Expanding Learning Scenarios
Opening Out the Educational Landscape
Proceedings of the European Distance and E-Learning Network 2015 Annual Conference
Barcelona, 9-12 June, 2015
ISBN 978-615-5511-04-2
ISSN: 2707-2819
doi: https://doi.org/10.38069/edenconf-2015-ac-0065

TOWARDS A COLLABORATIVE SPACE FOR LEARNING DIGITAL SYSTEMS

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Abstract

Practical skills such as Programming Languages or Digital Systems Design are learned by experience. Such skills are not mechanical processes, but rather a creative one. For this reason, students should practice repeatedly and receive constant feedback in order to further progress in their learning process. Nevertheless, it is difficult for instructors to give constant and individual feedback in this type of exercise, as there are many different correct strategies to construct a valid solution. Intelligent tutoring systems can be used in order to automate individual feedback, however the lack of intervention of the instructor or other students in the process of solving the design hinders the learning process. This study aims to examine the effect of the combination of a automated tutoring system for learning circuits design with an asynchronous collaborative space organized in different groups. Findings indicate that the student retention, the students' performance and collaborative knowledge construction is enhanced with this combination.

Introduction

Most of the degrees in Computer Science or Engineering have subjects related to the specialty of Digital Systems. Several skills are acquired in the area, such as the design of digital systems. The student learns to understand the digital world, and consequently the digital circuits, and how a set of output values are produced from a set of inputs values using logic gates, combinational blocks, such as, multiplexers or adders, and sequential blocks, such as, registers or memory elements. These subjects are commonly taught in the initial semester of the degrees since the learning concepts are required for more complex subjects in the area of the computer organization, networking and electronic systems.

Teachers involved in these subjects have two main challenges. First, to design an introductory course where the learning objectives previously described have to be acquired; and second, to design a course for newbie students in higher education. Additionally, degrees imparted in virtual environments have an extra handicap related to how instruct students in skills that need practice. The first challenge is a well-known problem. Several works [6] have already showed evidences about misconceptions the students have related to the learning of digital systems. Therefore, different approaches have been designed to instruct the courses [1, 7]. Some of these works rely on face-to-face learning and laboratories without taking into account

distance learning. The second challenge is a common issue in subjects on the first semesters of any higher degree [11]. Students are not used to learn in a higher education environment producing low performance and high dropout rates. An additional challenge is when the degree is delivered on a distance learning environment where other learning resources have to be added in other to teach concepts that need practice: simulation software, intelligent tutoring systems, virtual labs.

All these learning resources on distance learning tend to provide an individual environment to learn without taking into account the collaboration perspective due to the difficulties on the communication. Our research questions are related to evaluate the possibility to promote collaborative learning on these individual tutoring systems. This paper presents a new design and classroom organization of the course Computer Fundamentals in our university in a virtual learning environment. A new classroom organization based on small groups and a plenary laboratory group combined with a intelligent tutoring system helped to increase the student performance, student interaction and collaborative knowledge construction.

Course Overview and Learning Methodology

In the course of Computer Fundamentals, a student has to acquire the skills of analysis and synthesis of small digital circuits and to understand the basic computer architecture in 150 hours. The synthesis process is presented at the logical level without describing all the inherent electronic problems. Moreover, a student should be able to implement the FSM of simple sequential circuits with data path. The assessment is divided in 3 continuous assessment activities (CAA), one final project and one final exam.

The course combines three types of learning resources: i) The material of the course is organized as a textbook. The book contains all the theoretical aspects with several practical examples to illustrate their application. ii) There is an online discussion forum moderated by an instructor, where the students can interact. There are insights that there is a positive relationship between collaborative student engagement and course performance [4] in distance learning. The forum promotes a collaborative channel where a student can benefit from doubts, errors and comments of the other students. The students help each other and gain better understanding of the proposed exercises. They can discuss their assignments; share and compare methodologies to solve exercises; synthesize proposed solutions via reasoning/arguing; and reach agreements/explore disagreements. The value of the collaborative learning is essential to stem social interaction which increases retention and mutual knowledge construction. The collaborative learning is enhanced by the moderation of an instructor by validating the comments of the students and giving guidelines to increase the quality of the learning process and the construction of knowledge within the online forum. In our learning methodology, the online forum is one of the primary tools since they involve active participation from students by writing posts, asking specific questions about a specific exercise or concept, and sharing resolutions in order to be criticized by other students (and not only by the instructor). iii) An intelligent tutoring system, called VerilUOC [2] is used to practice the design of digital circuits. The objective of the system is two-fold: In one hand, the

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student has an edition and simulation tool to design and test the digital circuit. In the other hand, there is a complementary module where exercises from the textbook, the continuous assessment activities and the exams of previous semesters can be solved. The module allows to automatically validate the correctness of the design performed by the student compared to the canonical solution provided by the instructors. In case of mismatch, the tutoring system gives a counterexample as a personalized feedback to guide the student to the correct solution. This tool was conceived assuming an experiential learning method combined with a problem-based learning. Learning from experience is important to clarify the concepts and practice. The set of exercises proposed in the systems should be enough to acquire the sufficient level of knowledge in order to be able to design simple difficulty circuit and to pass the course.

All the three learning resources are combined in order to provide a successfully learning experience. The potential benefit of collaboration during problem-solving is that a deeper elaboration can be reached. Although students may produce non-canonical solutions or even incomplete solutions [8], detecting differences between solutions or comparing erroneous and correct examples [3] can guide the students to a higher level of knowledge construction. Although the intelligent tutoring system can be used without any interaction among students, we have detected the interaction using the online discussion forum enhances the knowledge construction. Note that, the forum gains relevance on a virtual learning environment (VLE) where there is no face-to-face interaction.

The number of students of Computer Fundamentals is approximately 300 students for each semester. Until 2013 Fall Semester, the course was organized in different virtual classrooms with a reduced number of students (60-70) per classroom. The aim of this division is to provide a higher quality education since the teacher who performs the instruction has a reduced number of students in the classroom. Therefore, the moderation of the forum, the evaluation of the activities and the personalized feedback can be managed properly. In this last semester, we observed a significant decrement of the activity on the forums. Students started tending to study individually and few students used the forum to post messages. The instructors also complained that there was an increment of individual messages via the instructors' email address that students posted in the forum on the previous semesters. This is a serious concern since the knowledge acquisition is no more shared among students. Additionally, we observed also a decrement of the number of exercises performed using the tutoring system. The students have difficulties on solving exercises and they asked directly of the instructor instead of asking on the forum. There is some well-known issues in our VLE that produces this undesirable behaviour. Students typically choose our online university because they have a professional activity or familiar commitments. This means that some students tend to study part-time and they are very conscious about the use of their time. Therefore, students who feel unprepared for an activity or a course are more likely to abandon it rather than submitting low quality solutions. Moreover, some students in these initial courses realize the degree they started is not the professional outcome is looking for. These issues cause high dropout rates reaching in some cases more than half of the enrolled student and affecting severely the collaborative interaction in the forum.

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On 2014 Spring semester, we decided to try to amend this tendency to the total individual study by reorganizing the structure of the course. We propose to connect the students who seek collaborative learning by adding a new space. This space that we called laboratory class is basically a plenary new discussion forum where all the student of the course (of every classroom) can post messages and it is moderated by another instructor. A similar approach has previously presented in 10 where the organization of the course was divided in small groups in the first eight weeks of the course and an opportunistic plenary group in the last weeks. The research pointed out this organization produces positive results on the learning process. Authors in 9 also proposed a study related to the organization of a course with small groups with a plenary class. The collaboration was enhanced with scripts to foster the online search competence. Our organization combines characteristics of both approaches: small groups plus a plenary group during all the semester but without scripts. We are interested in forums where students can freely communicate without any restriction. The previous forums were not removed, we only change their orientation. The theoretical aspects and questions related to the organization of the course are discussed on the small group forums, whereas the new forum is only intended for the practical activities and the exercises proposed using the intelligent tutoring system. We claim that the new organization can foster again the collaborative learning at least in the practical aspects of the course and improve the collaborative knowledge construction. The concerns that we address are the research questions of the study: i) How does this new space improve the collaborative learning? ii) How is the students' performance affected? iii) How is the knowledge construction affected by the new space?

Findings

Participants and context of the study

In order to answer the previous questions, different data has been collected from two semesters. One semester corresponds to the 2013 Fall semester with the old organization, and the other one corresponds to the 2014 Spring semester with the new organization. Table 1 summarizes the total number of students and its distribution among the virtual classrooms. As we can observe, we have a large sample of students in both semesters. Note that, on the 2014 Spring semester, the course had less number of students (there are commonly more enrolments in the course on the fall semesters). Therefore, the fifth classroom was not opened for instruction.

Table 12: Number of students in each classroom

	Class 1	Class 2	Class 3	Class 4	Class 5	**Total**
2013 Fall Semester	77	72	67	67	66	349
2014 Spring Semester	69	61	60	60	-	250

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The new organization fosters the collaboration

In order to analyze whether the new space increases the collaboration among students, the total and average number of messages the students have posted have been analyzed. Taking into account that there were 100 students less in the course in the last semester, the total number of posts increased by 20%. Although the number of posts per students on each classroom decreases in the last semester, the average number of messages per student also increases from 3.46 to 5.80 with a similar variability on the number of messages (reflected by the standard deviation). We assume that the decrement of messages is due to the introduction of the new space since all the message related to the practical aspects were moved to the laboratory class. Although Table 2 gives some evidences of the increment of the participation, the results do not reflect the number of active participants. The second analysis tries to reflect this fact.

Figure 1 shows the distribution of students based on the number of published posts. The figure shows a high number of inactive students in all the forum in both semesters due to the issues explained aforementioned. There are cases where this number reaches the half of the classroom. Moreover, many students only posted one message corresponding to the presentation message leaving the active participants (we assume students with more than one message) on 30% on average. However, the introduction of the laboratory space increases significantly the number of active participants reaching the 40% of the total enrolment on the course. Some students that only posted one message in the forum of their classroom were active in the laboratory.

This result proves that the new space helps the students involved in the course to find a communication channel with students with similar concerns. Students that want to work individually or drop out the course remains in the small group classroom, leaving the laboratory to students interested in increasing their knowledge. Moreover, all the messages posted in the laboratory class are focused on the practical issues. Messages without learning outcomes, such as presentations or opinions, do not tend to be posted. For example, we can observe that students that posted one message are less than the 9% of the students (19 messages). With respect to the moderation task of the instructor of the laboratory, we conclude that the class can be assumed by one instructor since the number of active participants finally was 40% (around 100 students).

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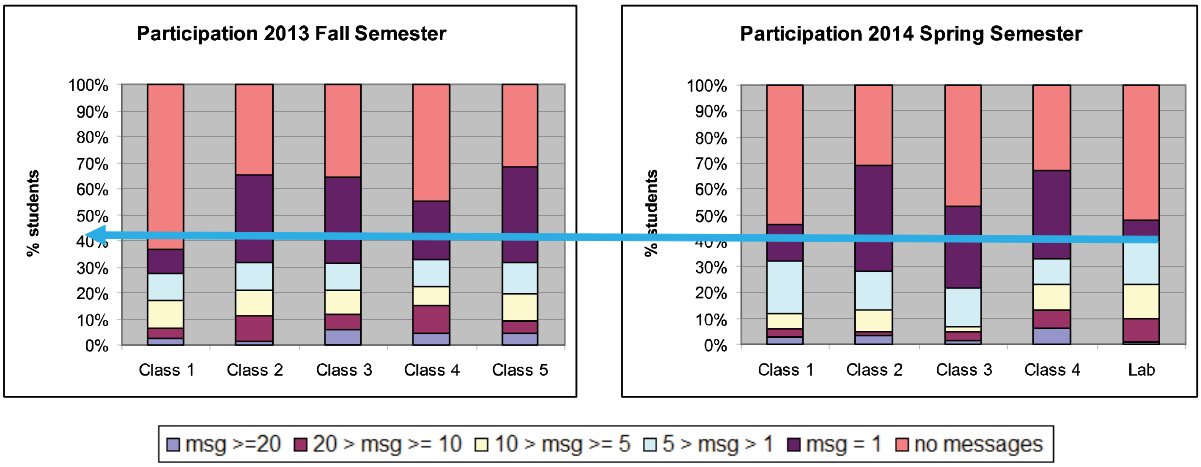

Figure 1. Distribution of students versus the number of published messages

The students' performance and retention improve with the new organization

It is important to check how the laboratory space affects the students' performance. Table 2 summarizes the submissions and the pass rates on the continuous assessment activities, the final project and the final exam.

Table 2: Students' performance on the assessment activities

	2013 Fall Semester		2014 Spring Semester	
Classroom	**% Submission**	**% Pass**	**% Submission**	**% Pass**
CAA 1	84.57	76.00	86.80	80.00
CAA 2	66.57	52.00	65.20	50.80
CAA 3	53.71	40.57	54.00	42.00
Final Project	46.00	34.29	49.20	42.80
Exam	47.43	32.29	50.40	40.40

The results are not the expected ones in the continuous assessment activities. We expected a significant increment of the submissions, but the percentage remains similar to the previous semester. Therefore, the dropout rate remains similar between semesters. However, the students' performance is slightly better in the last semester during the continuous assessment activities and superior in 8% in the final project. The exam pass rate also increases by 8% giving the perception that the knowledge acquisition at the end of the course has improved.

The collaborative knowledge construction increases

We propose to compute the knowledge construction by two evidences: the success rate between submissions and solved exercises in the tutoring system and the correlation between the activity of the new space and the submission in the tutoring system. The first evidence shows the individual and collaborative knowledge production in the system. The second one gives some hints between the relation of the submitted exercises and the collaborative work in the forum. Table 3 shows an important increment of the utilization of the tool between semesters. In terms of the number of submissions, the increment was nearly an 80%, meanwhile the number of solved exercises was nearly a 91%. This is also reflected on the average number of exercises submitted and correctly solved. Both numbers increased by nearly 8 exercises per student. However, the distribution was notably different in the last

ISBN 978-615-5511-04-2

semester indicating that many students solved a large number of exercises. Note that, this statistical result takes into account users that never accessed the tutoring system. If these students were not taken into account, the number of correct exercises increased to nearly 22 exercises in the last semester, outstandingly better than the 10 exercises of the previous semester.

Table 3: Knowledge construction in the VerilUOC system

	2013 Fall Semester		2014 Spring Semester	
	Submitted exercises	**Correct designs**	**Submitted exercises**	**Correct designs**
Total	1896	1651	3424	3151
Successful rate		87.10%		92.02%
Avg. by student (stdev.)	5.41 (6.95)	4.71 (6.47)	13.70 (20.79)	12.60 (20.04)
Avg. by active student (stdev.) -- active students in the tool	8.60 (6.85) -- 192	9.88 (6.73)	20.07 (23.40) -- 157	21.80 (22.93)

Finally, we wanted to reflect the impact of the new space in the submission of exercises in the tutoring system. Figure 2 illustrates this correlation that was 0.66 in total. The dates with major activity in the forum highly correlate with the major activity in submissions in the tutoring system. Note that, dates with major activity corresponds on submissions of the second (CAA2), third (CAA3) continuous assessment activities and final project (FP). The first CAA is not reflected in number of submissions since the tutoring system is not used for this activity. Discrepancies between both data appears on the beginning of the semester where messages with presentations and questions about configuring and deploying the tool were posted and at the end of the semester where the students prepared the final exam. The total number of submissions was 11,394, a significant increment (44%) compared to the 7,896 submissions of the 2013 Fall semester.

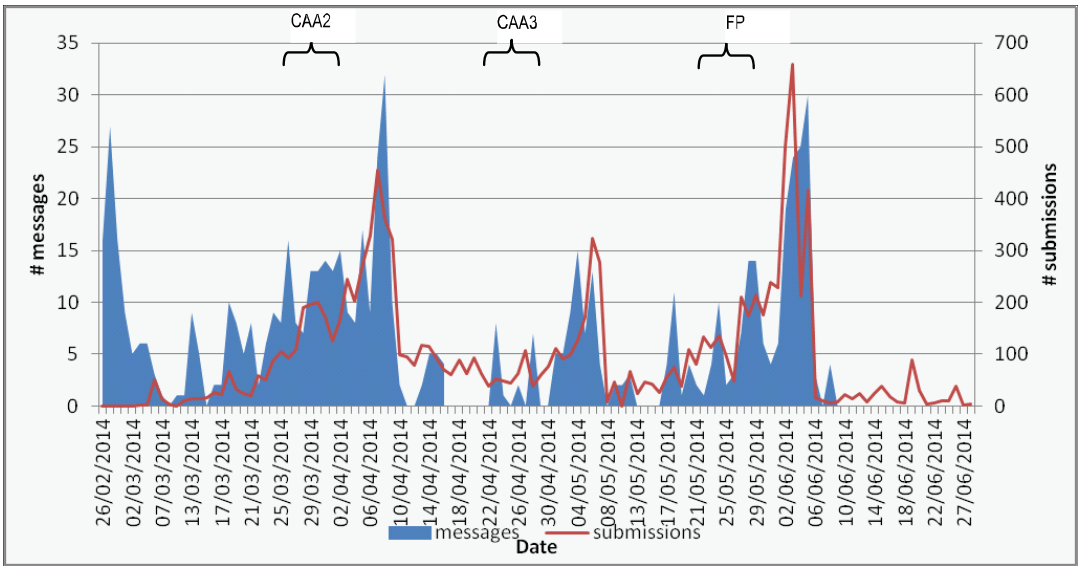

Figure 2. Comparison forum activity vs. submissions in tutoring system

ISBN 978-615-5511-04-2

Conclusions and discussion

Asynchronous communication tools like forums are highly recommended for any collaborative learning methodology. Others tools can be also used like wikis, blogs, but this selection highly depends on the type of collaboration. However, sometimes depending on the type of skills or competences have to be learned (in our case digital systems design) other learning tools like intelligent tutoring systems have to be used. Thus, the intelligent tutoring system VerilUOC was implemented. Although, this system can be used individually to learn the design of circuits, the analysis performed in this paper shows evidences that the skill of circuit design was not properly learned with this standalone tool and, therefore, the cohabitation with this new organization of the communication channels impacts in the learning engagement of the students. Many advantages have been showed: increment of the engagement of the student in the classroom activity, (slightly) increment on the students' performance and increment on the collaborative knowledge construction in the course.

We are aware that there are some threads to validity in this study. First, the global pass and submission rates on assessment activities should not be comparable between semesters, as they are affected by other external variables, such as deviations in the level of difficulty of the exams and activities or changes in the instructor assigned to each class. Hence, the comparison of the student performance should be performed within each semester and not among semesters. However, we were not able to create multiple groups of study in the same course, since there are some policies in our university that demand an equitable opportunity to learn for all the students. Therefore, the study was performed between semesters.

With respect to the utilization of the forums, the analysis shows a low number of posts per student and this seems to prove a lack of utilization of the forum. As aforesaid, many students have professional and familiar commitments that directly affect the time invested on the course. Therefore, students only use the forum when it is necessary. Moreover, the high dropout rates, i.e. Table 2 shows that the half of the students have not submitted the activity in the third CAA (the middle of the course), implies that the activity of the forum is sustained by a lower number of active learners compared to the enrolled students.

The additional threads to validity we have considered are the interaction of different treatments and selection bias. A potential threat to construct validity is the interaction of different treatments. The reader may think the improvement of the diverse evidences is due only to the utilization of the tutoring system. The tutoring system was introduced in the course on 2012 Spring semester. During all these semesters, the utilization of the system was similarly low to the 2013 Fall semester (1,120 submissions on 2012 Spring semester, 8,262 on 2012 Fall semester, and 7,882 on 2013 Spring semester). However, a significant increment has been showed in the previous section on the semester of study (11,394 submissions). Therefore, we assume that the impact was related to the new organization of the course. Moreover, there was an increment of the number of messages and even the major activity in the collaborative discussion forums matches the dates where the continuous assessment activities are submitted (See Figure 2).

ISBN 978-615-5511-04-2

Another potential threat to internal validity is the selection bias. Students that tend to get better scores are more active in the forum and the utilization of the tutoring system. These students may bias the global results, i.e. the number of messages or submissions in the tutoring system may be produced by a small population of the learners. However, we can observe with the different data we provided that the increment is generally in all the students of the course. Figure 1 depicts that the active participants increased in the last semester in the laboratory class and this fact is not only affected by proactive students. Moreover, Table 3 also proves an increment of the exercises submitted by different students.

As future work, we are interested to analyze if this tendency is confirmed on next semesters. Finally, the new organization will be applied on other courses with similar characteristics (large number of enrolled students, practical skills, learning support tools) to observe if similar results are obtained.

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Acknowledgment

This work was funded by the Spanish Government through the project: TIN2013-45303-P "ICT-FLAG: Enhancing ICT education through Formative assessment, Learning Analytics and Gamification".

ISBN 978-615-5511-04-2