Evaluating Engineering Competencies: A New Paradigm

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***Abstract*—The team that has developed this project is part of a consortium of several European institutions that have joined with a common goal: to help the current engineering teaching-learning system, so that to make possible a competencies-based assessment. Moreover advocacy and networking will be part of the consortium activities during the whole project. RULES_MATH acronym corresponds to 'New rules for assessing mathematical competencies', and that is exactly what we propose: to work with the mathematical competencies, specifically try to incorporate them into the assessment process. We focus on science and engineering degrees, since in all these studies several Mathematics courses are part of their curriculum, mainly in the first couple of years. In this paper we present one of our first activities that we want to achieve under the project: the selection of several tools and rules that will make possible an assessment and evaluation according to our high education common European space. These ideas are part of the objectives of promoting and institutionalizing good teaching practices and the enhancement of teaching materials. Other goals are to improve the dissemination of academic activities to the business world, administrations and society in general.**

Keywords—competencies; assessment; engineering; mathematics

I. INTRODUCTION

Because of changes in the Engineering Degrees curricula, and according to the guidelines of the Bologna Accord, monitoring student's learning to make them responsible for their learning process, is now required. It is necessary to implement more effectively a system of continuous assessment and competencies-based learning.

Additionally, there are serious difficulties in teaching mathematics to engineering students. One of the big problems is that engineering students use to find difficulties not only in learning mathematical contents but even more in acquiring mathematical competencies and be competent in mathematics. When we teach our Engineering students subjects such as Calculus, Linear Algebra, Statistics, etc, one of our main concerns is usually how we can motivate them to learn mathematics. Engineering students do not often see the relation of mathematics with others subjects, like electricity, mechanics, robotic, automatic, or electronic.

Very often, there are other problems as well: fear of mathematics lessons, finding the relation between mathematics and students future careers. Hence, we want to use realistic big problems in our classes, and solving them with the help of computer-aided tools. This will allows students to understand the true reach of a problem or the effectiveness of an algorithm.

For all those reasons, we consider that this RULES_MATH project (https://rules-math.com/) will have visible impact. Actually, our different groups that participate in the project have already published several papers, with particular examples, where the impact of this competencies-based learning has been measured. See "CAS and real life problems to learn basic concepts in Linear Algebra course" [1], for example. We were conducting a pre-test and post-test survey that includes 13 questions about math learning to different grades of Engineering. The identical pre-test and post-tests have been used to collect quantitative results to measure the advantages of this methodology. We noticed that student's satisfaction raised, and they understood better the relation and importance of mathematics in their real and daily lives or their future work. As a consequence, students participate more often in classes, and their grades were higher than before using these techniques. Some papers related to the project have been included in the special session of EDUCON 2018: "Evaluating Engineering Competencies: A New Paradigm".

Furthermore, the RULES_MATH project provides an opportunity for both students and teachers to be in contact with other teachers and students from other European countries, which means direct contact with other educational systems and cultures. This is the way in which our institutions can work in a multi-cultural framework and share ideas, experiences and

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methodologies, and also compare the different ways in which the participating institutions implement a new methodology using the ICT needed.

Some of our groups have worked together previously (as for example, in the papers cited above). However, we consider that this project will improve our relations, and it will facilitate the mobility of some of our professors and students, and these will strength future collaborations.

Thinking about mathematics, we want our students be able to think mathematically and in fact, to live maths as part of their daily lives. Trying to use maths in different careers, we started thinking for example in taxi driver work, a taxi driver could think that maths is not useful for him, as he asks the customer where he wants to go, the taxi driver takes him to his destination, give the customer the cost, takes the payment, and that is all. No need of understanding maths concepts. But in all this kind of proposals, trainers could give students the reasoning about mathematics explaining all topics included in this or other business.

A second part is that if we have an assessment activity, e.g. a rubric, for measure if the student is able to model a problem, we automatically need to reformulate our working methodology. Thus, we understand immediately that if we want from students to model an AC circuit, we don't need to tell them about fourth root $\sqrt[4]{i}$ or $\sqrt[4]{7+i}$. We, as educators, need to understand the meaning of the corresponding competence that we want to address.

The general idea in this study is to explore among all, if the assessment strategies we use are reasonable or not.

The first step for establishing an assessment method is to agree on the teaching and learning methodology, and later on continue with the assessment. Let us suppose that we are teaching differential calculus, so the student is expected to be able to calculate dx^2/dx, or know how to recognize the graph of $y = x^2$ and $y = -x^2$. This is simple and in this specific case we can focus on telling this. Or even we can tell learners a general mechanism to graphically represent a function. This issue is a well-known statement, with an also well-known outcome. For the graphical representation of a function, students take out the domain of definition, then the inflection points, then obtain the extremes, and so on. Although with the tools that we currently have, simply by clicking a key, only knowing x^2, we already obtain the representation we are looking for.

So, we think that the first task is to change the methodology and then, depending on our teaching strategy, we have to see what kind of assessment is more reasonable for our propose. When we say that the student must be able to solve problems, what problem is it? Because if the problem is to represent x^2, we finish soon, but if the student must be able to design an electrical installation or a heat pump, then it is a different problem. We have to teach him in another way.

II. Competencies-based methodology

A. Realistic Mathematics Education

One of the methods we use to develop a competencies-based education is the realistic education of mathematics (known as RME by its acronym in English, Realistic Mathematics Education) [2], which try to describe mathematical concepts based on their relationship with the phenomenon that originates them and considers mathematics as a human activity. Based on this educational paradigm, students can use mathematical tools to formulate and solve problems that arise in other subjects, real-life problems or even more, problems that they can imagine. The aim is to make students actively participate in their own learning process (one of the propositions of the Bologna agreement). For this purpose, one of the activities we have developed was the proposal to the students to develop problems and teams works, with a work plan that followed the following principles [3]:

1) Activity: everyone will be an active participant in their own learning process. It is about learning by "doing", instead of by reading or watching.

2) Reality: apply the content of the subjects to the resolution of real problems.

3) Principle of the levels: in the learning process you go through several levels of understanding until you are able to see the whole problem. This principle is closely related to mathematical models, which establish a bridge between the most purely formal and the most applied teaching.

4) Interconnection: the subjects of the different courses of the degree are not sealed compartments within the curriculum of the courses, but are integrated with each other.

5) Interactivity: Learning is a social activity and not just an individual task.

6) Guiding principle: it is related to the proactive role of teacher-tutors, they are guides and counselors of the long-term teaching-learning trajectory.

B. Authentic Mathematics Learning

Students usually prefer doing things and not only listening to the teacher or reading books. Moreover, engineering students' goal is to do things. Authentic learning adds the motivation to students as they have to solve real-world problems [4].

We also propose our students case studies, complex problems, and activities from engineering-real-world. So they will be able to address the mechanical, electrical, electronic, automatic, or chemical engineering problems as part of their mathematical subjects.

The promotion of a positive attitude among our students is a direct consequence of the previous sections. With the use of the computer, tablets or mobile phones, the student will be more motivated to acquire the competences of his/her degree.

Despite of the fact that classical teaching which uses paper content is important, we currently resort more to computer and mobile devices. This approach is not only more modern and more attractive, but also allows students to develop habits for faster solving of the particular mathematical problem, varying parameters, experimenting, visualizing results and publishing them, communicating, clarifying ambiguities and variants with colleagues and more.

III. Software and tools for each subject and each degree

Since the University of Salamanca began using Moodle as its learning environment, the teachers who have collaborated in this study have used it as a tool in their classes.

In particular, as part of this teaching study, some of the activities that have been used were:

- Lessons: composed of a set of pages with information and/or questions that allow going forward and making a dynamic content.
- Questionnaires allow the teacher to design and propose questionnaires with questions multiple choice type, true/false, coincidence, short answer and numerical answer.
- Messages and forum information about the development of the courses.
- Files with papers, presentations and some other useful information.
- Videos about interesting topics available on Internet.

One of the advantages of the Moodle's questionnaires is that tutors can configure the activity. It is possible that questionnaires can be tried several times, with questions ordered or randomly selected from the bank of questions. A time limit can be established. Each attempt is scored automatically, with the exception of questions from type "essay", and the result is saved in the grade book. The teacher can determine if they are displayed and when the user is checking the results, the feedback comments and the correct answers.

IV. Competencies-based assessment. Our proposal

The change in the educational paradigm of recent years with the organization of supranational spaces of education needs a profound revision of the teaching methodology. This new methodology must be applied in various scenarios that the technological revolution allows, and should reach a consensus in the form of evaluating competences that the students should acquire at different educational levels. To achieve these objectives the organization of professional teams should be done outside the local (departments) and national (inter-university collaboration in a country) levels. Therefore, in order to achieve supranational goals, supranational teams are required.

As it is well known, the regulatory framework of the European Higher Education Area has highlighted the need to develop new quality teaching materials to be used by different teams of teachers in the different schools of engineering and faculties. This need goes beyond the national level and requires, in our opinion, a collaborative task to be developed in a supranational level, with the participation of teams of trainers from different European countries to produce multilingual teaching-learning materials that will be used freely by all the university staff in the different subjects of mathematics.

The report: "A Framework for Mathematics Curricula in Engineering Education" [5] provides a European framework for the teaching of Mathematics in engineering degrees. On the basis of that paper, where a group of higher education teachers reached a consensus on the competencies-oriented contents for mathematics curricula in engineering education, we will develop the RULES_MATH project to try to get a new consensus in how we could assess the mathematical competencies.

The Framework document has a part which contains rather specific, fine-grained specification of potential content-oriented learning outcomes. Its intended usage is that lecturers and/or curriculum designers develop from it a concrete curriculum for a specific study course. This enables us to have it as a starting point for the RULES_MATH project. That document details the mathematical contents (specific curricula) for a range of study courses such that lecturers could create a competence-oriented curriculum much easier.

Having done this, the question comes up of how to support lecturers to achieve the educational goals of the curriculum and to be more precise, how to assess the competencies acquisition. Here, the RULES_MATH project come in and will provide assessment standards for doing this.

The learning of mathematics is based on the acquisition and development of the eight mathematical competencies [6]:

1) Thinking mathematically.

2) Posing and solving mathematical problems.

3) Modeling mathematically.

4) Reasoning mathematically.

5) Representing mathematical entities.

6) Handling mathematical symbols and formalism.

7) Communicating in, with, and about mathematics.

8) Making use of aids and tools.

For specifying and measuring progress on such competences, three dimensions are used: degree of coverage, radius of action, and technical level.

The methodology we intend to apply in RULES_MATH project will be included in the project handbook, and will contain at least these steps:

1) *Analysis of the SEFI document* to get the Mathematics Curricula (not only the framework) and contents for engineering courses. RULES_MATH project will treat what is called Core Level 1, which corresponds to the contents that the early stages of a university program include:

- Analysis and Calculus.
- Discrete Mathematics.
- Geometry.
- Linear Algebra.
- Statistics and Probability.

2) *Identification of components* and description of competence-oriented learning activities for the Mathematical competencies.

3) *To share examples* about contents - competencies - maths applications, from partners' experiences and work that has been done.

4) *Identification of educational standards*, and proposal of new rules (a framework) for assessing mathematical competencies.

5) *The analysis and selection of the tools* and software that will be used to create educational resources.

6) *To develop the entire project keeping the quality assurance*. Guide templates will be develop by the quality expert team, in collaboration with all partners (reports, high level analysis and technical design docs, ICT tools and comprehensive short guides for using mathematical and statistical software packages). Material format will also be considered, assuring that all the materials will incorporate a detailed description. The quality guide with the templates and procedures will be available on the project platform.

7) *The ethical approval*, standards or copyright rules will be part of the project process. The proposed development will be subject to ethical approval processes with the relevant academic partner. To check the validity and the Creative Commons License for the files and resources that will be used during the whole project.

V. Conclusions and Future Work

The work of the RULES_MATH project will become a part of the consultancy, training activities and practices provided by the partner institutions who will be interested in their on-going success. The competencies-based standards and resources will be inside a dataset of electronic educational materials in English first (and national languages when possible).

The increasing demand for the development of new computer aided educational solutions, electronic study materials and e-learning facilities will play a crucial role in the process of integration of the project dataset into the internet education scheme. In addition, these centers will provide the most up-to-date information and they will promote usage of ICT as the most advanced platform.

Once established, the RULES_MATH project, we will continue working on it, as we are already working on mathematical competencies. There will be a natural interest from educational institutions to maintain this dataset not only for their own purposes, but also, in the transnational European context, to be informed about the development of the standards, platforms and newly developed educational strategies in mathematics. So, the target groups will be mathematical trainers and learners from engineering degrees from all over the word: at our institutions (in all engineering degrees and we could also add sciences degrees), in other universities from our countries (as this project outcomes will be available on the internet), at EU level (to achieve the goals of a common European higher education area), and to the rest of countries, as the publications of the results will be as papers contributions in international conferences and journals.

The project results will be extended to other interested countries and institutions. New members interested in working within the framework of European institutions will be welcome. They can enlarge the range of available resources and materials, and contribute to solutions for education of mathematics for engineering students at the European level, and they can bring new methods and views on the ways of promoting mathematical competencies and enhanced understanding in the European context. This will help universities to confirm and strengthen their role as leading centers for engineering and life-long learning cooperation with other institutions in the educational and research sectors and other possible sectors (industry, via the Internet at private households for self-learners, including disabled and other disadvantaged people) will contribute to the development of the whole society towards the objectives stated in European policy for the near future.

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