AN EFFECTIVE METHODOLOGY FOR TEACHING PROFESSIONAL ENGINEERING COURSES AT A LATIN AMERICAN UNIVERSITY

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Abstract

Many educators complain about the poor level of the engineering students that we have in the classrooms nowadays. This problem is accentuated in private Latin American universities that depend economically on the tuition fees paid by students for their education in professional programs, where the admission process for the students does not include a rigorous qualification examination. Besides, in the case of engineering programs in Latin American universities many of the admitted students come with poor competences in language skills, in the fundamental basic sciences like mathematics, physics, chemistry, and biology. The environment has changed, we are in the era of internet, the social networks, the convergence of all communication technologies that has widespread the access to mass communication media. The students have changed, the educators also have to change. All of this makes very challenging the task of educators in engineering programs nowadays. The purpose of the paper is to present an effective methodology for teaching professional engineering courses at a Latin American university that has been devised to address the problems mentioned before. The methodology is based on several facts recognized by the author in more than twenty years of teaching experience: first, recognize that teachers do not teach, students learn by themselves; second, recognize that the best way of learning is to “learn by doing”; third, recognize that the teacher's task is to establish an environment where students can "learn by doing", motivate them to learn the subject under study by showing the relevance of the topic in the discipline through real-world applications and guide students in their learning process; fourth, recognize that the evaluation is not just a way to measure whether the students acquire certain competences or not, instead, the evaluation is an essential part of the learning process, the evaluations must be a continuous process in the learning process of the students, must be oriented to essential competences on the topic of the courses taught, the evaluations must be objective and must be followed by immediate and effective feedback to the students; and fifth, recognize that in professional courses it is essential to include real cases of study where the students can “learn by doing”, by practising the methods studied in the course applying them to a real problem, involving computational tools to do so. In the paper, some results obtained by implementing this methodology in the courses of “Flight Dynamics” and “Automatic Flight Control” of the program of Aeronautical Engineering of the Universidad Pontificia Bolivariana, at Medellín, Colombia, are presented.

Keywords: Engineering education, higher education methodologies.

1 INTRODUCTION

Latin American universities are struggling to improve the quality of their education [1]. According to QS Latin American University Rankings 2020 and the QS World University Rankings 2020, the best ranked University in Latin America is the Pontificia Universidad Católica of Chile which is ranked 127th in the world, while the 25th ranked university in Latin America is the Instituto Politécnico Nacional of Mexico which is ranked 651-700th in the world [2], [3]. In the case of Colombia the best ranked university is Universidad de los Andes which is ranked 4th in Latin America and 234th in the world [2], [3]. Only 12 universities in Colombia are ranked among the 1000 best universities in the world [3], just three of them are public, even though the majority of the students attending higher education institutions (HEI) are in public universities. Many HEI are conscious of their need to improve the quality of the education and for this reason they are looking for a high-quality accreditation. For this purpose, the government of Colombia has created the National System of Accreditation in Colombia [4]. The author has more than twenty years of experience teaching in a HEI in Colombia, Universidad Pontificia Bolivariana, which is a catholic private university with the main campus located in the city Medellín, the second city of Colombia. Universidad Pontificia Bolivariana is a university with a wide coverage in Colombia, it has campuses located in the cities of Medellín, Bucaramanga, Montería, Palmira, and Bogotá, it has the Multicampus High Quality Accreditation conceded by the Ministry of National Education of Colombia [5]. Universidad Pontificia Bolivariana is ranked 10th in Colombia, 64th in Latin America, and 551-560th in the world [2], [3]. The experience acquired by the author in all these years of teaching at the School of

Engineering of Universidad Pontificia Bolivariana and his postgraduate studies in the United States, and the desire to improve the quality of his courses has allowed him to develop an effective methodology for teaching professional engineering courses that is presented in this article.

The paper is organized as follows: in section 2 a brief history of the experience of the author that led to the development of this methodology is presented, section 3 describes the methodology, section 4 shows some results obtained applying this methodology is two of the courses taught by the author, and section 5 presents some concluding remarks.

2 BRIEF HISTORY

After completing his studies in Electronics Engineering in 1988, the author started teaching at the School of Electrical and Electronics Engineering of Universidad Pontificia Bolivariana in 1989. Most of the teachers at the university only had an undergraduate degree by that date, and it was common that many of the teachers were recently graduated and inexperienced like the author at that time. It is important to note that the undergraduate programs at the university are five-year programs which are equivalent to a bachelor degree with one year of graduate work in many universities in North America and Europe. This stage for the author career extends until 1994, year in which the author started his Master studies. During this first stage in the career of the author as a university teacher, some courses were provided by the university to improve the quality of teaching, and the author learned English. This stage of teaching was characterized by the traditional methodology that many teachers still practice in Latin American Universities: traditional lecture using the chalk and the board, evaluation composed of a few exams (maximum 5 exams), where the evaluation purpose was just to assess whether the students pass or fail their courses. Even though the courses taught by the author where mostly theoretical, in some of the courses the author tried to include some practical or lab exercises to be done by the students to have some hands-on experience applying the theories studied in the courses. The only extra material used in the courses where the text books proposed as reference material for the courses. During this stage the main courses taught by the author where: “Systems and signals I” to students of Electrical Engineering and Electronics Engineering, “Systems and signals II” and “Solid state electronic devices” to students of Electronics Engineering, and “Numerical calculus” to students of Electrical Engineering, Electronics Engineering, and Chemical Engineering. In this stage the activities of the author were focused on teaching, and so were the methodologies used by the author.

After completing the Master of Science in Electrical Engineering in The University of Texas at Arlington (Arlington, TX, USA) in 1996 the author returned to Colombia and continue teaching at Universidad Pontificia Bolivariana. The author continued teaching undergraduate courses, started teaching some other graduate level courses, and started getting involved in some research projects. During this stage of his career the author tried to improve his courses based on the new acquired knowledge, in particular, influenced by the methods experienced during his Master studies, the author complemented his courses with many homework assignments for the students so they could practice by themselves the concepts studied in the lectures. The idea was to promote more the self-study to improve the learning of the students. Given that was difficult for the university to provide the teaching assistants required to help in reviewing and correcting all of the homework, the author just started providing questionnaires and proposed problems that the students could use for their self-study, and motivating the students to use computational tools like Matlab to practice the concepts studied in the courses. During this stage the author continued teaching undergraduate courses like “Systems and signals I” and “Automatic control systems” to students of Electrical Engineering and Electronics Engineering, “Systems and signals II” to students of Electronics Engineering, and some graduate courses in “Univariable control”, “Multivariable Control”, and “Neural networks”. The methodologies used during this stage were based in the traditional lectures but emphasised the autonomous work of the students, and some use of computational tools to improve the students learning.

In the year 2000 the author started his PhD studies in Electrical and Computer Engineering at Georgia Institute of Technology (Atlanta, GA, USA), and after completing his PhD, the author came back to Universidad Pontificia Bolivariana. After coming back the author focused more in research activities, continued teaching some undergraduate courses taught before, and started teaching some other graduate courses like “Robotics”, “Intelligent control”, “Linear control”, and “Advanced control”. During this stage of his career the author did not pay much attention to his courses, he centred the courses more in the new knowledge disregarding methodological aspects. This is an error that the author recognized and made him reflect about how to improve the methodology to improve the quality of his courses.

Even though the author continued teaching the courses in Electrical and Electronics Engineering, since 2007 he started teaching courses in the School of Aeronautical Engineering that was established in 2003. First, he designed and taught the course of “Automatic flight control”, then, in 2010, he started teaching the course “Dynamics of Flight”. Since 2009 the author changed the methodology in the courses of “Systems and signals I” and “Systems and signals II” of Electrical and Electronics Engineering. These courses were core courses in these programs but given that they introduced many fundamental concepts and use several mathematical tools to do so, the author recognized the difficulty for the students. These courses were very dense and required the students to invest a lot of effort in them.

Before 2009 the author had used the traditional methodology with lectures, a few exams without much feedback, the only material that the students have for studying were the class notes and the text book and proposed problems given by the teacher. With this old methodology it was not uncommon to have courses where almost all the students failed. Furthermore, the students were unmotivated and did not recognize the importance of these courses in their program of study. Some of the courses, although they were passed by the students, presented a lack of motivation and a little use and appreciation by the students.

In 2009 the author started changing the methodology. First the courses were planned carefully trying to focus in the fundamental concepts, all the competencies that need to be acquired by the students were recognized. The course program was organized in weeks and a questionnaire and a set of proposed problems for each chapter of the course were prepared. The students were provided with a detailed document describing all of the competencies that were expected to be acquired with the course, the detailed program and schedule and a list of references that can be used by the students to study the subject. Each week the students were provided with the questionnaire and the problem set for the subject of the week. The way of presenting the lectures were changed trying to start with motivational discussion of the possible applications of the subject under study, then followed the presentation of the subject under study, and some examples and problems were developed in class motivating the active participation of the students in the class, the classes were finished with concluding remarks for the studied subject and some motivation for the next subject. The participation of the students in the class was encouraged to discuss the subjects under study. Each week of the semester the students had to present a short quiz that lasted maximum half an hour. All the material covered the last week was evaluated. Immediately after each quiz, it was resolved and all the doubts about it were clarified to give immediate feedback to the students. The quizzes were graded and returned to the students in the next class. At the end of the course a comprehensive exam was presented by the students to certify that they had acquired the required competencies with the course. With this methodology the students were motivated to participate more in the classes, improved the autonomous study and the study in groups and to go to solve doubts in the schedule of attention of the teacher. The application of this methodology to the courses of “Systems and signals I” and “Systems and signals II” of Electrical and Electronics Engineering programs was very successful, improving the motivation and the learning outcomes of the students. The students' appreciation for the topics studied in these courses and the application to other subjects of the program increased significantly.

3 METHODOLOGY

The methodology proposed in this paper is based on several facts recognized by the author in his more than twenty years of teaching experience:

- Recognize that teachers do not teach, students learn by themselves.
- Recognize that the best way of learning is to “learn by doing” [6], [7].
- Recognize that the teacher's task is to establish an environment where students can "learn by doing", motivate them to learn the subject under study by showing the relevance of the topic in the discipline through real-world applications and guide students in their learning process.
- Recognize that the evaluation is not just a way to measure whether the students acquire certain competences or not, instead, the evaluation is an essential part of the learning process, the evaluations must be a continuous process in the learning process of the students, must be oriented to essential competences on the topic of the courses taught, the evaluations must be objective and must be followed by immediate and effective feedback to the students [6].

- Recognize that in professional courses it is essential to include real cases of study where the students can “learn by doing”, by practising the methods studied in the course applying them to a real problem, involving computational tools to do so.

The methodology resulting for taking into account these facts is a modification of the one mentioned in previous section, that was first implemented by the author in the courses of “Systems and signals I” and “Systems and signals II” since 2009. The idea was to add support material for student self-learning, include at the end of the course a project to solve a real problem by a team of students and intensively use computational tools that are very important in engineering today. The key aspects of the methodology are presented in next subsections for the courses taught by the author at the school of Aeronautical Engineering in Universidad Pontificia Bolivariana.

3.1 Course planning

Course planning is an essential part of the methodology. All of the competencies that the student is expected to acquire with the course are identified. Then the contents of the course are organized in chapters and each chapter is disaggregated in the competencies that are covered in it. A time table is prepared which includes all of the activities programmed for the course using the experience of previous courses to make it realistic in the time allowed for the course. These activities include the lectures, the quizzes, the course project, and the final exam.

3.2 Course material preparation

All the material for the course is prepared in advance. The course material includes the presentations that support the lectures, the handouts for the students with the presentations for the lectures, the questionnaires and the proposed problem sets for each chapter. The course project formulation and the bank of problems for the quizzes can also be reviewed before the beginning of the course, however all the material can be reviewed and improved during the course. The materials for the course should be dynamic and change continuously to improve the courses and keep them up to date.

3.3 Lectures

The lectures are an essential part of this methodology. Contrary to the traditional lectures that are rigid and are static, so the students have little space to participate, the idea is to have very flexible and dynamic lectures where the students take an active role in the classes. The participation of the students is encouraged all the time to discuss the topics under study and make questions, the presentations prepared for the lectures just present key aspects of the topics, the examples are just formulated but not solved in the presentations, encouraging the students to help the teacher to solve the examples presented in class. It is very important for the teacher to have a deep knowledge and preparation of the topics under study so he can emphasize some aspects of the subject or propose new examples or problems according to the student’s interests. In some cases, the class can be paused to allow the students to propose solutions for the problems presented in class that apply the concepts just covered in it.

3.4 Lectures using computational tools

In professional engineering courses like the ones the author teaches, it is important in some lectures to use computational tools in class to solve the problems related to the subject and motivate the students to use these computational tools. For instance, in the course of “Dynamics of flight” the author uses Octave or Matlab to build a computational simulation model for a fixed wing aircraft, this task is done with the students in class. Then, the model is used to do calculations required to analyse the static and dynamic behaviour of the aircraft. The students do the calculations in their computer so they “learn by doing” how to create the model, perform the simulations and the calculations using the computational tools. The same is done in the course of “Automatic flight control”, where the students use the code developed in the previous course of “Dynamics of flight” to calculate a model that is used for the design of the flight controls of the aircraft under study. The design, analysis and simulation of the flight control systems is done in class with the students using the Matlab/Simulink computational tools.

3.5 Weekly quizzes

In the proposed methodology weekly quizzes are done once a week, during the first thirty minutes of the second class of the week that cover the topics of the last week. The quizzes are programmed since

the beginning of the course, so the students are forced to be up to date and to solve the questionnaires and problem sets that every week are delivered to them. Each quiz is carefully designed by the teacher so they have five questions with multiple choice answers. The questions could be problems or part of problems that require in some cases several calculations. Each question addresses a particular criterion for an essential competence that is expected to be acquired by the student at the moment of the quiz. The quizzes are designed so the students have the opportunity to apply the concepts under study. Given that they are fed back immediately after the quiz, this is a essential part of the methodology that completes the learning process of the students. The author has developed a computational tool to generate the quizzes, and a bank of questions for the quizzes that is being continuously reviewed and updated with new questions.

3.6 Take home tests solved using computational tools

In some cases, the subject under study require the use of computational tools to solve a problem. In these cases, the weekly quiz can be replaced by a take home test, in which every student has to solve a problem using a computational tool. For the case of the courses taught by the author, he has developed some computational tools that allow him to automatize the formulation and correction of these take home tests.

3.7 Course project

The idea of including a course project in the courses is to give the students the opportunity to solve a more realistic and complex problem related to the course. The course projects are realized in teams so the students can develop competences that are essential for any engineer, the ability to communicate and negotiate with his peers, discuss the solution to the problems, and do team work. The course project is another opportunity for the students to practice their skills using the computational tools. Methodologically the course project combines the “learning by doing” with the “problem-based learning” strategies.

3.8 Final exam

The final exam is a comprehensive examination that is implemented to assess how the students have acquired the competences that they were expected to acquire with the course. The questions of this exam are similar to the ones of the weekly quizzes where each question address a particular criterion for an essential competence that is expected to be acquired by the student. This exam is composed of twenty questions of key aspects of the course. This exam is included to assess the student performance in the course and is not fed back.

3.9 Teacher role

In the proposed methodology the teacher does not teach, he just establishes an environment where the students can learn, he motivates them to learn, guides them through the learning process, and gives some feedback that is essential in the learning process.

3.10 Students role

In the proposed methodology the students learn by themselves; they learn to learn; they learn to be responsible for their learning; they learn to solve problems related to the topic under study, solving the problems; they learn to use the computational tools to help them solve the problems, using the computational tools. The students “learn by doing” what they want to learn, and they learn by solving problems related to the topics studied in the course.

4 RESULTS

The results obtained by implementing the methodology proposed in this paper to the courses of “Flight Dynamics” and “Automatic Flight Control” of the program of Aeronautical Engineering of the Universidad Pontificia Bolivariana, at Medellín, Colombia are presented in Tables 1 and 2 respectively.

Table 1. Results for the Flight Dynamics course.

Year	Semester	min	max	mean	# students	# students failed	Student evaluation
2010	2	3,48	4,50	3,95	9	0	
2011	1	3,02	4,45	3,54	8	0	3,89
2011	2	3,23	4,81	4,04	8	0	3,72
2012	1	3,59	4,51	4,03	10	0	4,39
2012	2	2,81	4,82	3,71	22	1	4,57
2013	1	3,24	4,52	3,89	13	0	4,43
2013	2	2,50	4,78	3,50	18	4	4,40
2014	1	2,40	4,63	3,77	29	1	4,41
2014	2	3,02	4,65	4,15	13	1	4,74
2015	1	3,41	4,47	3,99	17	0	4,64
2015	2	2,83	4,79	3,77	30	1	4,51
2016	1	3,01	4,78	4,07	19	0	4,42
2016	2	3,01	4,43	3,72	15	0	4,20
2017	1	3,00	4,80	3,92	29	0	4,66
2017	2	2,72	4,47	3,85	25	2	4,88
2018	1	3,15	4,71	4,01	15	0	4,67
2018	2	2,28	4,60	3,63	30	3	4,84
2019	1	2,87	4,48	3,60	18	1	
2019	2	2,87	4,82	3,96	54	1	4,79

In Table 1, corresponding to the “Flight Dynamics” course, the first and second columns represent the year and semester of the courses taught. Columns three, four, and five present the minimum, maximum, and average scores obtained by the students that semester. The sixth column shows the number of students taking the course and the seventh column present the number of students failing the course. The eighth column shows the scores of the evaluation that the students make on the course based on a survey prepared by the university. All the scores are in a scale from zero to five. A student fails the course is the score is bellow three. The methodology proposed in this paper has been applied to the course since the second semester of 2014. It is interesting to note that the number of students failing the course are kept very low, the average score for the students approaches a good score of 4.00 and the most important thing is that the perception that the students have about the course has increased, with student evaluations of the course between 4.6 and 4.8.

In Table 2 corresponding to the “Automatic Flight Control” course the first and second columns represent the year and semester of the courses taught. Columns three, four, and five present the minimum, maximum, and average scores obtained by the students that semester. The sixth column shows the number of students taking the course and the seventh column present the number of students failing the course. The eighth column shows the scores of the evaluation that the students make on the course based on a survey prepared by the university. All the scores are in a scale from zero to five. A student fails the course is the score is bellow three. The methodology proposed in this paper has been applied to the course since the second semester of 2009. It is interesting to note that the number of students failing the course are kept low, the average score for the students approaches a good score of 3.50. It is important to take into account that this course has a higher level of difficulty respect to the “Flight Dynamics” course. Note that the perception that the students have about the course has increased with the consolidation of the methodology in the course, obtaining scores in the last semesters that surpasses 4.9.

Table 2. Results for the Automatic Flight Control course.

Year	Semester	min	max	mean	# students	# students failed	Student evaluation
2007	2	3,10	4,40	3,56	4	0	
2008	1	3,03	4,94	4,10	11	0	
2008	2						
2009	1						
2009	2	3,45	4,55	4,13	9	0	
2010	1	1,80	4,25	3,28	8	1	
2010	2	3,18	4,63	3,92	22	0	
2011	1	2,76	4,59	3,62	16	2	4,23
2011	2	3,38	3,85	3,61	6	0	4,00
2012	1	1,13	4,53	2,85	8	6	4,56
2012	2	3,35	4,60	3,84	19	0	4,75
2013	1	3,00	4,40	3,73	22	0	4,05
2013	2	3,05	4,64	3,85	8	0	4,72
2014	1	3,48	4,45	3,92	18	0	4,53
2014	2	3,30	4,47	3,84	17	0	4,62
2015	1	2,78	4,43	3,66	15	1	4,83
2015	2	2,72	4,36	3,49	17	1	4,62
2016	1	2,53	4,55	3,67	26	1	4,50
2016	2	2,64	4,68	3,59	39	3	3,83
2017	1	2,55	4,02	3,53	18	1	4,27
2017	2	3,01	5,00	3,98	21	0	4,57
2018	1	2,25	4,15	3,43	24	1	4,88
2018	2	3,19	3,84	3,59	7	0	4,94
2019	1	1,95	4,48	3,44	38	5	
2019	2	2,83	4,68	3,53	21	1	4,94

5 CONCLUSIONS

In this paper, an effective methodology for teaching professional engineering courses has been presented. The methodology emphasized the fact that the students learn by themselves so the best way to conduct the class is to establish an environment where the students can “learn by doing”. The role of the teacher is just to be a guide in the process of learning that help the students to pursue their learning outcomes. The teacher also has to motivate the student in in his learning experience by encouraging his participation in all the class activities. The methodology also emphasizes the use of computational tools to solve problems presented in professional engineering courses. Some results of the implementation of the methodology in two professional courses of the program of Aeronautical Engineering at Universidad Pontificia Bolivariana were presented, showing how the perception of the courses has improved with time despite the degree of difficulty of the courses taught.

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