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Promoting Critical Thinking in a Large Class through Outcomes-Based Approach by Means of an Audience Response System

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One of the first considerations that comes to bear in the design of a new course will inevitably be the learning outcomes. Some of the learning outcomes are specifically related to the subject matter while others may be more broad-based goals like the honing of critical thinking skills. The General Biology course that is offered at the National University of Singapore (NUS) is one such course in which the promotion of critical thinking skills is incrementally weaved into the various learning activities and assessment components of the course. The large enrolment of the course also necessitates taking into consideration the affordances of technology in the outcomes-based design of the course. This paper aims to share how the General Biology course, using the topic of fermentation as an example, could be designed using outcomes-based approach, with learning activities supported by an audience response system, in order to promote critical thinking in a large class setting. As this is a work-in-progress project, some preliminary findings from the feedback of the students of the course are presented here.

Keywords: Outcomes-Based Education; Large Classes; Critical Thinking; Formative Assessment, Technology

Introduction

The General Biology course is a non-majors biology course that serves as a bridging course for those who are majoring in the Life Sciences but do not have a pass in A-Level Biology, as well as an elective course for non-Life Sciences students. Despite being offered every semester, including one of the special terms during the vacation, the enrolment for Semesters 1 typically ranges between 600 to 800 students. Inevitably, the challenge of crafting appropriate and yet logistically-manageable learning activities and assessment components would include the use of appropriate technology with the aim to better engage the learning of the students.

According to Race (2010), the connections between the factors for successful learning may be compared to ripples on a pond, as illustrated in Figure 1. Using the 'Ripples on a Pond' model, which is based on the constructive alignment framework (Biggs, 2003; Biggs & Tang, 2007), the learning activities for each topic of the course were carefully scaffolded through design and development, and aligned with the intended learning outcomes, one of which is the ability to think critically, and to formulate and apply the concepts acquired to new contexts.

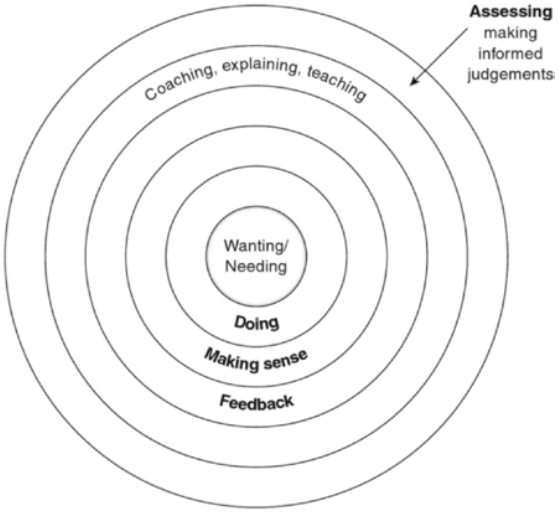

Figure 1: 'Ripples on a Pond' Model of Successful Learning (Race, 2010)

While there are numerous definitions of critical thinking, in recent years, critical thinking has been defined as the development of 'effective reasoning, interpretation, analysis, inference evaluation and the monitoring/adjustment of one's own reasoning processes' (Mummery & Morton-Allen, 2009). According to Hammer & Green (2011), many 'universities and university teachers face increasing pressure to produce graduates who can think critically', and they further indicated that many authors (Jones, 2007; Kirkpatrick & Mulligan, 2002; Paul *et al*., 1997) claim that a substantial number of university teachers 'struggle to conceptualise and teach forms of critical thinking that are relevant for their specific disciplinary, teaching context'.

An in-house audience response system developed by the Centre for Instructional Technology at NUS, known as questionSMS (qSMS), (Shyam & Musthafa, 2010) was used to support one of the learning activities, the in-class quizzes. Essentially, qSMS enables an instructor to receive responses during an in-class session (e.g. lecture or seminar) on a web browser without interrupting the flow of the class. When the service is enabled by the instructor, students will be able to send their responses (questions, feedback or answers) during the in-class session by accessing the Wi-Fi-enabled online system either through various mobile devices (e.g. smartphones, tablets or laptops) or short messaging service (SMS). Students will also have an opportunity to view and to vote for the responses of their classmates. For example, each question posed can be ranked in real-time based on the number of votes received. At the appropriate juncture during the in-class session, the instructor could address selected questions posed by the students. The polling feature can also be used the instructor to design higher-order questions for students to answer. Hence, qSMS serves as a useful tool to facilitate deeper learning.

The following section provides an illustration on how, using the topic of fermentation as an example, the selected learning activities have been designed and scaffolded based on the intended learning outcome of promoting critical thinking, highlighting the use of the polling feature of qSMS in providing responses to good quality questions higher-order thinking through in-lecture quizzes. Besides in-lecture quizzes, other learning activities are also discussed.

Vignette

The intended learning outcomes for the topic of fermentation is that students will be able to describe the process of fermentation in living cells, identify the concepts behind the fermentation process, relate the process and concepts of fermentation with other energy-related biological processes in the cell, and employ the concepts to solve problems in various scenarios and settings. In addition, students should also be able to demonstrate the ability to think critically, formulate and apply the concepts to new contexts. Table 1 provides an overview summary of how the intended learning outcomes for the topic of fermentation were mapped out through the various learning activities. However the focus of this paper is on how critical thinking has been promoted through the design of learning activities which incorporates the use of qSMS for the in-lecture quizzes.

Table 1: Overview Summary of How Intended Learning Outcomes for the Topic of Fermentation Were Mapped Out Through Various Learning Activities

Intended Learning Outcomes At the end of the topic, students will be able to:	**In-Lecture Quizzes***	**In-Lecture Review Questions**	**In-Lecture Demonstration Questions**	**In-Laboratory Discussions**	**Laboratory-Based Assignments***
a) describe the process of fermentation in living cells;	✓		✓	✓	✓
b) identify the concepts behind the fermentation process;	✓		✓	✓	✓
c) relate the process and concepts of fermentation with other energy-related biological processes in the cell;	✓			✓	✓
d) employ the concepts to solve problems in various scenarios and settings;	✓			✓	✓
e) think critically, formulate and apply the concepts to new contexts.	✓	✓	✓	✓	✓

An asterisk (*) indicates that the learning activity involved the use of technology.

In-Lecture Quizzes

Quizzes are administered at appropriate junctures during the lectures using qSMS. The in-lecture quizzes consist of previous years' final examination questions. Since the final examination of the course is an open-book exam, the questions are application-based higher order questions that require several steps of processing before arriving at the correct answer. The following example is one of the questions posed:

> The formation of dental cavities is due to the corrosion of the enamel layer of tooth surfaces by lactic acid. The lactic acid is produced by the bacteria that live as thin layers of sticky bacterial colonies on tooth surfaces known as dental plaques. The production of lactic acid may be best explained by the process of
> A. Aerobic cellular respiration by the bacteria as the enamel layer is rich in glucose from the food consumed.
> B. Alcoholic fermentation by the bacteria as the dental plaques are not very permeable to oxygen diffusion.
> C. Glycolysis by the bacteria as the enamel layer is rich in glucose from the food consumed.
> D. Anaerobic fermentation by the bacteria as the dental plaques are not very permeable to oxygen diffusion.
> E. Hydrolysis by the bacteria as the enamel layer is rich in glucose from the food consumed.

The students were taught that there are two main types of fermentation processes, namely alcoholic fermentation in yeast cells and lactic acid fermentation in muscle cells. They were also told that, unlike aerobic cellular respiration, fermentation does not require oxygen. Since lactic acid is a product, the students were expected to eliminate options A, B, C and E as all the four processes do

not yield lactic acid. Furthermore, the statement that dental plaques are not very amenable to oxygen diffusion should help strengthen the choice of option D as the correct answer.

The students were given about five minutes per question to submit their responses using qSMS, during which they were allowed to refer to their notes, check the internet, and even to discuss with those who were seated next to them. After the time limit, the instructor would disclose the answers. Explanations of how the answers may be derived, similar to the preceding paragraph above, would also be made known to the class (4th ripple of Figure 1).

In addition to helping the students to recall what they have been taught, the quizzes are useful in helping the students to see and learn the processes involved in arriving at the answers, providing them with an opportunity to understand the thinking process of the instructor. Furthermore, as the answers were being explained, the students would also have the opportunity of interacting with the thoughts that they had when they were attempting the question earlier.

In-Lecture Review Questions

While explaining the fermentation process, the instructor had to review concepts that were already taught before. Instead of recapitulating the concepts, the instructor kept asking the class questions at appropriate junctures to help the class recall those concepts. As a result of the large class size, not everyone responds to the questions. However, it is highly probable that many do attempt to answer the questions mentally, if not orally. As such, the in-lecture review questions provide the students with an opportunity to make sense of their learning (3rd ripple of Figure 1) through the practice of answering questions (2nd ripple of Figure 1).

In-Lecture Demonstration Questions

To further reinforce the concepts taught, demonstrations are also held in the course of the lectures. Returning to the topic of fermentation, the instructor conducted a beer-brewing demonstration during the lecture (1st ripple of Figure 1). The instructor would pose questions as he added the various ingredients into the brewing tank, some of which were asked to help the students recall the concepts, while others to help the students to delve deeper into the topic. For example, the students were asked to predict what would happen if the lid of the tank was not properly closed. An answer directly related to the topic would be that the fermentation process might not occur since fermentation occurs in the absence of oxygen. However, the instructor would probe the students further to get them to come to the conclusion that there might also be a possibility of other microorganisms contaminating the brewing broth, resulting in other products.

In-Laboratory Discussions

Besides lectures, the learning activities of the course include laboratory-based practical sessions, in which the students deepen their learning by doing (2nd ripple of Figure 1). For the topic of fermentation, students were organised into groups of four and given the task of preparing the Korean pickled vegetable, kimchi (1st ripple of Figure 1). Besides the instructor, the students were also guided by well-trained teaching assistants, who would also use discussion questions (5th ripple of Figure 1) to help the students to relate what they were doing with what they had learned during the lecture.

Laboratory-Based Assignments

Additionally, the students are required to complete a graded assignment of 4 to 5 short-answer questions (2nd ripple of Figure 1) that are related to the topic of the practical after every laboratory session. The questions of the assignments serve to further develop the thinking skills of the students. For every question that a student had been unsuccessful in obtaining full marks, personalised feedback would be provided using the Gradebook tool of the in-house Learning Management System of NUS (4th ripple of Figure 1).

Methodology and Preliminary Findings

As bring-your-own-device (BYOD) open-book examinations were incorporated for the course, pre-

and post-exam online surveys were administered to solicit the perceptions of the students of for the course. One of the questions of the post-exam online survey was on whether students had found that the examination questions had helped them to either think deeper or provoke their thinking about the course. The questions of the survey were piloted with a few individuals and further fine-tuned before being administered to the students.

Further to the survey, focus group discussion (FGD) sessions were held approximately 4 months after the BYOD exam. Open invitations were sent out to all the students for the FGD sessions, and a total of 4 sessions were held. To ensure that the students did not feel hindered in voicing their opinions, none of the instructors of the course were present during the FGD sessions. The instructor of the sessions led the participants in more elaborate discussions of the questions posed for the pre- and post-exam surveys. One of the questions asked during FGD session was how the course had helped them to think deeper and had provoked critical thinking.

The responses of the online surveys and FGD sessions were collated and analysed, using the spreadsheet software, Microsoft Excel, and the text mining software, IBM SPSS Text Analytics.

The results of the survey that was administered to the students of the Semester 1 2013 cohort found that 87.7% of the respondents (n=406) either agree or strongly agree, out of a 4-point Likert scale, that the course examination questions had helped them to think deeper and provoked critical thinking. The FGD question on how the course had helped them to think deeper and how the course had provoked critical thinking yielded the following key findings:

Alignment of Learning Activities for Each Topic throughout the Course

One of the feedback received from participants indicated that they appreciated that the lectures, laboratory sessions and examination questions were all interconnected for each of the topics. This implies that participants could relate the relevance of the various learning activities, including in-lecture quizzes, planned for the various modes of delivery for each of the topics.

Questions Scaffolded Throughout the Course

Many participants had in their feedback mentioned that they value the kinds of questions posed during face-to-face sessions, such as the laboratory sessions. Some commented that the kinds of questions posed by teaching assistants during laboratory sessions allowed them to think critically and helped to scaffold their learning.

Demonstrations during Lectures

Participants also appreciated the demonstrations presented during the lectures. For instance, real-life specimens such as transgenic fishes that fluoresced, plants and animal heart were brought to the lecture, and the participants also commented that the way lecturers presented the specimens with guiding questions engaged them at a deeper level.

Bring-Your-Own-Laptop Examination

Many participants also commented that the application-based multiple-choice questions that were posed for the BYOD final examination had triggered their critical thinking skills. One respondent commented, “I really liked how the questions tests us on our understanding of various biology concepts instead of questions just fully based on memory work”. Some had also given the feedback that media-rich comprehension-based MCQs helped them to appreciate the relevance of some biology concepts learnt in real-life application. One such example that was cited was the use of a news clip about the personal genomics company, 23andMe, for several of the final examination questions.

Limitation of the study

It is noted that in this work-in-progress preliminary study, there is less clear indication that qSMS has impacted students’ learning during in-class sessions. Similarly, more explicit questions could be posed during FGD. For the next round of study on this course, more questions focusing on students’

perception on the use of qSMS during in-class sessions will be incorporated into the survey and FGD sessions.

Students' level of critical thinking before and after attending the course could also be measured in a systematic manner. This could carried out by administering the Cornell Critical Thinking Test Level Z (CCTT-Z), which has been described as a reliable and valid instrument in measuring critical thinking skills (Ennis *et al*., 2005).

Next Step

This preliminary study has provided an insight of how an outcomes-based course design (Race, 2010) to promote critical thinking has impacted learners, which is timely as literature has suggested the need to articulate the conceptualisation of critical thinking that is both discipline- and course-specific (Hammer & Green, 2011). Furthermore, Hammer & Green (2011) have also reported that studies on designing appropriate learning experiences to develop students' critical thinking are still at an experimental phase. It is therefore proposed that a more in-depth evaluation study on the impact of such outcomes-based course design on students' critical thinking skills be carried out. Considering that the course is being re-designed into a blended online course, studies on how critical thinking skills can be scaffolded, based Krathwohl's recent revision (2002) of Bloom's Taxonomy as one possible example, for such a blended online learning mode could be conducted.

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