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The Online Tutorial Room (OTR): Improving the Sampling Frequency of the Engineering Knowledge Signal!

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1. Introduction

Motivating engineering students to practice problem-solving has always been on the minds of engineering educators across the globe. Active Learning [1], Problem-Based Learning [2], and the Flipped Classroom [3], among other methodologies, are educational techniques designed to improve learning retention through the continuous improvement of problem-solving skills. In the following, the process of conducting a problem-solving activity for engineering students is termed *assessment*, whereas the process of evaluating the performance of engineering students on an assessment is termed *evaluation*.

The relationship between assessments and learning has been widely addressed (e.g. [4] and [5]), and not only has the type of assessment been linked to the level of learning retention, but also the assessment frequency [6].

Along the same lines, introductory engineering textbooks implicitly emphasize the importance of the frequency of problem-solving by advising engineering students to devote "at least 2 to 3 hours of studying for each hour of class time" [7], and research on learning retention underscores the notion that, "practice by doing" increases the level of long-term learning retention to about 75%, as opposed to just 5% for attending a lecture [8]).

In a recent theoretical study based on signals and systems theory [9], the engineering assessment process was modeled as an ideal sampling process and the frequency spectrum of the so-called engineering knowledge signal was used along with the Nyquist-Shannon theorem to deduce that the sampling frequency (i.e. assessment frequency) needs to be larger than a certain bound (or limit – termed the Nyquist Frequency), below which the reconstruction of the continuous signal from the sampled signal (a process involved in the evaluation of the acquired engineering knowledge signal) may well be affected by aliasing errors [10].

One of the simplest manifestations of "aliasing" is the phenomenon that takes place upon watching on TV the turning wheels of a speeding car. Under certain conditions, the observer may perceive that the car wheels are turning in one direction, whereas in reality they would be turning in the opposite direction. This phenomenon can be attributed to the insufficient sampling frequency of the camera shutters [9], and implies that, in engineering knowledge assessment, aliasing may lead to a significant difference between perceived and actual knowledge acquisition (i.e. learning).

To avoid aliasing, the Nyquist-Shannon theorem states that at least two samples (i.e. two assessments) are necessary in the smallest period of the knowledge signal [9].On the other hand, a 2013 engineering education survey revealed that one "average period" of the engineering knowledge signal is approximately 1.9 weeks [10]. This means that one necessary condition to avoid aliasing is to conduct at least two assessments every about one fortnight.

With the above observations in mind, the Online Tutorial Room (OTR) was built for the main purpose of increasing the frequency of genuine assessments (so as to maintain a minimum limit of about two assessments per fortnight) in order to improve the accuracy of learning evaluation, in addition to the level of learning retention, without significantly affecting the students' or the instructor's time resources or the engineering institution's financial resources.

In fact, the OTR could be perceived as a platform for the application of active learning through the use of modern-day technology. As will be shown, the OTR is not restricted in time or in space, and thus it offers the student a better chance of improving his/her academic engagement. On the other hand, and after the initial inception phase, the OTR will typically be run by students for students. Consequently, it will offer the instructor a wider margin of freedom along with a clearer conscience, knowing that his/her students are being properly assessed as frequently as possible.

In the next section, the main elements and tools of the OTR are outlined. In Section 3, the activation of the OTR is described along with its regulations. Its deployment in the years 2014 and 2015 is described in Section 4 along with some of its early results, followed by a discussion of its strengths and weaknesses in Section 5. The last section is a brief summary of the overall project.

2. OTR Elements and Tools

The OTR was conceived as an online, student-run, low-stakes, problem-solving platform supporting an Active Learning Policy that prescribes a number of classroom quizzes distributed throughout the semester for the purpose of improving learning continuity. The OTR offers the student the opportunity of gaining bonus points that are added to the average of the grades obtained on the classroom quizzes to form the so called Active learning Performance (ALP) grade. The ALP grade constitutes a fraction (typically one fifth to one fourth) of the overall course grade that includes, in addition to the ALP grade, the grades of a number of high-stakes assessments.

2.1. Student Teams and Moderators

One major element of the OTR is teamwork. At the beginning of the semester, students are asked to form 3-to-4-member teams, and collaborate with their teammates to improve their problem-solving skills while competing with other teams to obtain the highest ALP grade in the class. The work of the student teams is governed by the Active Learning Policy, distributed to students at the beginning of the semester. This policy includes the rights and responsibilities of the students as well as the rules and regulations of the OTR (Section 3).

Another important element of the OTR is student moderation. Periodically, the top three students with the highest ALP grades in the class are offered the opportunity to volunteer as OTR Moderators. In this role, moderators are given the privilege of moderating the problem-solving process and evaluating the problem solutions after an appropriate training session, based on a document entitled Moderators' Guidelines, which describes in detail the moderators' rights and responsibilities, including the conditions under which bonus point rewards are offered to the moderators in return for performing their tasks. The three moderators are given the liberty to either compete for or agree among each other's on the moderation and evaluation tasks. In this regard, the evaluation of the problem-solving process is governed by strict guidelines, as outlined in Section 2.3. In addition, since the OTR moderators are also team members, a number of measures are put in place to avoid conflicts of interest and the possibility of receiving unfair advantage.

2.2 Course Segments and Focus Problems

In parallel with the selection of student teams and the appointment of OTR moderators, the course material is partitioned into Forums (i.e. chapters) and Segments (i.e. sections, subsections or topics), with one Focus Problem associated with each segment. To each of these forums or segments a corresponding space (sometimes called thread) is created in the discussion board of the Learning Management System under which the OTR is operating (e.g. Blackboard Learn™ [11]). The list of course forums and segments as well as their corresponding focus problems is communicated to the students at the beginning of the semester.

2.3. Performance Evaluation Process

Since the OTR problem-solving process is moderated by students for students, and only monitored by the instructor, it was necessary to establish a strict performance evaluation (or rating) process based on competence, rigor and transparency. The first step towards this objective is achieved by requiring from the concerned moderator to send his/her own focus problem solution to the instructor and not initiate the evaluation/rating process before receiving the corresponding instructor's comments. In this fashion, a high standard of the focus problem solution is ensured, with minimum time investment on the part of the instructor. Subsequently, the moderator can carry out the solution evaluation process, under the watchful eyes of the instructor, based on a fairly rigorous performance evaluation rubric (Figure 1). The results of this process are summarized in a so-called Focus Problem Rating Table and posted by the moderator on the OTR (Figure 2).

The rubric is based on four performance criteria: 1) correctness, rigor, and completeness (with a 50% weight), 2) justification and critical thinking (weighted at 20%), presentation (weighted at 20%), and timing (weighted at 10%). The various levels of each performance criteria (ranging from 1 (unsatisfactory) to 4 (exemplary) are well defined to a point that leaves little room for

Level / Criterion	Unsatisfactory 1	Developing 2	Satisfactory 3	Exemplary 4
1 Correctness, Rigor, and Completeness (weight = 50%)	Most of the presented solution is wrong or uses the wrong approach(es), technique(s), and method(s) and/or the presented solution is missing most parts or sections of the focus problem.	A significant part of the presented solution is wrong an/or uses the wrong approach(es), technique(s), and method(s), and/or the presented solution is missing numerous parts or sections of the focus problem.	The presented solution is mostly correct and generally uses the right approach(es), technique(s), and method(s), and/or answers most required parts or questions of the focus problem using proper units and symbols (e.g. phasor symbols.	The presented solution is correct, uses the right approach(es), technique(s), and method(s), and thoroughly answers all required parts or questions of the focus problem in a rigorous fashion, including units and symbols (e.g. phasor symbols).
2 Justification, Interpretation, and Discussion /Critical Thinking (weight = 20%)	The solution is solely composed of equations and or sketches. No or little justifications are made for the strategies, techniques, methods and approaches used. No discussion(s) and/or interpretations are given in the solution. No critical assessment of the results is conducted.	A significant part of the strategies, techniques, methods, equations, formulae and/or sketches used in the presented solution are not properly justified. Insufficient interpretations and/or discussions are given in the solution. Insufficient critical assessment of the results is conducted.	Most strategies, techniques, methods, equations, formulae and/or sketches used in the presented solution are properly justified. Most critical points are addressed and/or most results properly interpreted. Most pertinent ideas and important concepts are critically assessed.	The strategies, techniques, methods, equations, formulae and/or sketches used in the presented solution are all properly justified. Critical points are discussed and/or important results properly interpreted. Thought provoking ideas and concepts are raised and/or interesting notions are inter/extrapolated.
3 Presentation (weight = 20%)	The solution is mainly presented in a careless fashion. It lacks clarity and organization; no or few illustrations are presented; and no or little attention is given to the separation of various parts of the solution.	The presentation, organization, and clarity of the presented solution need significant improvement. Insufficient attention is given to the illustrations, and to the separation of various parts of the solution.	The solution is mainly well presented, clear and well organized. Generally, no writings are present in the margins, illustrations are carefully built and different parts of the solution are separated from each other's.	The solution is typed or written in a very clear, organized, and reader-friendly fashion. No writings are present in the margins, and a number of tools are used to add clarity, improve the presentation and highlight the main points and results (ruler, colors, etc). Illustrations are carefully built and different parts of the solution are clearly separated from each other's.
4 Timing (weight = 10%)	The solution is posted between the twelfth and the fourteenth day after the initial, in-class examination of the corresponding focus problem.	The solution is posted between the eighth and the eleventh day after the initial, in class examination of the corresponding focus problem.	The solution is posted between the fourth and the seventh day after the initial, in-class examination of the corresponding focus problem.	The solution is posted within the first three days after the initial, in-class examination of the corresponding focus problem.

Performance Criteria	
1-	**Be able to solve the focus problem correctly, rigorously and thoroughly, using the right strategies, techniques and methods**
2-	**Be able to justify the problem solving strategies, techniques, methods, and equations used in solving the focus problem, critically discuss important points, logically interpret the results obtained, and suggest alternative or novel ideas**
3-	**Be able to present a clear, highly organized, and reader-friendly solution, including small details and pertinent illustrations**
4-	**Be able to meet deadlines, work under pressure, and submit the required work within a specific timeline.**

Figure 1 - The OTR Rubric.

Forum	Chapter 5	
Segment	5.15	
Focus Problem No.	Pb. 5.29 p. 295	
Date of Posting:	Friday, June 19, 2015	
Student Name:	Student X	
Rigor and Completeness		**2**
Justification and Interpretation		**1**
Presentation		**2**
Timing		**2**
Weighted Total:		**1.8**

Comments: Pay attention not to mix up between the frequency response, $H(\omega)$ and its magnitude! Also, the last part seems to be missing; you need to find the power spectral density of the output signal.

Figure 2 - Sample Focus Problem Rating Table.

ambiguity. For example, the slightest imperfection, such as the omission of units, could be captured through the first performance criterion.

2.4. Team ALP Competition

Team ALPs:				
			ALP	**AWARD**
TEAM A	B.	Elias	**57.5**	**4.3**
	C.	Fady	**94.375**	**7**
	C.	Jad	**67.5**	**5.0**
	E.	Roy	**43**	**3.2**
		Average	**65.594**	
		Standard Deviation	**21.664**	
TEAM B	A.	Joe	**69**	**7.0**
	A.	Abd El Basset	**76**	**7.7**
	H.	Joseph	**99**	**10**
	S.	Elie	**47.5**	**4.8**
		Average	**72.875**	
		Standard Deviation	**21.223**	

Figure 3 – Partial View of a Sample Team ALP Competition Results Table.

To motivate students to continuously improve their problem-solving skills, while ensuring a high level of transparency, ethics, and accountability, an online competition is organized among class teams for the purpose of obtaining the highest Active Learning Performance (ALP) grades. In this regard, while the (student) ALP grade is essentially the average grade obtained by the student on the quizzes conducted in class augmented by the bonus points that he/she obtained on the OTR, as mentioned previously, the Team ALP is defined as the sum of the ALP grades of all team members. The bonus points are first posted by the moderator on the OTR, through the so-called Focus Problem Ranking Table, and then recorded by the moderator on a Moderation Form, and sent to the instructor, at the end of the moderation period of the last segment of each forum (Section 3). At this point, the instructor uses the Moderation Form to build the ALP Competition Results Table (Figure 3).

In this competition, the three teams with the highest ALP grade average receive three awards (up to 10, 7, and 4 bonus points, respectively, on the final exam), as long as the standard deviation of their ALP grades falls within a higher bound (typically 15 to 25%). If the standard deviation exceeds the pre-announced bound the corresponding team is disqualified. This measure has the added benefit of promoting intra-team cooperation and collaboration while maintaining inter-team competition at the same time.

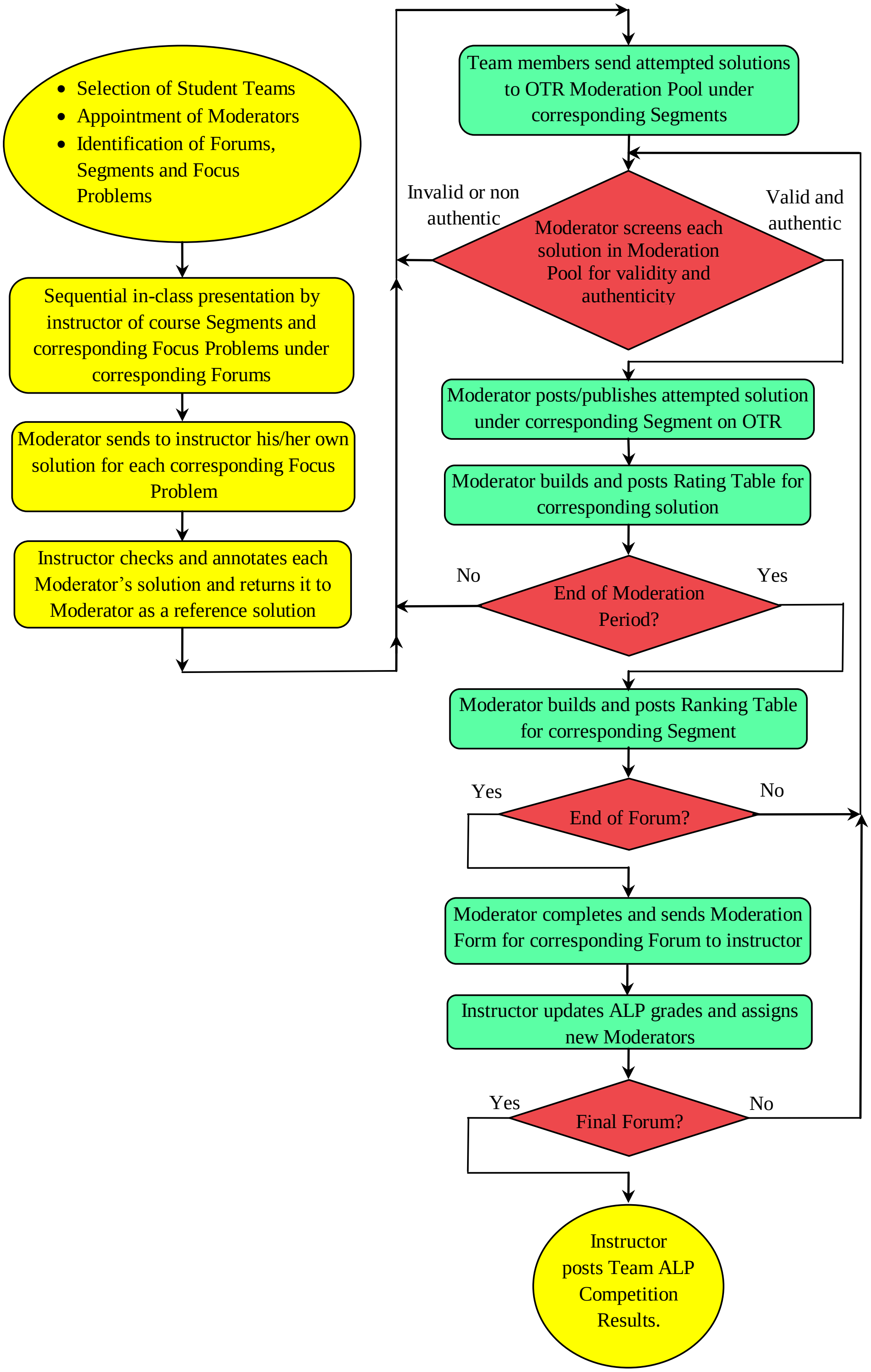

Figure 4 - OTR Flow Chart.

3. Activation and Regulations

Upon the selection of student teams and the distribution of course forums/chapters and segments on the Learning Management System being used (e.g Blackboard) at the beginning of the semester, the Online Tutorial Room is first activated by the instructor presenting the first course segment of the course material. Both the theoretical and the applied component (focus problem) of the segment are presented and discussed in a team environment (Figure 4).

The so-called moderation period for that particular segment starts immediately after that classroom presentation and lasts for two weeks. During that time, one of the assigned moderators can e-mail his/her own version of the full solution of the focus problem to the instructor, who returns it back to the moderator, in due time, with the appropriate feedback. In the meantime, any student, in collaboration with his/her team members, can post his/her own version of the solution to the same focus problem. On Blackboard, all received solutions, go first to a moderation pool, waiting to be screened by the appropriate moderator.

The same moderator, in coordination with the other moderators, is then expected to keep an eye on the moderation pool and screen the posted solutions for validity and authenticity. Checking for validity means making sure the posted solution refers to the focus problem under consideration or adds value to its corresponding segment; on the other hand, checking for authenticity means attempting to ensure that the posted solution is not copied from an external source. Two elements help the moderator in this task, full transparency of all posts and the competition among teams, as mentioned in Section 5. As a result of the initial screening process, the posted solution is either *published*, i.e. allowed to be posted for everyone in the class to see, or *returned* to its sender with a brief explanation.

Before the end of the moderation period of each segment, the moderator is expected to evaluate each of the posted solutions, based on his/her own solution, the instructor's feedback, and the OTR rubric, and post the corresponding focus problem rating table, effectively rating the solution vis-à-vis the four performance criteria, i.e. rigor, interpretation, presentation, and timing (Section 2.3).

At the same time, other students can repeat the above focus problem solution posting process, in collaboration with their teammates, and the moderator makes sure each valid and authentic posted solution is rated via its own focus problem rating table. However, at the end of the moderation period for that segment, the same moderator compares the weighted totals of all posted rating tables and posts the focus problem ranking table (Section 2.4), identifying the recipients of the first, second, and third prize (1.5, 1, and 0.5 bonus points), in addition to the eventual recipients of any extra bonus points allocated for that particular focus problem.

When the forum/chapter is fully presented, the moderator completes and sends the moderation form (Section 2.4) to the instructor, listing the names of the bonus point recipients for that particular forum, and the details of the corresponding segments/focus problems, allowing the instructor to update the class Active Learning Performance (ALP) grade, including the total ALP grade for each team. This team grade is used at the end of the semester to announce the results of the Team ALP competition.

The moderation cycles are repeated for every segment of every chapter of the course. As a reward for their services, the moderators are offered one bonus point for each three (3) properly moderated postings. In addition, if any segment does not receive valid and authentic postings during the moderation period, the opportunity is given for the moderator of that segment to post his/her own solution, which is then rated by the instructor.

4. Deployment and Early Results

The Online Tutorial Room was first deployed in Fall 2014, with the Circuit Analysis, Signals and Systems, and Electronics for Non-ECCE courses. Subsequently, it was used in Spring and Fall 2015. Based on the lessons learnt during each semester, some modifications were introduced in subsequent semesters (e.g. number of OTR moderators, maximum number of posts in the moderation pool, etc.). In addition, a limited version of the OTR (instructor acting as sole moderator, less formal moderation, no ALP competition) was implemented in Spring and Fall 2016.

Following each of these test trials, an indicator of the assessment frequency was recorded for each of the above courses, and compared with the corresponding indicator for previous semesters, where only three main assessments/exams were conducted per semester. This indicator took the form of the average number of assessed problems per month. It is to be noted that the assessment period associated with the OTR is equal to the 2-week moderation period, and is therefore clearly less than the assessment period associated with the 3-exam-per-semester assessment scheme (Table 1).

Table 1 - Comparison of average assessment frequencies with or without the use of OTR.

	Signals & Systems	**Circuit Analysis**	**Electric Circuits (Non ECCE)**
Average Assessment Frequency - Without OTR - in problems/month)	4.3	4	4
Average Assessment Frequency - With OTR - in problems/month)	12.4	12.0	17.1

Additionally, the class average and the standard deviation were recorded for each of the above-mentioned courses and compared with similar indicators obtained during earlier semesters. Figure 5 depicts the class averages delimited by the corresponding standard deviations for the Signals and Systems course given in Fall 2014, Spring 2015 and Fall 2016, during which the

OTR was deployed, and compared with similar indicators for Fall 12 and Spring 13, during which no OTR was used. Moreover, Figure 6 depicts the same indicators for the Circuit Analysis course given with OTR in Fall 2014, and without OTR in Fall 2013 and Spring 2014 (two sections). Note that similar results for the Non ECCE Electronics course followed a comparable pattern and are not depicted here for brevity.

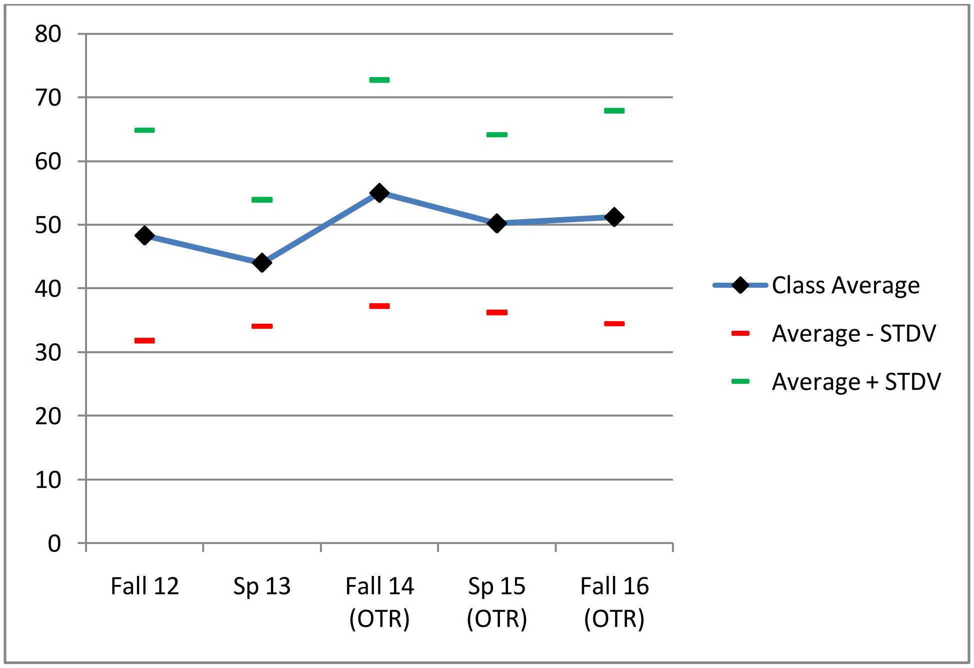

Figure 5 - Average and standard deviation for the Signals and Systems course over several semesters.

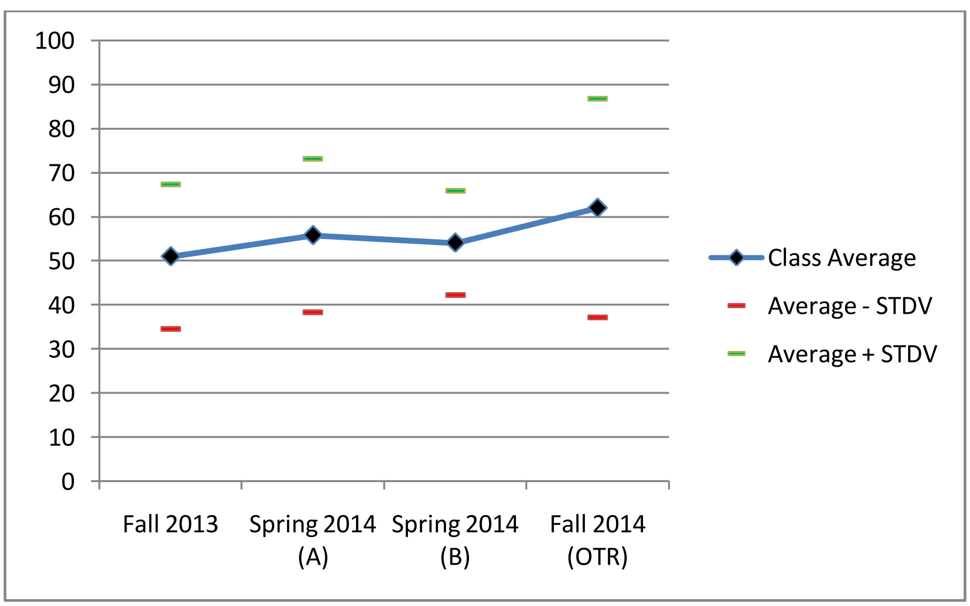

Figure 6 - Average and standard deviation for the Circuit Analysis course over several semesters.

5. Discussion – OTR Strengths and Weaknesses

As suggested in the introduction, the direct objective of the OTR is to increase the frequency of engineering assessments for the purpose of (indirectly) improving the accuracy of learning evaluation, in addition to the level of learning retention, mainly based on the theoretical results outlined in [10]. In this respect, a quick look at Table 1 reveals that the direct objective has largely been achieved. In principle, however, the indirect objectives of improving learning evaluation and retention as a result of problem-solving activity could be essentially left to the numerous studies conducted for that purpose (e.g. [12], [13] and [14]).

Nevertheless, we may note that a higher accuracy of learning evaluation (involving aliasing-free knowledge signal reconstruction [10]) due to a larger number of samples could be readily understood. However, the expected improvement of learning retention doesn't seem to be reflected in the results depicted in Figure 5 and Figure 6! At first glance, these results may appear below expectations until we realize that there are a number of factors that may justify their conservative nature.

First, it should be noted that the deployment of the OTR introduced a real culture change among the engineering students who used it. Having been used to the two or three main assessments per semester scheme [6] for an extended period of time, many of these students found it obviously difficult to adapt to a more frequent assessment scheme. In this context, it is possible to interpret the results of Figure 5 and Figure 6 as simply short-term results, and expect the true effect of the OTR on learning retention to materialize only in the long run. This seemingly slow behavior of the engineering student learning system could be further understood if we note its Multi-Input-Multi-Output (MIMO) nature [9], in the sense that the engineering student has to adapt to the learning styles of many educators at the same time.

Another factor affecting the above mentioned results may well be the statistical limitations of the recorded data. In fact it is well known that the average and standard deviation are not generally considered as good statistical instruments, especially when the population samples, the assessment tools, and the assessment conditions are not the same.

A third limitation of the OTR may be its perceived structural complexity. In fact, it may take quite some time to get used to the notions of segments, focus problems, moderation, etc.

On the other hand, however, the main strength of the OTR is perhaps its realizability as a highly efficient, highly ethical, low resource (financial, human, and time) problem-solving platform.

- OTR is effective because of the higher number of assessments it prescribes per unit time (Table 1)
- The high ethical standard of OTR is the result of its full transparency (solutions are posted for everyone to see in the class) and by the spirit of team competition (teams watching each other's for possible academic dishonesty)

- The low cost of the OTR is due to its virtual nature. No physical facilities or material are used
- No extra human resources (academic support, TAs, graders, etc.) are needed since the OTR is practically run by students for students. This and the previous feature are particularly attractive for low budget, undergraduate engineering schools
- Minimal time investment is expected of the instructor, since his/her role is restricted to monitoring and supervision, with a minimal time needed for grading assessments (only one version of each assessment – the moderator's assessment – is evaluated by the instructor.

6. Conclusion

This paper describes the Online Tutorial Room (OTR), an online problem-solving platform that allows engineering students to acquire problem-solving skills, discuss solution methods with their colleagues in a highly ethical environment, receive valuable feedback under the watchful eyes of the course instructor, and be rewarded for their participation, all from their preferred location, at any hour of the day and any day of the week.

Given the structure of the OTR, all of these benefits come at minimal cost to the institution, minimal human resource requirement, and with minimal time spent and effort applied by the instructor. In practice, the OTR is designed to actually substitute for a physical tutorial room, as large in size as the reach of the internet, and as lasting in time as long as the academic semester.

Integrated within a Learning Management System, the OTR comprises several elements: student teams and moderators, course segments and focus problems, in addition to a performance evaluation process and an Active Learning Performance (ALP) competition. Moreover, the OTR uses a number of tools including an active learning policy, moderators' guidelines, an OTR rubric, a moderation form, as well as a rating table and a ranking table.

The activation and regulations of the OTR are described in detail, and some of its results are presented. These results indicate that the OTR helps improve the frequency of quality assessments, in a highly ethical environment, while maintaining low requirements on financial, human, and time resources. These features are especially attractive for undergraduate, low-budget engineering schools, where academic support is limited.

At the same time, early results highlight a number of remaining challenges including slow dynamics of the engineering student learning system, statistical limitations, and structural complexity. However, with some additional institutional support, it is expected to overcome these hurdles and streamline the reliance on the OTR for the purpose of improving the students' problem solving skills, increasing the assessment frequency, and consequently improving the level of learning retention and the accuracy of learning evaluation at the same time.

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