Towards the STEM knowledge homogenization of pre-university students in 21st century

MOOC: The Language for Engineering

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***Abstract* —For the past five years, Engineering students from Barcelona School of Civil Engineer in UPC BarcelonaTech have shown that educational intervention in first-year engineering programs can positively affect students' awareness of Science, Technology, Engineering and Mathematics (STEM) concepts by introducing students to basics concepts and motivating them to follow next ones. At Terrassa School of Industrial, Aerospace and Audiovisual Engineering, also belonging to UPC BarcelonaTech, STEM concepts are strengthen to high school students by means of the Mercat de Tecnologia, (a science fair among schools) and by some recommended but not compulsory propaedeutic courses of basic subjects, carried out the week prior to the official start of university studies. Still, many students entering university show some lacks on theoretical items, particularly those who do not follow the usual way to access to tertiary studies after obligatory secondary education but a parallel and more practical one. In fact, there is a large heterogeneity in terms of the average previous knowledge of every subject as well as in the individual curriculum of each student, since they might have enrolled different courses before entering the university.**

Due to those lacks, some professors at both aforementioned schools have developed a MOOC oriented to new university students. The designed MOOC is useful in order to improve the basic knowledge of new students regarding these sciences.

Keywords — Engineering, self-learning, STEM, MOOC

I. Introduction

The Spanish university system includes public and private universities across the whole country with different fees depending on the type of institution (fully public, assigned or fully private) and also on the region where the university is located. Universities offer academic degrees approved by the Government and that must follow the European Credit Transfer and Accumulation System (ECTS). Particularly, all the curricula of UPC BarcelonaTech that lead to the obtaining of an official bachelor's degree in Engineering include an initial stage of 60 ECTS, corresponding to the first academic year, divided in 2 semesters of 30 ECTS. In this initial stage, students follow, among others, basic subjects such as Mathematics, Physics, Chemistry, and Technical Drawing in Engineering which belong to the metadiscipline [1] of Science, Technology, Engineering and Mathematics (STEM).

In the academic year 2014-2015, the global enrolment in bachelor's degree at UPC BarcelonaTech was of 4,187 new students. The 77% of them where accepted through a weighted average of the high school qualifications and the results of a regional A-level exam, whereas about a 10% of students were admitted after obtaining a sort of associate degree which deals with more practical and technical education. The rest of students enter the higher education by particular entrance exams for adults.

However, the number of students who complete the degrees is lower. It is noteworthy that the current regulations of UPC BarcelonaTech enforce a minimum academic progress in this initial stage. As a general rule, a student who enrolls in a bachelor's degree course must pass at least 12 ECTS credits in the first academic year, regardless of the number of credits for which the student enrolls. Additionally, depending on the school, students must pass between 42 and 60 ECTS of the initial stage in a maximal period of 2 years. If students fail to meet these requirements it is assumed that they have not attained the minimal skills to appropriately follow Engineering studies and, consequently, they are removed from the course and are barred from beginning any other course taught at the same school that shares the same initial stage [2].

Hence, it is clear that in order to maintain the enrolment in the university, students must demonstrate a good knowledge of the aforementioned basic subjects. Unfortunately, the evaluation of the performance results of the last 4 years shows that the percentage of students who fully pass the 60 ECTS credits of the initial stage during the expected period of 2 semesters does not reach the 50% (43.9%, 45.3%, 44.2% and 48.0% respectively since academic year 2011-12 to 2014-15). It is difficult to identify the key factor responsible for such situation but the results of an in-house survey carried out with freshmen pointed out 2 main reasons: i) students admitted that their prior knowledge of basic subjects was below expectations and ii) students did not correctly understand the technical and practical language used in Engineering.

In order to improve this situation, a multidisciplinary Massive Open Online Course (MOOC) entitled "The Language for Engineering" has been elaborated to offset the initial deficits of students regarding some both basic and specific skills by reviewing certain key subjects. That might help students to successfully address the subjects of the initial stage while becoming familiar with the language for Engineering that will be common through the entire university period and professional life.

This transversal MOOC is intended to contribute to the improvement of the learning process of alumni and it is structured in 5 different modules corresponding to 5 subjects common to many Engineering studies: Mathematics, Physics, Chemistry, Technical Drawing and Automatic control. The course is aimed not only for future students of any bachelor's Engineering degree but also for those who are already in the first years of the same. In fact, any person accessing university could be a target student.

Based on the historical origin of UPC BarcelonaTech students and on the increasing number of exchange programs involving Latin American universities, Spanish has been chosen as language for this MOOC, with the aim of reaching a broader audience.

II. STATE OF THE ART

New and advanced technology has allowed institutions of higher education to deliver courses and degree programs to students through the internet. Different approaches can be implemented depending among others in the physical-digital, local-global and formal-informal dimensions [3]. Following such reasoning, MOOCs are platforms for delivering courses for free to anyone with an internet connection [4], [5]. MOOCs are often categorized as extended MOOCs (xMOOCs), connectivist MOOCS (cMOOCs) and quasi-MOOCs [6], [7]. xMOOCs replicate online the traditional courses with saved video tutorials, quizzes and assignments. They are offered in a traditional university model such as Stanford (Coursera) [8], MIT/Harvard (edX) [9], and Udacity [10]. cMOOCs are based on a connectivist pedagogical model that views knowledge as a networked state and learning as the process of generating those networks, in this case using online and social tools. Quasi-MOOCs provide web-based tutorials as the MIT's OpenCourseWare (OCW) for specific tasks learning and consist of asynchronous learning resources that do not offer the social interaction of cMOOCs or the automated grading and tutorial-driven format of xMOOCs.

In general terms, MOOCs offer a middle ground for teaching and learning between the highly organized and structured classroom environment and the chaotic open web of fragmented information. Most of these courses exhibit common characteristics that consist in massive participation, online and open access, lectures formatted as short videos combined with formative quizzes, automated assessment and/or peer and self–assessment, and online forums and applications for peer support and discussion. MOOCs can also be used to enhance the learning content in hybrid courses, giving students knowledge from expert faculty and allowing the teaching faculty greater freedom to use class time to discuss subject matter rather than the delivery of content [3], [11], [12].

Regarding the contents, very often MOOCs are subject-driven and are used to provide specialized information of a single topic. However, there have also been some attempts to use this tool for basic knowledge assurance, [13], [14], [15].

III. MOOC. The Language for Engineering

A. The project and its implementation

The MOOC "The Language for Engineering" is an innovative and efficient proposal that aims to facilitate access of students from high school to the university. It is noteworthy that the project was born from the university with a close collaboration with high school teachers.

As a key point, the MOOC allows for reviewing some basic concepts of the essential subjects related to Engineering as a whole, aiming to achieve a threshold level in every topic. Accordingly, this MOOC is organized into topics for students to focus on those that have been identified as more difficult for them. Questionnaires allow to evaluate the progress of the student and the working environment is very graphic, practical and entertaining. It also allows flexible and inclusive study. On the one hand, students can improve the subject anywhere with internet access. On the other hand, they can choose the rhythm of the subject to follow, and so they can go over the material as many times as necessary.

Working with the general methodology of the project, each item follows this development: 1) an initial level test, which measures student's previous knowledge. 2) theory and exercises videos and self-contained lectures notes and 3) a final level tests. Moreover as a key point to motivate the students, some gamification items are provided in the form of awards or gifts which include either games or advanced contents only available when some outstanding marks are achieved. Some examples of gamification items are mathematical games, crosswords, Engineering applications, lab tests videos and links to scientific results and novelties.

The basic subjects in the Mathematics module are: exponential equations, logarithmic equations, derivatives, integration, optimization problems, representations of functions, trigonometry, matrices, determinants, systems of linear equations and geometry. Some examples of gamification are:

- Introduction to spherical trigonometry: interactive application which allows manipulating spherical triangles. The addition of angles is not constant. The student must obtain the maximum value.
- Gram´s Determinants game: the user plays against de system writing zeros or ones in a three order squared matrix. When writing zeros, the system responds with ones alternately. The user's target could be to get a zero value for the determinant while the system tries to obtain a nonzero value, or vice versa.
- Personal magic matrix: this is an arrangement of distinct numbers in a square grid where the numbers in each row, each column, in the main and in the secondary diagonals, all add to the same number,

called "the magic constant". The user can obtain a personal matrix with his/her birthday in the first row and equals to the magic constant.

- Introduction to binary numbers. Especially on explain the properties of number 73 and link with the home page of the series "The Bing Bang Theory" where it is developed extensively.

The Physics module is organized into 12 items. Each item has a theoretical explanation, many exercises and a video with a solved example. First 7 items cover classical mechanics. After the seventh lecture the student can get the award of playing with and building an incredible machine using Newton laws. Chapters 8, 9 and 10 introduce fields, so they open the door to electricity and magnetism knowledge. The Physics module finishes with an introduction to vibrations and waves.

The Chemistry module implies 20 hours of student dedication and it is structured in 7 sections. The gamification of this part is based on the game module of Moodle and includes different kinds of games: the Hangman game and several quizzes in different formats (Snakes and Ladders, Millionaire's game, Crossword and Word Search). After passing each section, students must achieve the following skills:

1. Interpret the basis of the chemical language: Atoms. Atomic number, atomic mass, mass, isotopes, mole. Elements and the Periodic Table. (3 videos).
2. Interpret the basis of the chemical language: Oxidation states. Chemical bonds. Types of compounds. (4 videos).
3. Name and formulate the most important inorganic compounds. (4 videos).
4. Name and formulate the most important organic compounds. (10 videos).
5. Distinguish the states of matter and the corresponding changes of state and use the ideal gas law. (5 videos).
6. Apply the magnitudes of measurement of matter and calculate concentrations of solutions. (3 videos).
7. Balance chemical equations, identify the limiting reagent in a reaction, determine the amounts of reagents and products involved in a reaction and apply the stoichiometric calculations for the determination of yields, purities, and compositions. (3 videos).

Nowadays, in most of the Engineering degrees there is no obligation to have any background in Technical Drawing and elemental geometry. This is not helpful for the students because these subjects are much related with the development of capacities such as the spatial intelligence. It needs time and practice rather than concentrated studying hours. Consequently, the main goal of the Technical Drawing module is to provide the basic knowledge at high-school level for these subjects. It is very convenient that the students could train on their own, before the first university course. The module is currently divided in 2 main blocks: Multiview orthographic projection and basic geometry concepts. In the first part, students need to understand the concept of projection. The Multiview system is introduced in a simplified way: only 3 views at the same time (plan, elevation and some lateral view) and considering "first-angle projection". The figures are introduced progressively: those with only plane surfaces first and figures with curved surfaces afterwards. The second part covers basic constructions and concepts of two-dimensional Euclidean geometry. None of the concepts is theoretically proven and they are only introduced from a procedural point of view. The considered topics are: elemental concepts (such as scale, perpendicular bisector or arco capaz), regular polygons and the construction of the most common tangent lines. An important limitation is that the learning is passive. The student just watches videos, read documents, and choose options. In most of the evaluation tests the students need to choose an image among four. This image can represent a view or the correct geometrical construction/concept. This is not optimal, in the sense that technical drawing is a very practical subject. The final goal should always cover some type of project or real drawing. In that situation the students must construct a representation on their own which is very different than choosing a correct option. The current implementation of the module deals with the first part of the learning process: concepts. A second and more practical phase is required. In our case it is done during the standard university course.

The Automatic Control module is structured in 13 items gathered in four main areas:

- Modeling. Static and dynamic models of dynamic systems are treated; the static ones consider the process on steady state operation while the dynamic ones determine the transient response of the process in front of changes on the input signal. The Laplace transform is also reviewed since it is the powerful tool being used for operational calculus to solve differential equations of dynamic systems. Finally, the linearization of non-linear differential equations is explained so as to obtain a linearized model making possible the application the classical control theory tools.
- Analysis. The time response of first and second order systems is presented and analyzed.
- Feedback. Two main features of the feedback of dynamic systems are explained. First, stability by means of the Routh's criterion is presented and the conditions under which a feedback linear system is stable are stated. On the other hand, the precision or steady state error which is the widely used measure of accuracy and performance prediction of a control system is explained. This measure allows defining which control structure is necessary to achieve the specifications for the controlled system.
- Design. Once the stability and precision conditions for the feedback system are assured the tuning of the controller parameters becomes necessary. Both empirical and analytical methods for tuning controllers are developed and explained. While analytical methods can stand specific characteristics for the controlled system, the empirical ones fulfill specifications such as a concrete damping factor or the minimization of some criteria on the control error.

For each item a short video recording is available and a brief description of the issue is explained.

In the beginning of the project, the UPC BarcelonaTech was working to evaluate which MOOC platform would be the best to use as an institutional platform. For this reason, the MOOC "The Language for Engineering" was initially implemented using the same technology platform that supports the University's virtual learning environment based on the Moodle system. The main advantage to do so was that our teachers already had a working knowledge of this tool. Finally, we decided to run the MOOC on the UCATx platform (http://ucatx.cat), which operates on an Open edX software stack. We feel that this platform offers not only more visibility but also more appropriate features for these courses. UCATx brings together an entire catalog with all the MOOC's offered by 12 Catalan universities and offers a variety of course elements such as resources, activities, etc. This helps to achieve the goals of our MOOC, especially with quizzes and resources for self-evaluation which allow students to advance at their own pace. It also emphasizes the capacity of the platform to integrate with "WIRIS quizzes" creating advanced questionnaires with functions related to mathematics and Engineering.

Gamification is another innovation resource used in our MOOC in order to make the content more attractive and engage and encourage students to advance through the course. As aforementioned, we have created several advanced games programmed externally and linked to the platform using protocols supported by Open edX.

In addition to the platform we rely on the help of our IT services to facilitate a user friendly production of educational contents in high resolution video which will be hosted on the institutional YouTube channel.

All the alumni enrolled in the MOOC and belonging to any of the 2 schools of the UPC involved in the project, will be invited to participate in an assessment survey at the end of their first academic year with the aim to perform an assessment of the impact of the MOOC course in their academic progress and their grades.

B. Technical innovation and cooperative innovation

After having developed a large bank of questions for each topic in the project such the students could assess themselves and get feedback after few lectures, we developed the WIRIS quizzes [16]. WIRIS quizzes is a new system based on the WIRIS CAS technology, an online Computer Algebra System which allows to compute mathematical calculations on-line as well as produce mathematical contents, that is growing up to provide Moodle questions with random and new values. The main goal of this software is to allow the course instructors to create a random family of quiz questions just by programming one through variables than can take random data. It is, every time the questions are opened to be done, it displays random and new data values. Moreover, these new and random values are calculated online and in real time.

WIRIS quizzes enhance the computer-based assessment in science and are never used as an isolated application but appearing inside an existing Learning Management System (LMS), like our MOOC project, integrated with the Open edX platform [17], [18], [19] and [20].

The cooperative work among university and high school teachers significantly enriches this project, giving a broader view of the profile and the current weaknesses of the students in their stage of high school education to enroll in university courses in the Engineering field. During the secondary education, many concepts are given to students but some of them are not fully assimilated or it might be helpful to revise them before university. In parallel, university professors do not know the curriculum given in in secondary education and, consequently, they can fall into the error of taking some knowledge for granted. The university professor should fill these deficits of knowledge in the first university course but it is important to look for extra tools to facilitate knowledge and learning and make them available to the student. Therefore, a close cooperation between the two academic worlds is extremely necessary.

IV. CONCLUSIONS

So far, all the stages of the project have been successfully carried out as originally planned, and it has been possible to correctly manage all modules with the participation of a multidisciplinary team. The course has been tested by temporarily enabling the Technical Drawing module. Such preliminary experience has been useful to detect the needed improvements. Nowadays, the transfer of the course to a new platform is completed and it is expected that this marketing strategy will substantially increase the course diffusion and accessibility. Future work will be focused on the implementation of the course, evaluating key concepts such as participation, completion rates, average grades. Particular attention will be paid to alumni belonging to any of the 2 schools of the UPC involved in the project, so as to have a first impression of the course efficacy.

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