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E-Assessment System for Skill and Knowledge Assessment in Computer Engineering Education

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E-assessment has become increasingly interesting in higher education. However, it is not an easy matter. It does not work to transfer, directly, face-to-face assessment models to online education. Indeed, the nature of such assessments has often been limited to automatically corrected quizzes, compounds of simple type of questions such as 'multiple choice questions'. This kind of e-assessment can be considered knowledge-based but not skill-based because cognitive skills and practical abilities cannot be assessed via such a kind of simple type of question. On the other hand, formative e-assessment, which assists the learning process by being part of it, and not just occurring at the end of it, like the traditional face-to-face examination, seems to be the best kind for assessing skills acquisition. Thus, when it comes to an e-assessment in computer engineering education, where skill-based assessment is needed, there is no general system that can be used for both skill and knowledge formative e-assessment. Considering this, the paper proposes an e-assessment system that supports a formative assessment model that goes beyond simple types of questions and introduces an interactive dynamic environment for both skill and knowledge assessment in an online education. Furthermore, the impact of introducing formative e-assessments in computer engineering education to support and improve the students' learning processes was evaluated in a real scenario, a Logic course at a fully online university. Based on data analysis, it was observed that the use of the system and the model had a positive impact on student learning and performance. Students learned through more engagement with the system and, as a result, their performance in the final examination had improved. The system also provided added benefits to teachers through automated marking and tracking of students' progress throughout the whole course.

Keywords: e-assessment; higher order skills acquisition; knowledge acquisition; interactivity; online higher education; computer engineering subjects

1. Introduction

Assessment lies at the heart of the learning experience: how learners are assessed shapes their understanding of the curriculum and determines their ability to progress [1]. Technology can play a significant role in this process as, if used appropriately, it can add value to any of the activities associated with the assessment. Therefore, e-assessments can be denoted as the end-to-end electronic assessment process where Information and Communication Technology (ICT) is used for the management of the end-to-end assessment processes from the perspective of learners, tutors, educational institutions, awarding bodies and regulators, and the general public [2–4]. In other words, e-assessment involves the use of any web-based method that allows systematic inferences and judgments to be made about a student's skills, knowledge and capabilities [5].

In engineering education, assessment of skills is an important aspect as problem solving is a key factor implying the use of procedural and practical skills, as well as conceptual knowledge [6]. In the case of mathematics and statistics, Ferrao [7] reported encouraging results, with high correlations found between multiple choice tests and open-ended tests for evaluating the achievement of procedural skills. Nevertheless, this is not enough for all the engineering disciplines as problem solving has to be defined from a broader perspective. This involves understanding the information given, identifying the critical features of the systems and their inter-relationships, constructing or applying external representations (models), solving problems, and evaluating, justifying and communicating their solutions. Therefore, the students' role in the learning process is significant where students' active participation and engagement is needed along with a continuous formative assessment, which is carried out during the learning process [8, 9] and not just at the end of the learning process, as is usual in traditional face-to-face examinations [10]. Even though these examinations were justified for assessing the acquisition of specific knowledge and intellectual skills, according to Wellington et al. [11] the validity is doubtful, as a means of assessing students' ability to apply that knowledge to real situations. It is even less valid for measuring many of the real-world skills that graduates are expected to perform in the workplace. Formative assessment is needed for such matters, but also summative

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assessment, provided at the end of the learning process of a particular module, is also needed. The combination of paper-based and electronic tests can completely evaluate the conceptual knowledge, procedural and practical skills required in any mechanics subject in engineering education. It can also reduce the lecturer's workload in correction activities [6]. When it comes to skill and knowledge assessment in computer engineering education, mainly formative e-assessment is combined with face-to-face paper-based assessment. In most cases, knowledge assessment is offered through formative e-assessment with simple types of questions and skills assessment through face-to-face paper-based assessment. Therefore, it was not possible to find evidence where both skill and knowledge assessment is offered as an e-assessment in computer engineering subjects.

Moreover, when it comes to systems and tools used for e-assessment in computer engineering, there is no general tool or educational model that can be used for formative assessment of both skill and knowledge. Most of the currently available tools and models are either developed specifically for a particular subject or offer only simple types of questions, such as Multiple Choice Questions (MCQ), short answer, true/false and fill in the blanks. These simple types of questions rarely give any insight into the thought processes that students used to determine their responses [5, 11, 12]. Therefore, they can be used for knowledge assessment, but when it comes to assessment of higher order skills where students have to apply their analytic, creative, and constructive skills, one needs to go beyond MCQ and equivalent forms of basic assessment items. Also, practice is an important aspect of formative e-assessment in computer engineering education as it allows students the opportunity to act on the feedback [13, 14]. More emphasis should be given to feedback, as timely and constructive feedback motivates students to learn more efficiently [15, 16]. Considering the above, this paper proposes a design, development and evaluation of a general and standardized e-assessment model and a system supporting formative assessment of skill and knowledge acquisition, thus providing both practice and assessment purposes. After its design and development, it was evaluated in the real case of an online Logic course of a computer engineering degree program.

The rest of the paper is organized as follows. Section 2 presents a review of the literature based on formative e-assessment models and the tools for skill and knowledge assessment. Section 3 describes the proposed solution for skill and knowledge assessment through the definition of a formative e-assessment model and the development of a system that supports it. Section 4 presents the evaluation and the findings based on the data analysis carried-out and, finally, the paper ends with the conclusions and future work.

2. Background

2.1 Formative e-assessment models

As mentioned earlier, formative e-assessment is appropriate for evaluation in computer engineering education. It not only determines what students have learned but also help students to retain, reproduce, reconstruct and engage with the learning materials [17]. Therefore, the use of a proper formative e-assessment model is important to enhance the students learning experience by providing facilities to assess their own learning process via the feedback given. Among different formative e-assessment models [4, 18–20], the one proposed by JISC [4] was selected as the starting point because it clearly explains the relationship between e-assessment and effective learning.

According to this model, learning and e-assessment have to be integrated together, which we found suitable for our needs. In the JISC model (see Fig. 1), learning modules can be provided either as e-learning or blended learning through a Learning Management System (LMS). After completion of the learning module, students are provided with assessment activities either formative or summative, depending on the course. After completion of the assessment activity, if they have successfully completed it, they will be provided with feedback or the final qualification. If they are not successful in the assessment, they will also be given a constructive feedback and a revision module that they can practice on and they can take the assessment at a later stage.

2.2 E-Assessment tools for skill and knowledge

Currently, there is a large sample of tools used for online education in computer engineering education, but, often, they are not tools of e-assessment. While many of them can be categorized as tools for learning or the Intelligent Tutoring System (ITS), only a few can be categorized as e-assessment systems.

There are important differences between learning tools and e-assessment systems. The main characteristic of a learning tool or the ITS is to provide customized assistance and feedback to students while simulating the presence of an e-tutor or learning-assistant [21]. These tools facilitate learning through interactivity by monitoring each step carried-out by students in an exercise and providing some guidance such as error messages and feedback.

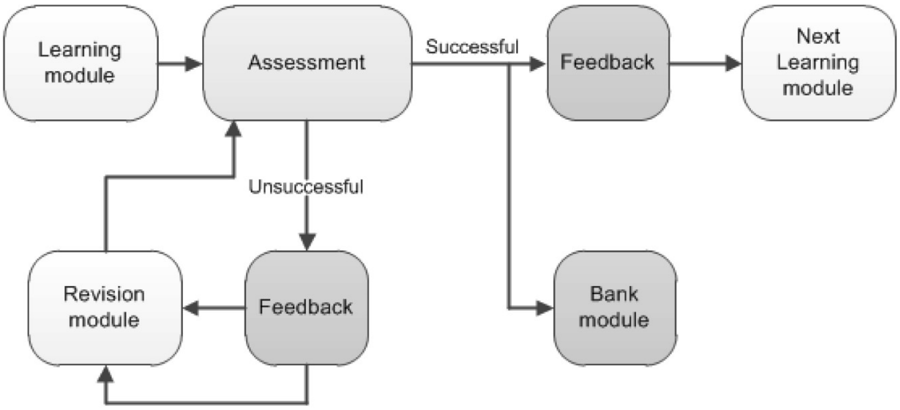

Fig. 1. JISC e-assessment model [4].

On the other hand, the main characteristics of an e-assessment system are: monitoring student progress through frequent assessments, immediate feedback, automatic marking, weighted-average grade calculation, applying a variety of interactive question types, promoting flexible learning and adaptive learning, personalization of quizzes, monitoring question quality using statistical analysis, reducing the potential for cheating by randomizing questions along with timers, and sharing questions via question banks [15, 22, 23].

There are some interesting and well-known tools available for e-assessment in online education [5, 12]. They can be noted as: SCHOLAR [24], Exam-Online [25], TOIA [26], Moodle Quizzes [27], Moodle Assignments [27], Turnitin [28], Hot Potatoes [29] and Maple T.A. [30]. Most of the available e-assessment tools and systems support only pre-determined simple types of questions such as MCQ, true/false, short answer and fill in the blanks questions [31, 3]. However, unless these types of questions are good for assessing knowledge levels of students [32], when it comes to assessing skill levels, it is needed to go beyond these types of questions to provide rich feedback [33, 10]. Cognitive skills and the application of methods cannot be assessed via multiple choice tests and equivalent forms of basic assessment items [34].

Therefore, a more complex kind of assessment activity is needed to be provided, especially when it comes to providing formative e-assessment.

2.3 E-assessment of skill and knowledge in computer engineering

Computer engineering is a field of study that encompasses the fundamental principles, methods, and modern tools for the design and implementation of computing systems. Computer engineering builds upon fundamental courses in mathematics, science, and the engineering disciplines in order to achieve a sound foundation and develop a breadth of knowledge. Knowledge assessment of students in undergraduate and graduate courses in many disciplines, especially engineering and computer science, plays an important role in the learning process [35]. Furthermore, according to Mihajlovic and Cupic [35], the teachers' goal is to enrich students' knowledge, improve students' ability to reason and nurture students' creativity. Therefore, not only knowledge, but skill assessment is also important for subjects in computer engineering.

As an example of the wide range of subjects used in computer engineering, in this paper we have considered Logic because it requires a higher level of skill acquisition in order to qualify in the subject. In that area we have studied some tools that can be used for logic and we have found that some of the existing tools fall into the category of general e-assessment tools for mathematics, and do not offer skill assessment activities for logic questions, for example: EASy [36], AiM [37] and OpenMark [38]. However, others falls into the category of learning tools or ITS tools for logic, for example: Pandora [39], Organon [40], and AELL [21,41], which do not offer proper e-assessment activities. Thus, it was impossible to find a general tool that can be used to conduct both skill and knowledge e-assessment for logic. That is, when considering most of the available e-assessment tools, they offer only 'knowledge' type questions (MCQ, short answer, fill in the blanks and similar).

What happens in the case of computer science and engineering courses is that only the ITS types of tool can offer the 'skill' type of questions for skill acquisition. Unfortunately, these tools do not support most of the required e-assessment characteristics. In addition to that, some of these tools are developed only for a specific context and not according to e-assessment standards and specifications. Moreover, integrating these tools with other existing tools in an online environment becomes a major problem because the tools have to be modified basically from scratch.

3. Proposed solution for skill and knowledge assessment in computer engineering

3.1 Proposed e-assessment model

An in depth analysis of the formative e-assessment model proposed by JISC [4], shows that practice, one of the key areas of online education and assessment [14], especially in engineering education, had to be given more emphasis. As stated in [42], 'one of the main drivers for learning has long been acknowledged as the assessment that students must undergo during the course of their studies'. However, in a formative e-assessment process, frequent feedback is a vital component as formative e-assessment assists the on-going learning cycle [43, 44]. Also, students must have the opportunity to act on the feedback [14]. This underlines the importance of allowing students the opportunity to practice before moving into the assessment. Considering this factor, the model outlined by JISC was enhanced into the proposed formative e-assessment model as explained below.

The main purpose of introducing this model was to provide more benefits for students to improve their learning process through practice. When introducing practice, feedback plays an important role. Whitelock [43] has coined a term, 'advice for action' as 'helping students find out what they do not know and how to remedy the situation can avoid the trauma of assessment'. Accordingly, feedback should be provided in a way that encourages the students to actively change their ideas and ways of organizing their answers and discourse within a given subject domain [43]. This was taken into consideration while defining the formative e-assessment model to make it generally used for any subject domain.

Thus, in the formative e-assessment model proposed here, after completion of each Learning Module (LM), students are provided with a new type of test: the Practice Test (PT), in addition to the Assessment Test (AT), which is already present in the JISC model.

In the proposed model, for a practice test, students are provided with an unlimited number of attempts and time to practice each test as it allows students to interactively engage in the assessment system while acting upon the feedback given 'then and there' to solve the problem [45]. Feedback is provided both in the cases of being successful and being unsuccessful. If they are unsuccessful, based on the feedback students are directed to the revision module. In the case of being successful, where students have obtained the required pass mark, they are directed to the assessment test. The restriction of a pass mark was imposed to benefit students and encourage them to practice more before moving to an assessment test [14].

For the assessment test, students are provided with a limited time (e.g. 2 hours) and a limited number of attempts (e.g. three attempts). The time allocated to complete an assessment test depends on the curriculum and the difficulty level of the assessment. The reason for a restricted number of attempts is to give students the possibility of obtaining the required marks within the given attempts. In most cases, students are allowed multiple attempts (usually three) at each question, with an increasingly detailed and tailored prompt allowing them to act on the constructive feedback whilst it is still fresh in their minds and to learn from it [14, 46]. This also gives a bit of pressure to students and at the same time it motivates students to think carefully about their answers, but thay can improve their mark through practice by paying more attention to their errors and mistakes [47]. This encourages an all-important 'focus on form' for students [47, 48].

In the case of assessment tests, to discourage guessing, minus marks are given. The questions offered within a particular attempt are selected randomly from a bank of questions. In the case of questions where students have to select the correct answer, the answers are also shuffled within each attempt. These are done to minimize the facilities of cheating and copying the answers as expected with the proposed formative e-assessment model [49]. The highest marks out of the given attempts are taken as the final mark. This is also done as a way to facilitate more practice as students tend to attempt the problems several times in order to obtain a higher mark. After completing the assessment test, students can move to the next learning module.

The proposed formative e-assessment model, shown in Fig. 2, can be used for managing the continuous assessment of a particular course, and, in particular, to obtain the continuous assessment mark. In this case, for each learning module, students are provided with both practice and assessment tests during the learning process. Additionally, a final face-to-face examination may also be offered, depending on the curriculum of the course.

The assessment model for a particular course based on the proposed formative e-assessment model can be displayed as in Fig. 3. For each Learning Module (LM), students are provided with both a Practice Test (PT) and an Assessment Test (AT). Depending on the subject, the number of

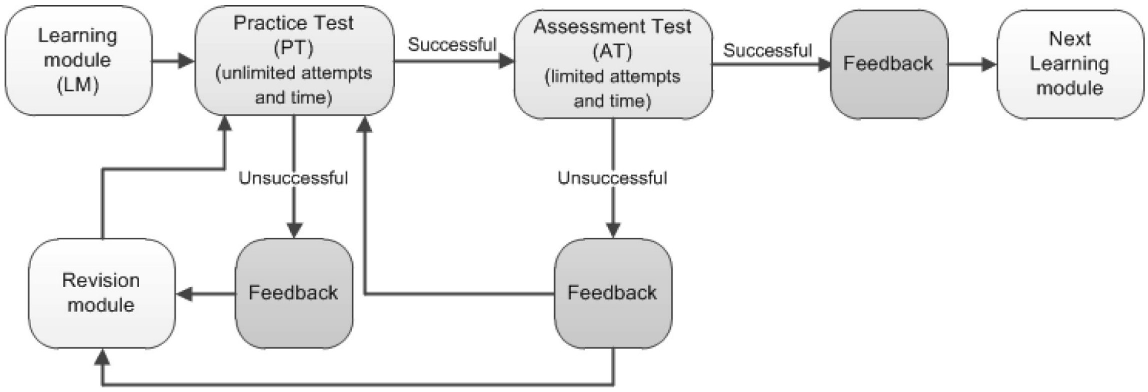

Fig. 2. Proposed model for formative e-assessment.

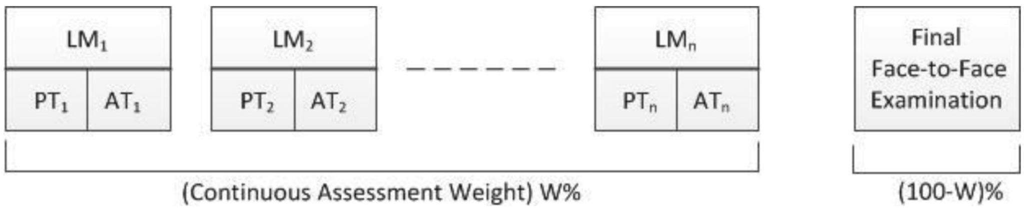

Fig. 3. The assessment model for a course.

PTs and ATs differs. As PTs are only used for learning purposes, when calculating the final mark of the continuous assessment, only the marks of each AT are taking into account. The continuous assessment mark (C) is calculated out of all the ATs. The weight of the continuous assessment mark (W%) depends on the general design of the course. In a non-formative assessment model W uses to be less than 40%, while in a model supporting formative assessment it should be greater than 60%. The final face-to face examination mark (E) has the complementary weight $(100 - W)$%.

The final assessment mark is, then, equal to $C^* W\% + E^*(100 - W)\%$.

3.2 *Proposed e-assessment system*

The proposed e-assessment system was designed and developed iteratively following a user-centered design approach [50]. To identify the features and functionalities of the system, data were collected in the form of surveys, focus groups and interviews. The system provides both learning and assessment facilities in both skill and knowledge assessment.

The general e-assessment system known as the 'Technology-Enhanced Assessment (TEA) system' consists of five modules: skill assessment, knowledge assessment, progress bar, competencies and gradebook.

The skill assessment module provides dynamic and interactive questions for both practice and assessment tests where students have to construct the answers with the guidance of feedback, errors and hints. The knowledge assessment module also provides both practice and assessment tests with a simple knowledge type of questions such as the MCQ. Also, for these questions, feedback is provided for each step performed by the student. The progress bar is a module that provides visual guidance for helping students to understand their progress with respect to the course. It shows the total progress obtained by each student along with the graphical presentation of activities completed, to be completed and not completed. Competencies module allows teachers to understand the competencies achieved by students in a particular course. These competencies are selected based on the marks obtained by students for a particular activity or test. Students can view the competencies that they have achieved as a progress bar and a list of tables. The gradebook module is used to display grades and outcomes obtained by students for each activity or test. These components help teachers to track students learning progress throughout the whole course period.

The modular architecture of the system was designed to be general and domain independent. Out of the above modules, the progress bar, competencies and gradebook can be taken as the common modules of any TEA system. Both the skill assessment module and the knowledge assessment module are domain dependent. The system can easily be integrated into any computer engineering curriculum course by mainly adapting the skill and knowledge assessment modules.

The users logged into the LMS of the educational institution can automatically navigate to the TEA system through the single sign-on facility provided by the IMS Learning Tools Interoperability (LTI) specification [51]. The principal concept of the LTI specification is to establish a standard way of integrating rich learning applications (often remotely hosted and provided through third-party services) with platforms such as learning management systems, portals, or other educational environments. This allows a seamless learning experience for students who gain access to rich applications that appear to take place inside the learning environment. Also, the modules within the TEA system are linked together using IMS LTI specification. For transferring data such as user data, grades, time spent and attempts, between modules, OAuth protocol [52] is used together with the IMS LTI specification. This protocol is used to secure its message interactions between the tools. The connection and the communication between tools are carried-out through both message-based and service-based connections. The proposed architecture of the e-assessment system can be illustrated as in Fig. 4.

4. Evaluation and results

The impact of introducing the formative e-assessment model to support and improve the learning process was evaluated following the action research methodology [54] and comprised two main activities: system testing and validation, in a real scenario.

For testing, a methodology was deployed in parallel with the system design and development process to evaluate the system. The testing methodology was comprised of three main tests, such as unit, integration and system testing. Under system testing, usability testing was also carried-out to observe people using the system to discover errors and areas of improvement. During testing methodology, the errors found were iteratively corrected under each test.

The validation methodology was defined with respect to a validation plan to verify the quality, performance of the system and the model, and whether it satisfies expected educational requirements and user needs. In other words, the objective of validation is to show 'proof of demonstration' in real life and show that the system and the overall process fulfill its intended purpose [54]. For validation methodology, a mixed-mode evaluation technique comprising both quantitative and qualitative techniques was used [55]. This was carried-out through a pilot study in the real online environment. For evaluation, conducting a pilot study is important as it allows one to identify whether there is a positive impact with respect to introducing the proposed model, then carry-out necessary modifications and introduce it into the actual classroom.

A first year Logic course in a Computer Engineering degree at a fully online university, Universitat Oberta de Catalunya (UOC) (http://www.uoc.edu), was selected as the scenario for evaluation. Logic is a course that requires a high level of skills acquisition in order to successfully understand the salient concepts. The Logic course, based on Propositional Logic and Predicate Logic, relates to other courses of a mathematical nature and provides student with logical–mathematical foundations that facilitate further study of courses from different areas of knowledge. It is a fundamental course in the whole area of programming languages because of its importance in providing algorithms of a good logical structure, and its relevance in formal verification and the derivation of algorithms. Within the area, it will be useful for subjects such as automata theory and formal languages. It is also essential for the study of databases following the relational data model, because the standard language is based on predicate logic. Overall, the Logic course was taken as a basis of a computer engineering curriculum.

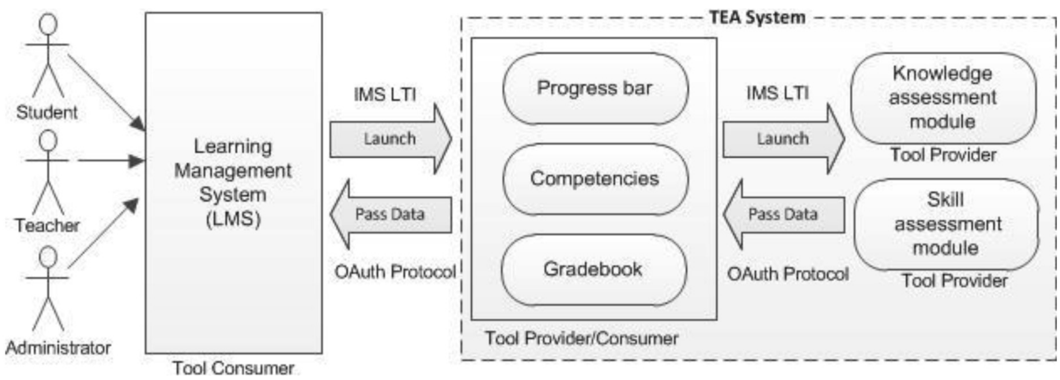

Fig. 4. Proposed architecture of the e-assessment system [53].

Also, since the system is developed according to a general modular architecture, it can easily be adapted to any other subject by changing the skill and knowledge assessment modules. For example, in programming subjects, the skill assessment module can be replaced with a module that can offer facilities to check the code of students in a step by step manner, while offering immediate constructive feedback and marks. The same method, can be applied to courses where it is needed to learn about construction of logic circuits, UML diagrams or databases.

Logic skills are also useful when learners are interpreting and analyzing problems. One goal of the course is to learn to formalize using the logic language. The skills and abilities required to formalize and to validate or refute arguments are essentially the same as those for detecting the problems of an incorrect specification. The contents of the Logic course are divided into eight learning modules and there is a significant interaction between them. Propositional Logic consisted of four learning modules such as Formalization, Natural Deduction, Resolution and Truth Tables. Predicate Logic consisted of another four learning modules, such as Formalization, Natural Deduction, Resolution and Semantics.

At the time of this research, according to the curriculum of the Logic course of the UOC, the assessment model of the standard Logic classroom, provided for 'standard' Assessment Tests (AT), which had to be completed after finishing two learning modules. The questions offered within an AT were the same for all students and, therefore, there was the risk of copying the answers from others. In addition to that, at the end of the course, students had to do a 2 hour face-to-face examination. Both the assessment tests and face-to-face examination were used as a summative assessment. Students were not provided with facilities for formative assessment. When calculating the final marks, 35% was given as the weight for the four ATs (understood as the continuous assessment mark) and 65% was given for the final face-to-face examination mark.

To incorporate formative e-assessment into the course for skill and knowledge acquisition, the proposed e-assessment model was introduced as an improvement to the assessment model of the standard Logic course through the developed TEA system.

For the evaluation, only one pilot study was used because it satisfied the requirements needed for the validation of the proposed solution. Before the use of the proposed model, formative e-assessment was not used in the Logic course. Therefore, our main aim was to evaluate whether the use of the system and the model to introduce formative e-assessment have a positive effect on students' performances. Also, whether the system can assist teachers to evaluate students' performances during the course duration.

To analyze the effects of introducing the proposed solution comprising the TEA system and the formative e-assessment model, quantitative and qualitative techniques were used. As for the quantitative techniques, t-student statistical analysis and Pearson correlation coefficients were used to evaluate the effects of using the system and the formative e-assessment model on students' performance. In addition, data automatically stored by the system were obtained to analyze the improvements in terms of practicing, and to evaluate whether it is possible to track students' performances during the course. As for qualitative analysis, a questionnaire which is anonymous and voluntary was given at the end of the course to obtain the students' perceptions about the proposed solution.

4.1 Formalization of the pilot study

For the pilot study, two classrooms of the online Logic course of the UOC were used. One classroom was taken as the pilot group, where the assessment was offered through the TEA system. The other was taken as the control group, which was the standard Logic classroom as explained before.

For the summative assessment, both groups were provided with the same final face-to-face (F2F) examination. Formative assessment was introduced only in the pilot group where students were provided with both Practice Tests (PT) and Assessment Tests (AT) according to the proposed formative e-assessment model. Both types of tests consist of questions for skill and knowledge assessment. As a summary, the assessment models used in the two groups can be shown as in Table 1.

As the Logic subject consisted of eight learning

Table 1. The assessment models used in the two groups

	Formative assessment	Summative assessment
Control group		Only skill assessment AT + F2F examination
Pilot group	Skill and knowledge assessment PT + AT	Only skill assessment F2F examination

modules, in the pilot group, students were offered eight PTs and eight ATs for continuous assessment, worth 35% of the marks. Therefore, for each learning module, students were first given a set of activities for both knowledge and skill as a PT with an unlimited number of attempts. In our implementation of the model, after obtaining a pass mark of 30% or more for each PT, students were allowed to move to the corresponding AT where questions were offered through the skill assessment module. The questions of the AT were offered in a randomized manner according to different difficulty levels and within a time restriction of 2 hours and three possible attempts. In addition to that, a final face-to-face examination, worth 65% of the marks, was given as the final assessment. The assessment model of the pilot group is illustrated in Fig. 5.

As a summary, the main difference between the control group and the pilot group is that, in the pilot group, students were constantly engaged in the TEA system for both practice and evaluation purposes.

4.2 Data analysis and results

The evaluation in a real scenario was done by comparing the pilot group data with the control group data, with the following propositions:

1. The TEA system supported formative e-assessment in terms of students' performance.
2. Using the TEA system and the formative e-assessment model helped in the final examination marks.
3. Using the formative e-assessment model helped students to improve their learning process.
4. Using the TEA system, it was possible for teachers to track the student learning process throughout the whole course.

These propositions were analyzed following the mixed method evaluation technique. For this pilot study, one Logic classroom consisted of 38 students was used as the pilot group, whereas another consisted of 28 students and was used as the control group. Results based on the four propositions mentioned above are explained as follows.

4.2.1 The TEA system supported formative e-assessment in terms of the students' performance

The experience with the pilot group showed that it was possible to introduce e-assessment in a course with a high need for skill assessment. It was shown that the learning process had improved through the formative e-assessment model and the facilities provided by the TEA system. One of the reasons was that students' had engaged more in the course through the system as they were satisfied with the facilities offered by the system. Another reason was that the formative assessment followed by the pilot group gave students a more reliable score in relation to their learning performance. Thus, their possibilities of passing the final examination were higher.

This could be further proved with the correlation coefficient calculated between the final continuous assessment marks and the final face-to-face examination marks. It was 0.7016 in the pilot group and 0.2284 in the control group; it shows a high correlation in the pilot group and no correlation in the control group. Therefore, it shows that using the TEA system in the pilot group has more reliability of the continuous assessment mark (no copying among students) and that the formative e-assessment model to perform continuous formative assessment helped to improve students' performances in relation to the final face-to face examination mark.

4.2.2 Using the TEA system and the formative e-assessment model helped in the final examination marks

To answer this proposition, a quantitative study was used. Under that, a t-student statistical test was carried-out on the pilot group and the control group. This was based on the mean of the qualifications obtained in the final face-to-face examination. As mentioned before, based on the formative e-assessment model, students had used the TEA system for practice and assessment purposes before moving to the final face-to-face examination. Therefore, the main aim was to check whether the use of the TEA system had a positive impact on the students' marks in the final examination. According to the t-student statistical analysis, there was not a statistical significant difference between the means as the *P* was equal to 0.04, although the mean value of the pilot group (3.86) is a bit higher than that of the control group (3.51).

We also analyzed the students' marks in the final examination, the semester just before the pilot study, the semester during the pilot study, and the semester immediately after the pilot study. Before the pilot study, the TEA system was not used in any

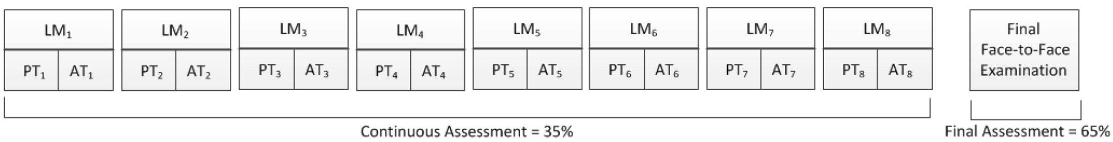

Fig. 5. The assessment model of the pilot group with eight learning modules.

Table 2. Improvement of students' marks and participation in the final examination

Final examination	Semester before Pilot study	Semester during Pilot study	Semester after Pilot study
Pass	40.8%	46.4%	54.8%
Attending	57.7%	62.6%	71.0%
Pass/Attending	70.7%	74.1%	77.2%

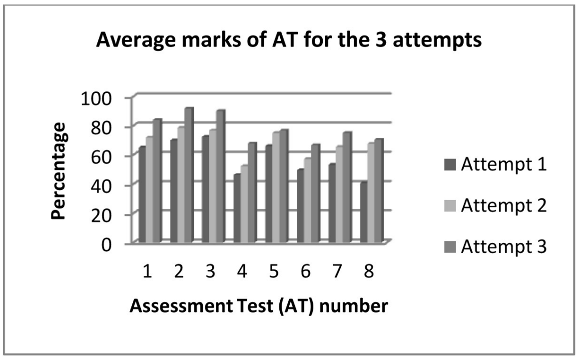

Fig. 6. Average marks of AT for the three attempts.

of the Logic classrooms. During the pilot study, student marks of both the pilot and the standard (control) classrooms were calculated and the mean of these marks was calculated. After the completion of the pilot study, the TEA system and the e-assessment model was applied in all the classrooms in the Logic course. Therefore, in the semester after the pilot study, all students used the system and it shows that both their marks and participation in the final examination had improved with the use of the TEA system and the model as shown in Table 2.

4.2.3 Using the formative e-assessment model helped students to improve their learning process

Under this proposition, first the impact of doing practice tests and then doing assessment tests were validated. The Pearson Correlation Coefficient between the final marks of the PT and AT in the pilot group is 0.915. Therefore, there is a high correlation between practice and assessment, which shows that the practice supported by the system helped the students in their learning process of continuous assessment.

Then, student data with respect to practice tests in the pilot group were analyzed based on the number of attempts taken and the way in which their scores have improved. Accordingly, it was observed that the students had spent eight or nine attempts in the first PT. This is due to the fact that students had used the tests more at the beginning to get familiar with the system and the practice tests. On average the number of attempts in all the PT was equal to two. For some tests, students have made more than three attempts. But it is interesting to see that students' marks have improved through these attempts. It shows that the more that students practice using the system, the more probability they have of obtaining a higher mark and improving their learning process.

Then a comparison between the practice tests and the assessment tests were carried-out to analyze the student improvements with respect to doing practice and then assessment. For this purpose, the average marks obtained by the students for each test were analyzed. These PT and AT were related as students had to pass one to move on to the other. Here, the aim was to analyze the impact on AT after doing PT. Based on the results, students average marks in AT had improved after doing PT. This had also been proved before with a higher correlation of 0.915 between doing the PT and then doing the AT.

Also, the average marks between three consecutive attempts for the eight assessment tests were also analyzed and accordingly the average marks had improved through the attempts as shown in Fig. 6. Therefore, as a summary, it can be seen that more students practice with the help of the automatic feedback and this has enhanced the learning experience of the students.

Finally, the students' feedback with respect to the implementation of the proposed e-assessment model was also obtained through a questionnaire, which was voluntary and was given after the completion of the course. Results are displayed in Table 3.

Overall, students were satisfied with the TEA system and the e-assessment model as it helped them to improve their learning process.

4.2.4 Using the TEA system, it is possible for teachers to track the students' learning process throughout the whole course

To track the students' learning throughout the course, data were obtained from modules such as

Table 3. Students' feedback to the proposed e-assessment model

It was helpful to practice using the system.	74%
The automatic personalized feedback provided was satisfactory.	89%
Marks obtained through the system fit the knowledge and skills developed.	89%
Tests helped to evaluate the skills and knowledge acquired.	74%
Tests were helpful for learning skills related to the course.	79%
Tests helped to understand the topics covered in the course.	79%
Tests helped to evaluate strengths and weaknesses in the course.	79%

the progress bar, competencies module and gradebook (outcomes were provided within this module).

The progress bar module was used to obtain the progress records of all the students. The average progress of students in the Logic course can be stated as 71%. The progress was calculated only after assessment tests had been marked and graded. As a conclusion, students had spent a considerable amount of time with the system and had also completed the tests assigned to them. As for the competencies module, 12 competencies were assessed based on the marks of the assessment tests. In order to obtain a particular competency, students had to obtain a minimum of 50 marks for the test. Overall, students had performed well in the Logic course with an average of 62% progress for all competencies. Even for the individual competencies, students were able to obtain a progress of more than 50%. Statistics obtained from the gradebook module regarding outcomes in the TEA system showed that the average course outcome was equal to 'Good'. Also, for all modules, student outcomes were either equal or above satisfactory. This can be taken as another indicator where students had performed well in the course. Therefore, through the progress bar, competencies module, and gradebook with outcome facility, it is possible for teachers to track student learning throughout the whole course.

5. Conclusions

The main goal of this research was to introduce formative e-assessment in computer engineering education to support and improve the students' learning processes. Under this, we proposed a general formative e-assessment model that offers both practice and assessment facilities to students. This model was introduced through a design and development of a standardized general e-assessment tool. The evaluation of the work described was performed in a fully online university and it was centered on the Logic course of the Computer Engineering degree. The Logic course was selected because it mainly requires students to acquire a higher level of skills than other courses.

Through evaluation, it was observed that due to the introduction of the formative e-assessment model, students were constantly engaged in the system for both practice and assessment purposes. As a result of it, students' performance in both the formative continuous assessment and final examination had improved. In particular, key elements of our proposed system, such as the progress bar and competencies module helped students to evaluate their own progress. The gradebook provided valuable information, such as marks, grades and outcomes obtained by students for each test. Overall, it can be stated that the proposed formative e-assessment model and the system had supported the students' learning process and as a result the students' performances had improved. Moreover, through the data analysis, it was shown that students had obtained the benefits of this model.

Furthermore, the proposed system helped teachers to track the students' learning process throughout the whole duration of the course. In addition, teachers could also obtain the students' practice and assessment data through reports such as logs, live logs, activity participation and course participation.

Overall, it can be stated that the introduction of the formative e-assessment model in a computer engineering subject, such as Logic, which was taken as a paradigmatic example of a course that has a high level of skill, had a positive impact on the students' performance and learning processes. In addition to that, the formative e-assessment model implies spending time with the system in practice and learning activities, as a central characteristic of the model.

As the system is developed according to a general modular architecture that can easily be adapted to any subject or context, by changing the skill and knowledge assessment modules, it can easily be used to contribute to any computer engineering subject that requires a high level of skill.

After completion of the evaluation studies, the system and the formative e-assessment model was applied in the real context of the online Logic course and, as a result, students' performances and participation in the course were also improved. As for future work, the model, along with the system, can be applied and tested in other contexts of both fully online and blended environments. Finally, with the ever increasing interest and adaptation of the e-assessment, this research had produced a model that is crucial in relation to the online educational environment, and is thus significant for further investigation.

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