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Catering to Engineering students: A flipped classroom case study

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Recommended citation:

Corrias, A. (2015) Catering to Engineering students: A flipped classroom case study.

Asian Journal of the Scholarship of Teaching and Learning, 5(3), 150-163.

<https://doi.org/10.24112/ajsotl.53322>

Catering to Engineering students: A flipped classroom case study

ABSTRACT

We present the design and implementation of a blended learning environment where concepts belonging to the flipped classroom paradigm are applied to a relatively large engineering class. Various technologies are employed with the objective of improving the learning experience of mathematics-intensive topics in the engineering curriculum.

One of the key ideas of this case study is to confine the most mathematical and theoretical aspects of the subject matter in prerecorded video lectures. Students are asked to watch the video lectures before coming to class. Since the classroom session does not need to cover the mathematical theory, the time is spent on a selected real world scenario that exposes the students to an actual application of the theory. The weekly cycle is concluded with a hands-on tutorial session in the computer rooms.

A potential problem would arise in such environment if the students do not follow the recommendation of watching the video lecture before coming to class. In an attempt to limit these occurrences, two key instruments were put in place: a set of online self-assessment questions that students are asked to take before the classroom session and a simple rewards system. Thanks to modern learning analytics tools, we were able to show that, on average, 57.9% of students followed the recommendation of watching the video lecture before class.

The efficacy of the learning environment was assessed through various means. Students' opinions were asked in a specific survey and in a focus group discussion. The gathered data support the view that the learning environment was well received by the students. Attempts were made to quantify the impacts on learning of the proposed measures by taking into account the results of selected questions of the final examination of the course. Although the presence of confounding factors demands caution in the interpretation, these data seem to indicate a possible positive effect of the technologically-enhanced environment on learning.

INTRODUCTION

The setting of this case study is a core undergraduate course in the engineering curriculum. The topic of the course lies in the field of data analysis and the class size is close to one hundred students. Like many other engineering courses, the various topics

covered involve the application of a relatively large body of mathematical/statistical theory to practical applications.

Being reasonably well versed with both theory and its applications is well within the scope of the specific learning objectives of the course. Nevertheless, teaching the theoretical part has always been more challenging compared to any practical application, especially if it involves mathematics (Yuen, 2014). Students typically find theory to be boring, dry and uninspiring. The result is a poor uptake of the subject and agonizingly dull classroom sessions.

Here, we present the design and implementation of a learning environment that makes use of several information technology tools. The objectives of this case study are to:

1. improve students' learning of critical aspects of data analysis, especially the most theoretical and mathematical parts; and
2. make the classroom session more lively and engaging.

THEORETICAL FRAMEWORK

In this section, we briefly introduce the two major and well established educational paradigms that influenced the design of the learning environment used in this case study.

The first is the use of technology to create a blended learning environment (Garrison & Vaughan, 2011). Drawing from the existing flipped classroom paradigm (Bergmann and Sams, 2012), we focus our attention on the use of 21st century information technology to meet the wide variety of learning styles existing among students as well as to try to increase the interaction between students and faculty and among students themselves (Spiliotopoulos, 2011).

The second is the authentic learning paradigm. The underlying idea of an authentic learning environment is based on the notion that learning may improve when conducted in an environment designed to be as close as possible to the real environment where the subject matter will be used. The successful implementation of this deceptively simple idea has been reported in various disciplines including history (Glendinning, 2005), economics (Perry & Reynoldson, 2006), literature (Fitzsimmons, 2006) and biology (Koenders & Cowan, 2006). Herrington & Herrington (2006) articulated a working definition of an authentic learning environment by specifying a list of nine elements of authentic learning. In this case study, we have focused on four of those nine elements, with specific attempts at *“providing an authentic context that reflect the way the knowledge will be used in real life”*, *“providing authentic tasks and activities”*, *“promoting articulation to enable tacit knowledge to be made explicit”* and *“providing coaching and scaffolding by the teacher at critical times”*.

DESIGN AND IMPLEMENTATION OF THE LEARNING ENVIRONMENT

Figure 1 shows a schematic comparison between the learning environment that was designed and implemented in this case study and a traditional framework typically employed in engineering courses. The syllabus of the course is first divided into a series of topics. Typically, one week is dedicated to the teaching of each topic.

The traditional way of structuring the learning environment for such core engineering subjects is to divide the contact sessions with the students into two stages: first, the theory is explained, and this is followed by a series of simple examples that illustrate how the theory is applied. Often these two stages are defined as lectures and tutorials, respectively. Although this approach is reasonable and has its merits, it also has several drawbacks. First and foremost, explaining the theoretical part takes a significant amount of class time. This results in very limited time remaining to devote to illustrative examples. In fact, in many engineering courses, the total time spent in tutorials is half of the total time spent in lectures. Moreover, the time constraints also force the illustrative examples in the tutorials to be small, clearly defined problems that have the sole aim of making the students understand the otherwise obscure theoretical formulas.

In this case study, we implemented a technologically-enhanced learning environment. For each topic, the key idea was to record a video lecture of approximately 15 minutes duration containing theoretical and mathematical aspects. This type of content is perceived by students as the most difficult and uninspiring (Yuen, 2014). It is important to point out that the simplistic solution of eliminating such content from the syllabus is not viable, at least in this case study. The reason is that mathematical theory constitutes the foundation of engineering education and eliminating it would simply worsen the quality of the education and diminish the skillsets of the graduates (Bird, 2013). Moreover, many professional engineering accreditation bodies require mathematics foundations as part of their accreditation requirements.

In terms of students' learning, the critical advantage of confining the mathematical theory to a prerecorded video lecture is that of providing the possibility of a personalized learning experience. This is mainly due to two reasons. First, the student may pause, rewind and relisten to the parts that he/she finds hardest and most complicated. Second, students may choose the time of the day to watch the video lecture: this is particularly important as it eliminates the problem present in traditional classroom settings when some students may already be tired at the start of the class after having attended many other classes on the same day.

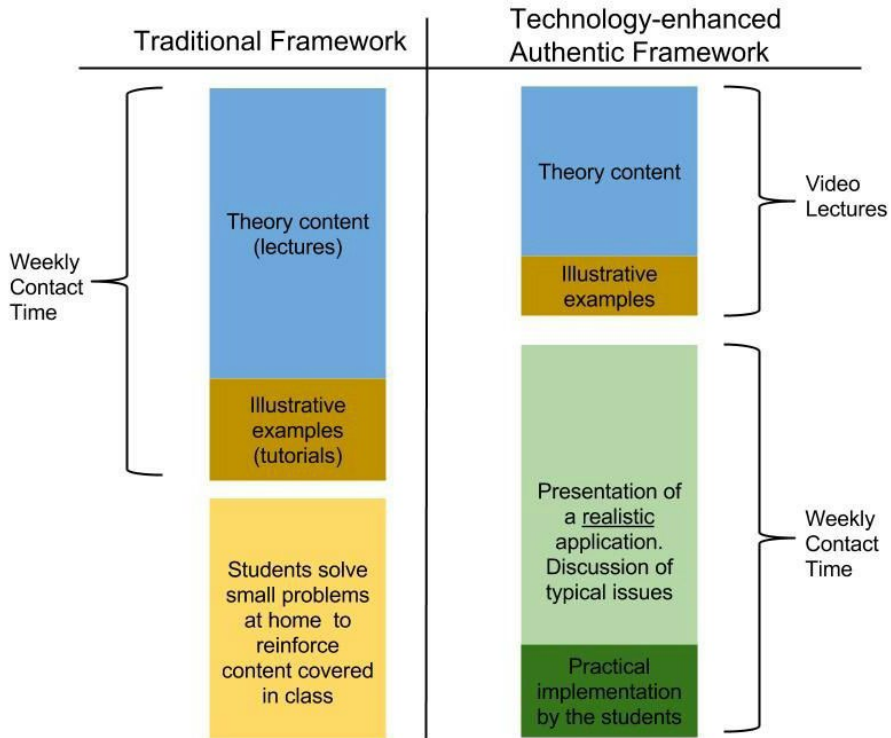


Figure 1: Schematic view of the technology enhanced authentic learning environment used in this case study compared to a traditional environment typically employed in engineering in tertiary education. The figure shows a weekly cycle of the learning environment. The weekly contact time with the students is the same in the two frameworks.

In terms of design of the learning environment, the critical advantage of confining the mathematical theory to a pre-recorded video lecture is that it changes the way the weekly classroom contact session is managed. For this case study, the theoretical content that underpins the data analysis application was not covered in the contact session in class because it was already covered in the pre-recorded video lecture. Instead, the contact session started with the presentation of a specific and realistic application. The video lecture was uploaded and made accessible to the students via a learning management system, known locally as the Integrated Virtual Learning Environment (IVLE) one week before the classroom session. Students were asked to watch the video lecture before coming to class.

It may be useful to provide an example of this shift towards a realistic application-oriented classroom session. One of the topics that was covered in the course was linear regression: a very commonly used data analysis tool. The mathematical formulas

underpinning the use of linear regression were explained in a pre-recorded video lecture. This included the derivation of formulas and the necessary mathematical proofs. The classroom session was prepared around one specific application. In this example, linear regression was used in studying certain mechanics related to knee injuries in ski jumping. Instead of beginning the classroom session with “today we talk about linear regression”, the idea was to start the session with “today we talk about ski jumping”. The first part of the lecture was dedicated to simply setting the context: videos and details of ski jumping were presented; students were told to imagine themselves in a laboratory where they were tasked to analyze some data coming from measurements on ski jumpers. As the details of this particular problem of ski jumpers were explained, students were brought to realize how this specific study on ski jumpers had broader implications to better understand knee injuries. They also realized, most importantly, that in order to complete the original task brought about by ski jumping, linear regression had to be used. At this point, the steps of linear regression were performed on a data set that was realistic for the application of knee injuries to ski jumpers. As we went through the steps, the theory aspects that were contained in the video lecture were mentioned again as they were being applied to the specific case. This framework allowed for more time in class to be spent on the details of the practical implementation, its pitfalls and common mistakes.

The example that was just provided also illustrates the shift towards “*an authentic context that reflects the way the knowledge will be used in real life*” and “*providing authentic tasks and activities*” - two of the key elements of an effective authentic learning environment (Herrington & Herrington, 2006).

One of the critical issues for the success and effectiveness of the classroom session in this particular learning environment was that students had to watch the video lectures every week before coming to class and have at least some basic understanding of the underlying theory topics. Failing that, the application that was discussed in class could have been hard to understand. To encourage students to come to class prepared, i.e., after having watched the video lecture, two specific measures were implemented:

Online formative quiz: An online self-assessment questionnaire was made available together with the video lectures. This typically consisted of a set of 10 questions: either multiple choice or multiple response questions. The students were encouraged to try to answer the questions after watching the video lecture. The questions specifically ask about the theory that was covered in the video lecture. After taking the quiz, students were shown the correct answer as well as a detailed explanation of the rationale of the answer. The self-assessment questionnaire was not graded and was intended as a measure for scaffolding the learning process. Multiple attempts were allowed.

Rewards system: Throughout the classroom session, the teacher asked the class questions. Students who had watched the video lecture should have been able to answer easily. The first student to answer the question was rewarded with a small prize, typically a small chocolate. This practice had the double objective of making classroom

sessions more lively and encouraging students to watch the video lecture before coming to class. Interestingly, this practice also had the effect of “promoting articulation to enable tacit knowledge to be made explicit” a key element of an effective authentic learning environment (Herrington & Herrington, 2006), as mentioned earlier.

The weekly cycle described in Figure 1 finished with a tutorial session, conducted with a smaller group of students in computer rooms. The objective was to let the students have a hands-on experience on the topic of the week. The topic of the course (data analysis) lent itself very well to the use of specific software in computer rooms.

The tutorial assignment was made available several days prior to the session. During the session, the lecturer did not solve the whole problem. Instead, at predetermined points, the students were given 10-15 minutes to continue trying a solution by themselves, before the lecturer eventually showed them the solution. The small size of the tutorial session allowed for the provision of “coaching and scaffolding by the teacher at critical times”, another key element of an effective authentic learning environment (Herrington & Herrington, 2006), as mentioned earlier.

The weekly cycle described in Figure 1 was implemented for 5 consecutive weeks. The number of students in the class was 97.

RESULTS

We have tried to gather as much data as possible to verify whether the objectives of the case study were achieved or not. We conducted a survey and a focus group discussion to gather students’ opinion on the learning experience. Furthermore, we tried to leverage on the emerging field of learning analytics (Johnson et al, 2013) to gain better insights on students’ reactions to the learning environment as well as to try to quantify any impact on learning.

Survey

We conducted a specific survey to assess whether the objectives of the case study were achieved from the students’ perspective. The survey was conducted at the end of the last lecture of the course. The following statements were presented to the students

- I found the video lectures useful
- The presence of video lectures was an improvement compared to a traditional lecture + tutorial format without any video lecture
- I found the self-assessment questions on IVLE useful
- The self-assessment questions on IVLE helped me identify areas and topics

of the course that I had not fully understood

- The rewards system (chocolate bars) made the lecture time more enjoyable
- The rewards system (chocolate bars) helped me thinking about the topics being covered during class

Answers were gathered on a 5-point scale, from “strongly disagree” to “strongly agree” (Figure 2). Seventy students responded to the survey (73% of the class). Regarding the video lectures, students found them “useful” (92% agree or strongly agree) and an improvement compared to a traditional framework (91%). A smaller percentage of students (78%) found the online self-assessment quiz useful and 81% of them agreed or strongly agreed that the online self-assessment questions helped them identify topics that they had not fully understood. Finally, 88% of students found the rewards system enjoyable and 73% of them agreed or strongly agreed that the rewards system helped them stay focused in class (Figure 2).

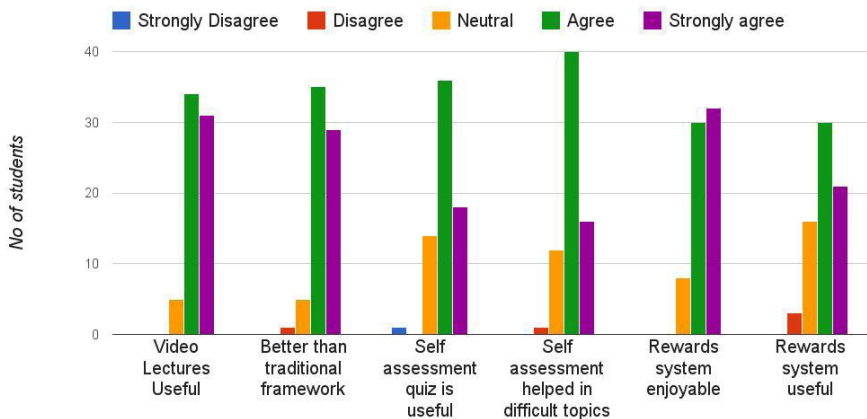


Figure 2: Survey results regarding the video lectures (first and second from left), the online self-assessment questions (third and fourth from left) and the rewards system (fifth and sixth from left).

Focus Group Discussion

Five (5) students were randomly selected for a focus group discussion. The objective of the discussion was to substantiate the results of the survey and gather more feedback and ideas from the students. It was conducted about six weeks after the end of the term. The discussion started with the video lectures themselves. Four out of five students had watched all the video lectures (one student missed a couple). They all agreed that the ability to rewind and relisten was critical to their learning and most appreciated that because in a normal classroom, at some point “my mind goes somewhere and I miss what the lecturer says”. The length of the video was deemed appropriate by all students. Two students watched the video before the actual lecture

throughout the course (as recommended). Two other students said that sometimes they would watch the video lecture before class, as suggested, but sometimes they would watch it only after the class, for example before the final exam.

The second topic of the discussion was the classroom session. All students agreed that the presence of video lectures was not a factor in their decision whether to attend the classroom session or not. They all attended the classroom sessions. They agreed that the focus on the application side of the problem made possible by the presence of the video lectures was useful. They all enjoyed the rewards system (chocolate bars) and explicitly encouraged me to maintain it next year. They suggested limiting the number of answers each particular student is allowed to give.

Taken collectively, the results from the survey and the focus group discussion seem to indicate that, from a student perspective, the objectives of the case study were achieved. Nevertheless, we decided to investigate further in order to determine a more objective measure of achievement.

Attempts at measuring impacts on learning through learning analytics

Thanks to the available instructional facilities, we were able to monitor how many students followed the recommendation of watching the video lectures before coming to class and how many of them took the online quiz before the actual classroom session. We found that the percentage of students who watched the video lecture at least once before coming to class oscillated between 40% and 74% (with an average of 57.92%) depending on the lecture. However, if we count the students who watched the video lecture at least once at any point in time, the percentage (average of all lectures) goes up to 79% indicating that a sizable portion of students probably only watched the video in preparation for the final exam. Only 6 students did not watch any video lecture; while we do not know for sure why these six students did not watch the video lectures, we have noted their generally lower than average performance in the course compared to the other students. On average, 72% of students attempted the self-assessment online quizzes. However, only a very low 3.7% took it before the classroom sessions as recommended. These numbers indicate that the survey results in Figure 2 paint a picture that is probably more optimistic than reality.

We then tried to assess whether watching the video lectures translated into improved learning of certain topics (objective number 1 of this case study). Finding a measure for this was difficult. In the absence of suitable alternatives, we chose to look at the summative assessment of the course: three questions of the final examination paper were selected as representative of three topics (marked as Q6, Q7 and Q8 in Figure 3 and Figure 4). Q6 was a question directly related to finding a regression straight line (as discussed in the authentic example of ski jumping) while Q7 and Q8 were testing the understanding of certain aspects of nonlinear regression.

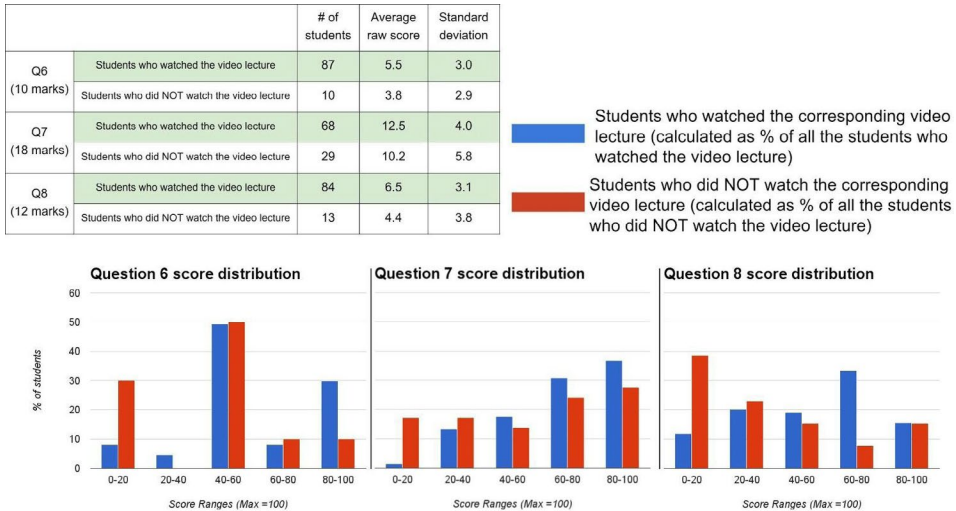


Figure 3: Three exam questions (Q6, Q7 and Q8 on the left axis) were chosen as performance indicators. Each of these questions had an associated video lecture. The table shows the number and performance of the students who watched the video lecture versus the students who did not for each of the three selected questions. The bar charts show the score distribution (scores normalized to 0100 scale) for each question.

These three topics were covered in three separate video lectures. For each, we looked at the performance of students who watched the corresponding video lecture versus the performance of those who did not. We found that in all three questions the average score of the students who watched the corresponding video lecture was higher than the score of the students who did not (Figure 3). However, the statistical significance of these differences is hard to establish. One could adopt an analysis of variance approach to test the statistical significance of the difference in scores between students who watched the video lectures and students who did not: in this case, such analysis would yield p-values of 0.09, 0.032 and 0.028 for Q6, Q7 and Q8 respectively. However, these values are hard to interpret because the samples that are being compared were not randomly chosen, thus violating an important assumption of any analysis of variance.

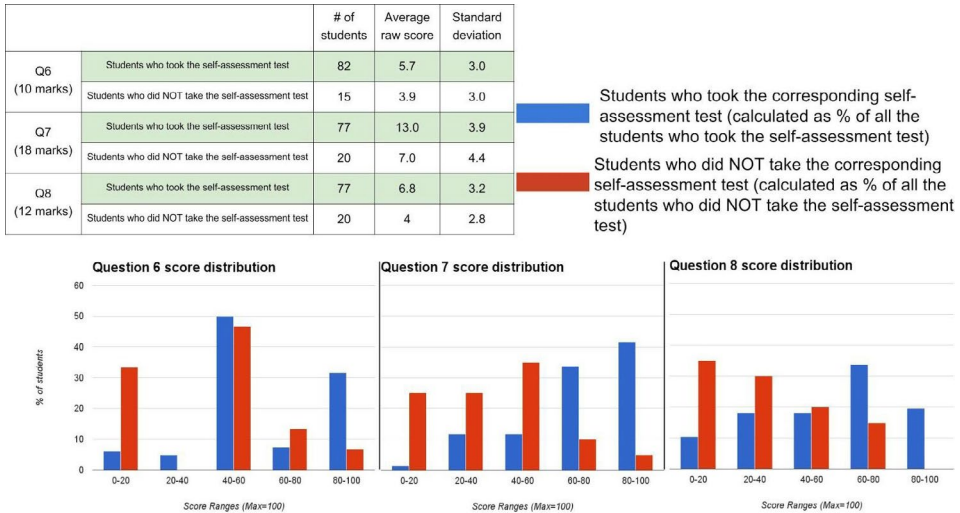


Figure 4: Three exam questions (Q6, Q7 and Q8 on the left axis) were chosen as performance indicators. Each of these questions has an associated self-assessment test. The table shows the number and performance of the students who took the self-assessment test versus the students who did not for each of the three selected questions. The bar charts show the score distribution (scores normalized to 0100 scale) for each question.

Similarly, we tried to assess whether the self-assessment tests translated into improved learning of certain topics. Once again, we relied on the assessment of the course as a measure for impact on learning. We used the same three questions (Q6, Q7 and Q8) as representative of three topics. Each of these topics has a separate set of self-assessment questions. For each, we looked at the performance of students who took the corresponding self-assessment tests versus the performance of those who did not. We found that in all three questions the average score of the students who took the corresponding self-assessment test was higher than the score of the students who did not (Figure 4). Once again, the statistical significance of these differences is hard to establish. One could adopt an analysis of variance approach to test the statistical significance of the difference in scores between students who took the selfassessment test and those who did not: in this case, such analysis would yield pvalues of 0.01, <1e-7 and <1e-3 for Q6, Q7 and Q8 respectively. However, as mentioned above, these values are hard to interpret because of the lack of randomization of the samples of students being compared.

CONCLUSION AND FUTURE DIRECTIONS

We have presented the design and implementation of a technologically-enhanced learning environment that tried to improve the learning of topics with high mathematical content and make the classroom sessions more lively and engaging. Elements

of well-established paradigms such as that of blended learning and that of authentic learning were combined in this case study.

In general, we found that the new technologically-enhanced learning environment was well received by the students. In particular, students appreciated the possibility of tackling the most difficult mathematical topics at their own pace by watching a pre-recorded video lecture. Students also appreciated the fact that the contact session was focused on a realistic application (Figure 2). Interestingly, these aspects of the learning environment that have been most appreciated by the students are quite independent from the topic of the course, suggesting a potential broader application of the learning environment described here.

Nevertheless, several issues still need to be properly addressed. First and foremost, the success of the learning environment presented here hinges on the students' compliance to the learning environment. In particular, the fact that students had to watch the video lecture before coming to class with a basic understanding of the theory is of paramount importance. We put in place two instruments to try to ensure this: a weekly set of self-assessment questions and a classroom rewards system. These two instruments only worked partially. On average, only about half of the class followed the recommendation of watching the video lecture before coming to class. Moreover, the vast majority of students used the set of self-assessment questions as exam preparation: they took the tests all in one go in the days right before the final exam. As a consequence, the intended aim as a weekly check of understanding of the topic was not properly achieved. Moving forward, one possibility would be to give the timely (weekly) completion of the self-assessment questions before coming to class a small weight in the computation of the final grade for the module: it is hoped that such a measure would encourage more students to come to class more prepared.

Another set of issues that needs to be addressed is related to the measurement of the impact of the proposed technologically-enhanced learning environment on learning. Our chosen indicator of exam performance showed encouraging results (Figure 3 and 4): students who watched the video lectures and took self-assessment questions performed slightly better in the final exam. As mentioned above, the groups of students who watched the video lectures and took the self-assessment tests were not chosen randomly. This is likely to introduce one or more confounding factors that make the statistical interpretation of the results in Figure 3 and 4 very difficult. The most obvious confounding factor is that watching the video lectures and taking the self-assessment questions was explicitly recommended by the lecturer: diligent students are the most likely group of students to have followed this advice because diligent students are the ones who tend to follow the recommendations of the lecturer. However, diligent students also tend to perform better in the exam, regardless of the nature, quality and defects of the learning environment. Therefore, any conclusion based on the results shown in Figure 3 and 4 must be drawn with caution. To address this issue, one possible solution would be to include a pre-selected and randomized control group of students: this group would be exposed to a traditional learning environment and their

performance would be compared to the performance of another group of students exposed to the proposed new learning environment. This proposed solution, however, could be seen as ethically suspect because of the potentially unfair access to learning resources by the different groups of students.

Acknowledgements

This work was generously supported by a Teaching Enhancement Grant (TEG) awarded by the Center for Development of Teaching and Learning (CDTL) of the National University of Singapore.

The author would like to express his gratitude to Dr Adrian Michael Lee and Mr Soong Swee Kit, Alan for valuable constructive advice and encouragement.

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