production by comparing the methane, carbon dioxide and pH levels for different inducers. Those two sets of online experiments and related courseware have recently been applied to two STEM courses, namely (A) Application of Web Technology in Science and (B) Environmental and Community Engagement: Theories and Practices. The course (A) lecturer comments that the online experiments well match with the learning objectives of his course, helping to develop students good awareness of the application of technologies in science education and in-depth understanding of the interdisciplinary features of related topics in STEM education. For the course (B), the course lecturer remarks that the online experiments can provide students with essential scientific knowledge in achieving sustainability and furthermore, the conduction of the online experiments is considered as a kind of public participation.

A third online experiment is to investigate the effect of different color of the light on the rate of photosynthesis and it is being used in the Ecosystem and Impacts of Biotechnology course. The course lecturer anticipates that the online experiment can equip students with opportunities to apply the skills of scientific investigation in ecological studies and furthermore provide demonstration and insights of how technology could be applied to facilitate students’ learning which are closely geared with the programme objectives.

Keywords: online experiments, remote-controlled experiments, science education, STEM education.

1 INTRODUCTION

In the information age, the socialization and lifelong learning have become an urgent need, and the distance education has also become the hot issues in current education reform. Through the Internet, the remote-controlled experiments will enable learners to control the server-side laboratory equipment, and to complete the real experiment process at distance places. The learners will be free from the conventional constraints of time as those online experiments will be available at any time. Through
remote experiments, students from different universities or campus can perform and access the laboratory experiment at distance places. Students from adult education will be able to select a non-working time such as at home or at work to carry out those experimental work for achieving the specific requirements of the distance learning courses, therefore enhancing the flexibility of teaching and learning. Thus, this kind of remote experiment approach has already gained worldwide attention and with applications in different subject disciplines and levels of education (from university to primary education) over the past two decades [1-5].

One of the authors (YY Yeung) at a teacher education university has recently formulated an innovative low-cost approach to develop online or remote-controlled experiments by using (i) the open-source microcontroller platform called Arduino (around USD10) plus the necessary sensors for control of experimental processes and data collection, (ii) an IP camera for long-time capturing of photos and instantaneous monitoring (Tho & Yeung, 2015) and (iii) a Linux server with various open-source software (such as php, Apache, ffmpeg and gnuplot) for delivering and managing the online experimental activities, storing and processing (including plotting graphs and synthesis of videos) data as transmitted from the Arduino board via the Intranet. This innovation is featured with the application of low-cost and open-source hardware and software for rapidly and easily developing online experiments which are embedded with effective pedagogies for facilitating teachers’ and students’ effective teaching and learning of STEM subjects. Through the internet, students can readily set and control the Arduino-based platform for conducting or observing authentic experiments in any computing or mobile devices at anytime and anywhere by using a web browser without installing any bulky or proprietary plugins. Furthermore, this invention has won the awards of a Gold Medal and a Special Prize (from The Association of Thai Innovation and Invention Promotion) in the 2018 International Invention Innovation Competition in Canada.

2 METHODOLOGY

To design and develop the online experiments and related courseware for students’ self-learning, the design-based research (DBR) [6,7] framework was adopted for the direction of approach because it is becoming very popular for technology-enhanced research in which it is used to integrate technology with real-world settings in education [8-10]. This framework embraces cycles of design, enactment, analysis, and redesign. The general framework is depicted in Figure 1. As a concrete example on designing a set of remote-controlled experiments in lighting technology, the schematic diagram (see Figure 1) below shows the essential components and connection of the system. The four lamps under investigation are placed inside a black wooden box. An Arduino Mega board (a microcontroller) is used to (1) control the power switch of every lamp via the relay, (2) monitor and (3) collect data on temperature from temperature sensors near each lamp, illuminance from the light sensor and environmental temperature and humidity from another sensor. It is operated by an Arduino programme consisted of more than 1,000 lines of codes as written by the present Project Coordinator. The collected data will be uploaded through its LAN card to a server located at vr.edu.hk for storage and processing (including automatic plotting of graphs and preparation of reports) as well as for security reason. All the learning activities are managed by another 2,000 lines of HTML and php codes which are also specifically written by the Project Coordinator for this courseware. A learner with a computer or a mobile device can use an ordinary web browser to access and control the Arduino system via the abovementioned server for conducting the online remote-controlled experiments at any time (if no one is using the system at that time) and anywhere.

![Figure 1. General framework for the low-cost design of online experiments](image)

Based on this new low-cost approach, we had successfully developed a number of online experiments in various science topics, including lighting technology, fermentation processes, generation of landfill gas, electrochemical processes and aquaponics system.

Some of the above remote-controlled experiments could be accessed at http://has.edu.hk/oe/
We have developed a specific questionnaire tool for evaluating the student's learning effectiveness and attitudes this online mode of learning. It was integrated into the courseware for the online experiments and students will be invited by the online system to anonymously fill in the questionnaire after completing all the learning activities.

3 RESULTS

We have successfully developed abovementioned online experiments with a few iteration for testing and refinement after receiving the feedback and comments from the learners. Photos of the actual experimental setup are shown in Figure 3.

Design of the two experiments are given below:
3.1 Remote-Controlled Experiments in Lighting Technology

There are four types of commonly used lighting devices selected for this experiment and their basic characteristics are summarised in Table 1 below:

<table>
<thead>
<tr>
<th>Lamp #</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>LED lamp</td>
<td>CFL (Compact Fluorescent Lamp)</td>
<td>Incandescent lamp</td>
<td>Halogen (quartz halogen) lamp</td>
</tr>
<tr>
<td>Power of lamp (W)</td>
<td>4</td>
<td>8</td>
<td>40</td>
<td>28</td>
</tr>
<tr>
<td>Brand and Model</td>
<td>Philips LED bulb, 4 W (40 W) E27 cap, white</td>
<td>Philips GENIE 8W WW E27 220-240V 2CT</td>
<td>Philips Standard 40W E27 220-240V A55 CL 1CT</td>
<td>Philips Halogen luster bulb 28 W E27 cap, clear</td>
</tr>
<tr>
<td>Photo</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
</tbody>
</table>

Students will be asked to find out the following properties of each lamp and they need to compare the relative performance of various lamps for making the best consumer choice:

1. Measurement of illuminance (light intensity) from each lamp and estimation of the corresponding relative luminous efficacy (~(light intensity in lux)/(power in watt)) which is an indication on how well a lighting device produces visible light.

2. Variation of light intensity of each lamp during the first few seconds when it is switched on and finding of the corresponding warm-up time (i.e. a period of time for the lamp to reach 90% of its full light output).

3. Heating effect of each lamp, i.e. change in the temperature of air surrounding the lamp.

Students will be guided to work on all 4 lamps one-by-one. Each student is required to complete the experimental activities within 30 minutes and then submit a simple laboratory report.

3.2 Online Experiment for Investigating Landfill Gas Production

Food waste is highly degradable among all solid waste (e.g. municipal waste, construction waste and chemical waste etc.). On one hand, it can easily cause odour and hygiene problems; on the other hand, it has a great potential for generating renewable energy – the Landfill gas utilization. The main objectives of this online experiment are:

a) To monitor the changes (methane level, carbon dioxide level, pH) in the landfill gas production process over a long period of time by an Arduino remote control platform.

b) To help learners get an in-depth understanding of the landfill gas production by comparing the methane, carbon dioxide and pH levels for different inducers.

The materials used for this experiment are summarised in Table 2 and Figure 4 below:
Table 2. Composition of materials in each jar for the experiment

<table>
<thead>
<tr>
<th>Jar Number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of rice</td>
<td>26 g</td>
<td>26 g</td>
<td>26 g</td>
<td>26 g</td>
</tr>
<tr>
<td>Inducer media and amount</td>
<td>Distilled water (300 mL)</td>
<td>Yakult (100 mL) + distilled water (200 mL)</td>
<td>Composter powder (0.15 g) + distilled water (300 mL)</td>
<td>Raw sewage (300 mL)</td>
</tr>
</tbody>
</table>

3.3 Adoption in courses at a teacher education university

Apart from the inventor, several other teachers at a teacher education university have adopted/incorporated one or more of the abovementioned online courseware in their courses as concisely outlined below:

3.3.1 Ecosystems and the Impact of Biotechnology

The participants of the online experiment for this module are 26 year-4 undergraduate students who are major in Science and Information Technology (SWT). They are studying the course “Ecosystem and Impacts of Biotechnology”. Photosynthesis is one of the topics in ecology, so the online experiment was designed to investigate the effect of different color of the light on the rate of photosynthesis. With the prior knowledge of photosynthesis, the online experiment provide students opportunities to apply the skills of scientific investigation in ecological studies. Besides, the learning objectives of this course is to aid students designing appropriate teaching and learning activities to fit with the secondary science curricula, online experiment provides demonstration and insights of how technology could be applied to facilitate student learning which are beneficial for their current and future study/career.

3.3.2 INS3032 Application of Web Technology in Science Education

A total of 22 year-3 undergraduate students who are major in Science and Information Technology (SWT) were involved in this study. The students have developed the understanding of subject knowledge in science and information and communication technology (ICT), but limited opportunities for them to attend the interdisciplinary activities involving the knowledge from both science and ICT.

The online science experiment is one of topics in the course of the Application of Web Technologies in Science Education, which is taught for year-3 students at university. In nature, the understanding of basic structure of online science experiments and the relevant components are well fit to the learning objectives of the course that developing students good awareness of the application of technologies in
science education and developing deep understanding of the interdisciplinary features of the technologies-science education related topics. Moreover, as the representative of STEM education, the online science experiments could better equip students with STEM related knowledge and skills.

3.3.3 Environmental and Community Engagement: Theories and Practices

A total of 30 undergraduate students were involved in this study. They majored in education for sustainability and were studying a course called ‘environment and community engagement: theories and practices’ during the study. The two online experiments: (1) Lighting technology and (2) Landfill gas production were arranged as students’ e-learning tasks. The instructor briefly introduced the online platform and the experiments in the lecture. Then, the students were allowed to login into the platform to conduct the experiments according to their preferences. Students’ diversities can be catered and self-directed learning can be facilitated because of two reasons. Firstly, time and venue were not restricted to university campus. Secondly, multiple attempts were allowed.

During the briefing session, students were attentive and they were interested to the experiments. It was suggested that the daily authentic contexts motivated students to engage in the experiments. The online experiments provided students essential scientific knowledge in achieving sustainability. Furthermore, conducting the online experiments is a kind of public participation. Therefore, the experiments provided students the opportunities for prompting their participation.

3.4 Preliminary results of evaluation

Our specifically developed questionnaire survey tool consists of four sections and the third section is directly related to the evaluation of students’ views and attitudes towards this online experiment and there are seven statements (see Table 3) which can be rated by the respondent with the fixed choices of strongly disagree, disagree, neutral, agree and strongly agree with the corresponding scores of 1 to 5, respectively. The mean and standard deviation (SD) for the respondents attending the two online experiments are reported in Table 3 below. N is the total number of valid questionnaires collected from the respondents of the online experiment concerned.

<table>
<thead>
<tr>
<th>No.</th>
<th>Statement</th>
<th>Lighting technology (N=94)</th>
<th>Landfill gas (N=41)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>1</td>
<td>I can conduct the online experiment activities smoothly as what I expected.</td>
<td>3.47</td>
<td>1.02</td>
</tr>
<tr>
<td>2</td>
<td>The educational objectives and the instructions of the tasks are clear.</td>
<td>3.67</td>
<td>0.95</td>
</tr>
<tr>
<td>3</td>
<td>The flexibility of conducting the online experiments at anytime and anywhere is beneficial to me.</td>
<td>3.84</td>
<td>0.84</td>
</tr>
<tr>
<td>4</td>
<td>Without spending time on the experimental set up, I could focus my time and efforts on conducting more meaningful activities such as collection and analysis of the experimental data</td>
<td>3.71</td>
<td>0.89</td>
</tr>
<tr>
<td>5</td>
<td>It is helpful that the system can plot the graphs for me automatically.</td>
<td>3.98</td>
<td>0.91</td>
</tr>
<tr>
<td>6</td>
<td>The online experiments can deepen my understanding of the science topic concerned.</td>
<td>3.68</td>
<td>0.95</td>
</tr>
<tr>
<td>7</td>
<td>I would like to have online experiments offered in different courses.</td>
<td>3.83</td>
<td>0.97</td>
</tr>
</tbody>
</table>

In general, most respondents showed supportive views and attitudes towards the online experiments and considered them as helpful or beneficial to their learning. Some written feedback from the open-ended questions were reviewed and used as a basis for the refinement and improvement on the design of the online experiments and their related courseware. For detailed analysis and discussion of all the findings, it will be presented in a full journal paper which is still under preparation.
4 CONCLUSIONS

Based on the principle of design-based research, we have applied the new low-cost approach for successfully developed two online experiments and a third one is near completion. They have been adopted for use in some science or environmental studies courses at a teacher education university by four different teachers in physics, chemistry, biology and information technology. Around two hundreds students were involved and we have collected feedback from a total of 135 respondents. Evaluation results are generally positive and we have already made use of some negative feedback or suggestions to refine the design of the experiments concerned.

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REFERENCES


