Follow-Up on a Numerical Methods Course Using m-learning and Proposal for an Evolution to Research Based Learning

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***Abstract*— Education is changing deeper than at any other time with the constant improvement of information and communication technologies. Particularly, the last five years have brought a fast inclusion of mobile technologies in education at all educational levels. This work presents a modern vision for a numerical methods course for engineers integrating mobile applications into a blended learning strategy. It currently combines class, Web and mobile activities to reinforce and to develop the basic knowledge proposed in the curricula. A five years follow-up is developed to evaluate its performance. Outcomes suggest moving the design into pure online learning to introduce new improvements in the course goals. The improvements are realized by the inclusion of a research-based learning component. The proposed approach could become a differentiated and flexible scheme of instruction powered by mobile applications, but introducing a new version based on project-oriented learning.**

Keywords-m-learning; b-learning; math; course design; assessment.

I. INTRODUCTION

Nowadays, several educative tendencies are identified with the acquisition of technological skills as part of a successful professional life. Today, new generations have based their learning expectative on some kind of technology. Prensky [1] states that today's students are native speakers of the digital language of computers, video games and the Internet. Instead, people born before, digital immigrants, have a limited dominion of these technologies. It sets a natural division among these generations. Technology is related to a more accessible and cheaper education. Today, the low quality perception of education based on technology is decreasing, while increasingly it is being considered more engaged and personalized [2].

Currently, mobile technology is the real option to be connected with the world and the information. In 2013, mobile technologies became the main media to reach the Internet [3]. Consequently, it is evolving into a creative medium where education can reach effectively the people. In terms of sensory stimulation and learning styles being privileged [7], several authors have stated deep relations between the general history of distance learning and the chronology of the generations involved [4][5][6]. Johnson et al. [8] described the impressive short time of adoption of mobile technologies, including in education. Today, many apps and tools allow the development of educational products directly; the perspective is open to educative innovation based on technology. Members of university faculty have been reluctant to adopt educational technology, but this situation is changing very fast.

Numerical methods course is mandatory in engineering programs. This discipline has evolved in the last decades, together with information technologies. It has changed its traditional teaching with the spread of computer systems and their implementation in the universities. Therefore, the specific course presented in this paper has transitioned from a numerical analysis course into a computer simulation course in only ten years. It includes the computer visualization of technical and scientific problems to boost the research abilities [9]: curriculum integration, use of technology, and development of higher level skills. In this evolution, several technologies have been used to state its mobile management and to carry out a mobile learning approach [10].

The aim of this paper is to report the advancement of technology in the numerical methods course in the last five years while the mobile revolution was developed. A detailed analysis of the online evaluation is given together with the usage analytics of the current resources included. The results suggest alternative and flexible instruction schemes for the basic skills acquisition. This flexibility proposes the next step in the evolution course as an open online course still combined with face-to-face sessions to conduct challenge integrated problems under an open research scheme. Section II describes the mobile learning strategy using activities delivered through several media and tools. Section III analyses the efficiency of online evaluation predicting the basic skill development based on the usage of these activities. Section IV discusses the potential design to evolve the course into a Small Private Online Research (SPOR) supported by mobile learning and a series of research problems to be solved in class. Finally, Section V includes the conclusions and the future work.

II. COURSE DESIGN AND MOBILE DEVELOPMENT

A. *Historical course description*

Requirements for engineering education are based on the technological advancement, imposing the adoption of new technologies. The numerical methods course depicted here has evolved this way. Ten years ago, it sparsely contained a limited use of Fortran or C^{++} as a programming language, a limited time of programming practice, and applied problems were rarely included. Since then, the use of technology has increased significantly: Mathematica [11], Python [12] for programming and visualization, as well as Blackboard [13] to deliver digital course materials and online activities. Those technologies boosted the Problem Based Learning (PBL) and Project Oriented Learning (POL) [14][15] strategies in the course, reducing the gap between academic and professional engineering [9]. It was the course stage in 2008, before mobile and blended learning were introduced.

B. *M-learning transitions and current design*

In 2011, the author was involved in an institutional effort to develop and promote the use of mobile technologies in all higher education faculties [16]. Then, after Blackboard, leaner technologies were used to replace this tool with tailor-made tools such as Winksite [17], Weebly [18], Googledrive [19], Jotform [20], Wolfram Alpha [21], Socrative [22] and Classmarker [23]. Another key element was a public You Tube channel for the course, including screencasts for each topic in the course. Digital programming codes were included and then followed by the students at their own pace. Surprisingly, most of the users became informal users in other universities and countries, gathering almost one hundred thousand accesses in three years. These technologies allow to deliver the media resources and the online activities directly on mobile devices dealing with some weaknesses in the curricula and carrying out periodic computer quizzes in class or online. In 2008, an e-book was prepared for the course. It began to be distributed on Amazon and i-store as a new mobile version in 2014. Finally, in the newest version of the site, the programming component of the whole course can be followed online, theme by theme, through sixty screencasts.

Despite some of last developments required necessarily the use of laptops in the beginning (in particular for PDF documents and Mathematica files involving homework, resources, etc.), in the current time, the technology evolution has generated PDF mobile viewers and the development of Wolfram Cloud (deployed in the version 10.0 of Mathematica), allowing a complete transition into mobile management using cellular phones or tablets, the final target for which began to be prepared some years ago.

Figure 1 depicts the course evolution into m-learning in terms of the technology added, spaces and management. All of them were deployed to set the schedule of online activities, delivery, and feedback. It includes evaluation with online quizzes and exams, which substitute some of the in-class evaluations. Other elements and activities give the assessment in programing and numerical implementations.

Despite the fact that these activities were primarily introduced to provide support in some weak learning areas, they grew to become naturally integrated on an official mobile site (Figure 2). Inclusively, some of them, as assessment or evaluation have replaced some face-to-face practices with good performance [10]. Under this blended scenario, the impact of the online activities should be evaluated in order to determine if they are a strong replacement of some traditional elements in the learning process.

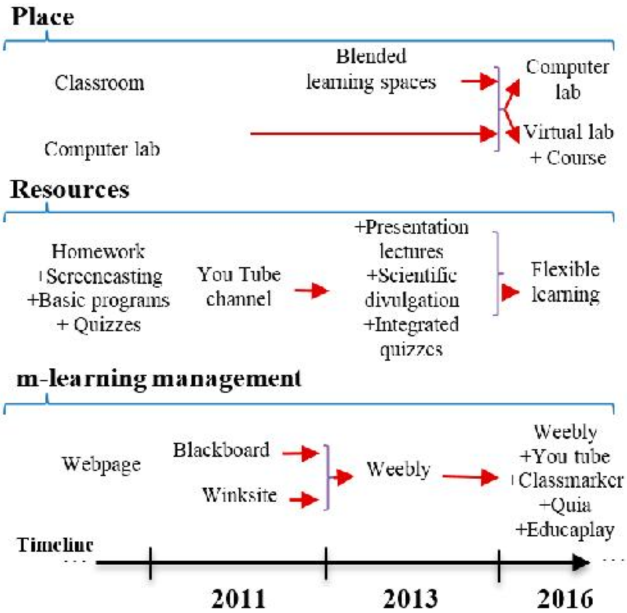

Figure 1. Five years of m-learning implementations in the numerical methods course in terms of tools, activities and resources.

III. Effectiveness of Mobile Resources

The numerical methods course evolution in the last ten years introduced technology in the classroom as a mandatory policy [10]. Due to this improvement, students are expected to be more skilled. It has required additional support to face-to-face instruction to scaffold the programming practice. In addition, several years ago, the inclusion of integrated scenarios in PBL and activities based on POL promoted the curriculum integration, seeking a more professional practice to develop engineering competencies [24]. Unfortunately, two last improvements have a time conflict in the course with respect to the necessary coverage of the contents. For these reasons, the mobile revolution began providing resources to address such conflict [9]. Today, the course is fully reached and covered by mobile devices (an achievement of the last five years), so a concrete assessment about their increasing intervention in terms of basic knowledge assurance is in order. This evaluation could suggest moving the basic coverage of theory into online instruction, the centre of attention of this work. This action could free time in the face-to-face sessions to solve integrated and complex problems related to the basic contents, in particular, short engineering and science research problems requiring analysis and visualization.

A. *Research objectives*

When the online activities were gaining terrain, including evaluation, the following question arose: could m-learning

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materials replace parts of the face-to-face instruction? There are sufficient structured materials for that: repositories, class videos, programs, theoretical class lessons in slides, mobile management, and continuous online evaluation. Most of them are open to the students to improve their performance in the course. But, what is the interest to substitute the face-to-face instruction by a mobile one?

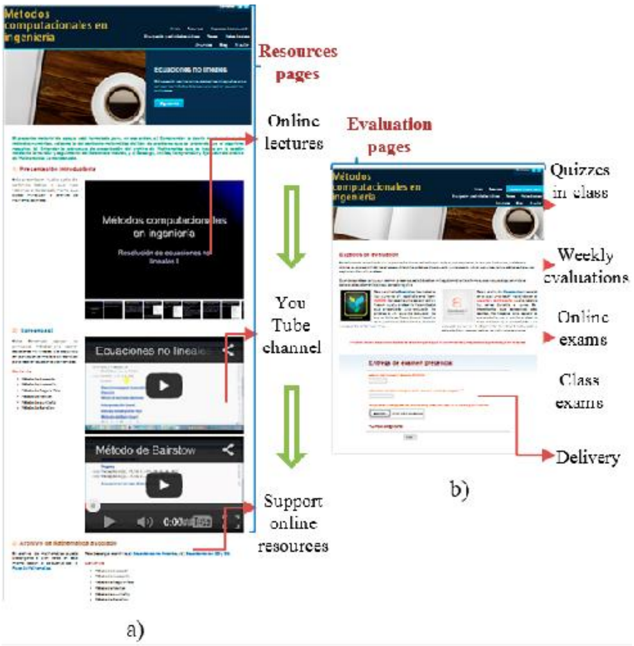

Figure 2. Views of numerical methods course site: (a) Section resource site, and (b) Evaluation section.

In numerical methods, the application of knowledge to challenge open problems is a more valuable educative task than just to learn the basics. Despite this, the first stage is normally reached when the second one is effectively done. Not all the numerical methods in the course are significant for all disciplines (and normally in the current professional practice some specialized software is used to solve attained problems). Thus, a combined structure including knowledge of numerical methods, programming and applications is finally more representative in terms of skill development. The main research question in this work is about the current mobile elements showing effectiveness in the teaching task of basic knowledge to address the face-to-face sessions into challenge problems solving.

A mobile implementation requires a deeper analysis of elements included and, in particular, from the evaluation conducted there. Currently, there are not sufficient criteria and specific analytics introduced in the mobile site to evaluate that. Despite this, there are historical usage analytics and quantitative information about for the online evaluation to get an introspective evaluation of those resources. Thus, the research objectives in this work have been settled as: a) to compare the effectiveness of online evaluation versus in-class evaluation, and b) to analyse the actual usage data to inquire the assigned value to the resources.

B. *Effectiveness of online evaluation*

On the course site, formative and summative evaluations are carried out with Socrative and Classmarker tools. It includes the access and the delivery of those evaluations through the forms developed in Jotform and integrated with Googledrive to submit the associated Mathematica files. In the last two years of the period considered in this work, partial evaluations have substituted the in-class evaluation. The final evaluation continues to be an in-class exam. This aspect is linked to the first research objective.

To address the corresponding analysis, the grades for the students in the last two years (2014-2015) will be considered. The results are presented in Figure 3 and the methodology is as follows. The ratio I/T between the averages of individual online work and online teamwork is considered for each student (it helps to discriminate the case when bad performance students obtain good teamwork grades). Then, I/T is related to the average of online evaluations in Socrative and/or Classmarker, but grouping students in three classes as a function of their final total grade (on a 100 point scale) and then deployed in Figure 3: a) less than 70, the students failing the course (black), b) between 70 and 85, the average students (red), and c) more than 85, the good performance students (green). Figure 3 includes three elliptic shades showing the mean and standard deviation for each axis parameter in each group. The horizontal dotted line marks the institutional limit to fail the evaluation. For the students with good performance, this graph exhibits a deep consistency between online individual work and teamwork together with a clear consistency in the online evaluations and the final grade.

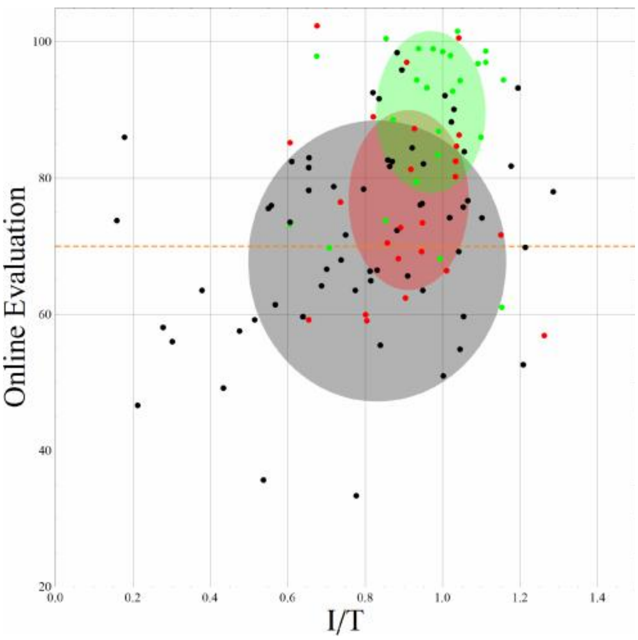

Figure 3. Analysis of effectiveness in the online evaluation.

For the students who failed, the dispersion is wider and the promotion is only barely predicted by the online evaluation, suggesting to keep the final in-class exam as a differentiating element.

C. *Analysis of usage statistics*

As was stated by [10], the mobile technology was first used to scaffold the potential learning weaknesses in the course. The repositories (simulations, programming codes, projects and applied complex problems) are constructed to follow the face-to-face sessions and the e-book content. Particularly, screencasts in the YouTube channel are integrated on the site as part of a three stages based learning methodology: a) online notes and lectures (in slides), b) screencasts, and c) downloadable Mathematica materials (as support to each screencast). They were primarily used to replace the face-to-face instruction for the students missing the session with a minimum of teacher tutoring. In addition, the daily class notes are downloadable files in another section. Finally, individual work and teamwork normally are online activities where a Mathematica file should be submitted. Class announcements and scheduled activities are published on the site. The blog contains questions, answers, and discussions about the course topics. The second research question can be addressed through the access analytics introduced in the last resources. They record the formal and informal students accesses (identified as the overseas students in the analytics) to each site section, revealing the demand on the open access resources.

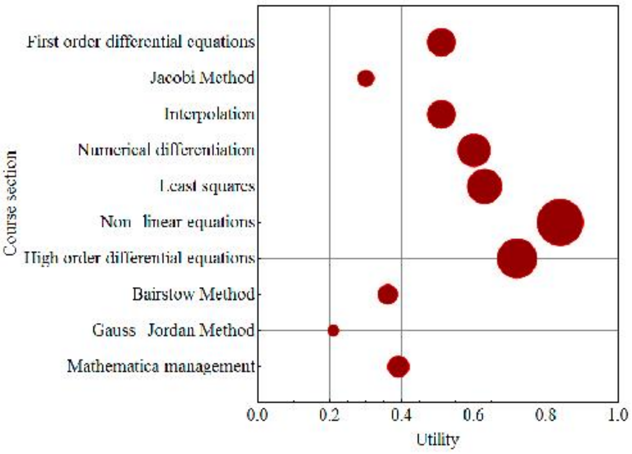

Figure 4. A utility index based on the percentage of visualization time versus Demand for each screencast on the mobile site.

The methodology to analyse this question was split into two parts. The first one is represented in Figure 4, where the average fraction of visualization (the part of the screencast effectively viewed) for all accesses is represented on the horizontal axis as a measure of the resource utility (1 means the best utility and 0 the worst), while the radius of each dot represents the relative percentage average with respect to the total accesses. Thus, the non-linear equations screencast is highly useful and strongly reviewed by a great number of students. While, for instance, the Jacobi method screencast is a resource highly reached by the students, it appears it is of little use because only a small part is effectively reviewed. The second part of the analysis is based on the usage of the different sections on the mobile site as a blended support to the face-to-face instruction for the formal students, as well as online resources for the informal ones. Data are shown in Table I for the 2014 users (near of 2000 accesses), where percentages were calculated for their own group. It reflects that the resources are valuable for both groups, as expected. Statistics for formal users show the Resources section as the most requested, while Resources and Daily notes sections are the most requested by informal students.

TABLE I. ACCESS STATISTICS FOR FORMAL AND INFORMAL STUDENTS BASED ON THEIR OWN GROUP

Sections	**Access percentage analytics for numerical methods site (2014)**	
	Formal students	***Informal students***
Resources	51%	53%
Evaluation	13%	1%
Homework	18%	2%
Daily notes	9%	37%
Announcements	6%	0%
Blog	3%	4%

D. *Discussion*

Summarizing the previous analysis, it suggests the online evaluations can substitute the whole basic knowledge evaluation, opening a wider horizon of flexibility based on a selective substitution of the traditional face-to-face sessions by the mobile learning resources (notes, screencasts and support files). The methodology discriminates which screencasts are being effectively used and which should be improved. Statistics suggest the importance given to these resources; nevertheless a deeper monitoring is still needed with more precise and linked analytics. Comparison between the two current communities (formal and informal) measures how the resources are valuable inclusively for the non-enrolled students.

Last outcomes are pretended to be taken as a support to use the mobile resources as a genuine space of online instruction to make room for a different learning approach oriented to solve open research and curriculum integrated projects. The new approach should address the course goals, taking care of the effectiveness of online learning strategy for the basic contents, still in the course basements.

IV. SMALL PRIVATE ONLINE RESEARCH APPROACH

Some years ago, the inclusion of complex integrated problems began in the course. Then, the development of the ability to solve applied and contextual problems (settled on engineering sciences) was shown in terms of deepness and knowledge usability (more than in grades improvement) [9]. This experience has been barely included, due to the limited time. Currently, the mobile scaffolding for the basic knowledge acquisition (materialized in the last years as

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concrete resources) opens an approach based on short research projects. The current section depicts this briefly.

A. Curriculum integrated education

More than fifteen years ago, the author was involved as a teacher in a curriculum integrated educative program in engineering. There, students had developed lifetime skills in research [14]. This practice has been carried out in other scenarios as single courses applying curriculum integration. The numerical methods course has been settled as this kind of courses due to its position in the curricula (after math and sciences courses and together with the beginning of engineering sciences courses in all engineering programs) [9][10]. Philosophy of curriculum integration matches research problems as a central goal in a course or group of courses. They normally should be solved with a multi-approach discipline based on the past, current and future curricula. This approach requires being considered as the main guideline in the course while basic knowledge apprehension becomes a subsidiary activity. Thus, mobile scaffolding can work a subjacent learning support to this implementation, if the previous conditions are fulfilled. Some pitfalls should be prevented [14]: a) the absence of basic knowledge spaces being included to clarify contents; b) the omission of a modified evaluation to include this kind of new skill development; and c) the absence of flexibility to fulfil a basic knowledge evaluation agenda.

B. The SPOR approach

As was stated before, the explicit development of technical skills related to numerical methods could be based on the use of mobile technology as scaffolding to substitute the face-to-face instruction for the basic contents. It frees most of the class time to introduce the open scientific or engineering problems solving based on research. This approach is referred to as Small Private Online Research (SPOR) due to the fact that the main contents are covered online, but the emphasis is on the research conducted in the face-to-face sections in a controlled size group. In it, a curriculum integrated approach should conduct the learning goals (instead of the dominion of basic knowledge), warranting a personalized evaluation of performance.

Due to the diversity of engineering programs attended in the course (industrial, mechanical, electrical, chemical and biotechnological), SPOR approach will require several parallel contextual problems based on the interest area of the students. The learning of basic knowledge rests on the online activities, requiring a deep effectivity of the mobile resources, including the associated evaluation. This orientation requires to restructure the current mobile site into a more concrete modular scheme, including resources and evaluation on each main topic in the current syllabus. This structure prepares and evaluates each student at a minimum allowed performance. The evaluation should be completed considering the contextual problems assigned in the course (individually or in teams). Results in the present work suggest widely this new step in the course evolution is affordable, but it requires the inclusion of more precise analytics and an effective evaluation to measure the learning outcomes at the basic knowledge level. Clearly, if students work in teams on the contextual problems, a differentiated evaluation should be required.

Currently, a semester deployment of this approach is running. There, a repetitive evaluation of basic knowledge in the course is applied together with a skill evaluation through the net of research projects. A complete mobile coverage of contents is developed through detailed screencasts and maker-based activities. Online evaluation of the basic contents of each course unit is applied up to three times at the own pace of each student to let him/her improve. Most of the face-to-face sessions are oriented to present, develop and work on open research problems based on scientific visualization.

V. Conclusions and Future work

Numerical methods courses have been evolving in the last decades by their natural approach to technology. Currently, the numerical methods course presented here is being developed and improved by sharing and discussing initiatives with colleagues in the faculty (who already have adopted the use of the computer lab and developed similar mobile resources). Faculty is prepared with a stronger training in new technologies to introduce blended learning scenarios. The potential developers of SPOR approach shares the interest to adopt the online-based instruction for the basic knowledge to then adopt the open research scenarios to guide the covering of contents.

For the numerical methods course depicted, the proposed improvement means not only to design a set of contextual research problems, but also a directed group of activities through several tools and channels covering the proposed learning objectives and supporting the individual monitoring of each student. The outcomes in the current work present a preliminary design of a mobile site with five years of mobile development. It includes elements working in the online education arena, but now being used under a different blended strategy. The analysis has shown that they can work under a pure online orientation in a controlled scheme introducing more specific analytics to assess their performance in the learning process. This change will free the face-to-face sessions to set the SPOR approach, a course version aligned with STEM initiatives [25].

Future work in the last direction should prepare more robust blended strategies linked with a net of parallel research problems covering the different interests for engineering students enrolled in the course. For the faculty, it is an opportunity to move the learning impact into professional standards. The innovation proposed should change the teacher position into a more professional role. For the student, a self-directed performance is expected. In this trend, it shows an approximation to the new education trends supported by technology being required in the world.

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