SMALL PROJECTS: A METHOD FOR IMPROVING LEARNING

Alfonsa García
Universidad Politécnica de Madrid, Spain
garcial@eui.upm.es

Francisco García
Universidad Politécnica de Madrid, Spain
gmazario@eui.upm.es

Gerardo Rodríguez
Universidad de Salamanca, Spain
gerardo@usal.es

Agustín de la Villa
Universidad Politécnica de Madrid and Universidad Pontificia Comillas, Spain
avilla@upcomillas.es

ABSTRACT

New methodologies, associated with the Bologna process, are needed. Ideas concerning problem-based learning (PBL) developed after running different experiences in different Spanish Universities, are discussed. The driver for introducing PBL has been the requirement for studying Mathematics by the Engineering students. After describing some experiences carried out during several years in different Spanish Universities, drawing some general conclusions and after analysing advantages and disadvantages of the introduction of PBL in the mathematical curriculum a hybrid of problem-based learning methodology for Mathematics in Engineering studies is proposed. The model is a combination of formal lectures, practical and laboratory sessions with autonomous small projects.

INTRODUCTION

The teaching of mathematics in Spanish engineering schools still uses in a significant way the traditional methodology: plenary lectures and practical sessions mainly. However, adaptation to the European Area of Higher Education (EAHE) must involve a new teaching and learning model, based on competences, with active methodologies. Therefore it will be necessary to adjust all methodological resources to this new scenario and analyze the influence of the new methodologies and evaluation procedures in the development of competences required.

In this paper we analyze a methodology proposed for Calculus and Linear Algebra for engineering students that is thought to contribute to competences development. It could be said that the meta-competence associated with Mathematics courses for first year engineering students is the ability to master the mathematical techniques that allow students to solve engineering problems. These techniques are beyond mathematical concepts. Thus, the teaching of mathematics should always be mindful of problem-solving strategies.

Problem-based learning (PBL) is a student-centered instructional strategy in which students collaboratively solve problems and organize their learning process, with support from a tutor or instructor and connecting disciplinary knowledge to the real world. Basic concepts needed to solve the problem are acquired during the process. This learning strategy enables engineering students to develop competences such as self learning, teamwork, use of new technologies, etc.

The use of PBL started in 1969 at McMaster University in Canada, for the study of Medicine. Today it is successfully implemented in many Medical and Engineering programs in different universities (Maastricht, Aalborg…). A study about the suitability of PBL for Engineering Education can be found in (Perrenet *et al*. 2000).

PBL contributes to raising the motivation of students and generating more interest in their subject matter. However, there are drawbacks to implementing this model as the principal teaching strategy in a first course of Mathematics in Engineering because, at least in Spain, very often students do not have enough technical and mathematical knowledge to understand and solve problems in a PBL context. Certainly PBL is useful when learners become more competent. But early in the learning process, learners may find it difficult to process a large amount of information in a short amount of time.

There are teachers suggesting that for beginners, minimally guided instruction is likely to be ineffective (Kirschner, Sweller and Clark, 2006). Because novice learners should be provided with direct instructional on concepts and basic procedures required by a particular discipline. Learning implies to effectively combine new information with old information stored in long-term memory. If nothing changes in long-term memory, nothing has been learned (Sweller, 2006).

Furthermore, several studies show that PBL early in the learning process is a less effective model than other hybrid methodologies (see Kirschner *et al*. 2006). In (Sweller 2006), worked example methodology is defended as an effective instructional procedure, using knowledge of human cognitive architecture. In the other hand, the presence of domain-specific knowledge is necessary during the different stages of the problem-solving process (Segers *et al.* 1999).

Strobel and Barneveld (2009) summarized, compared and contrasted the findings of several meta-analytical researches on the effectiveness of PBL in comparison to traditional forms of instruction. They established four categories:

- Non- performance, non-skill oriented, non-knowledge-based assessment.
- Knowledge assessment.
- Performance or skill-based assessment.
- Mixed knowledge and skill-based assessment.

For the *Knowledge assessment* category, measures tended to favour traditional learning approach. But for all the other categories measures are superior for PBL

However the teaching of mathematics in the first year of engineering school has its own peculiarities. Even some of the institutions promoters of PBL learning, (for example Aalborg University) do not use PBL as the unique learning strategy in mathematical topics in the first year curriculum.

Mathematical problem-solving within engineering asks for knowledge of mathematical concepts, skill in solving techniques and insight in the relationships between them. Definitions, concepts, methods and strategies need guided learning. Furthermore, computer technology is now commonplace in teaching and learning, and Computer Algebra Systems (CAS) have become indispensable tools for solving mathematical problems in engineering. Obviously, students need some training in the appropriate use of these tools.

Therefore, after several successful and unsuccessful experiences, we propose a hybrid problem-based learning methodology in Mathematics courses for Engineering called *The Small-Project model*.

The following sections introduce some of these experiences and the final section describes in detail the proposed model.

Experience in projects in the subject of linear algebra

At the Polytechnic University of Madrid in the new Degrees (Mechanical Engineering, Electrical Engineering, Chemical Engineering, Electronics and Automatics Engineering and Industrial Design and Product Development Engineering), that began to be delivered the academic year 2010-2011, 6 ECTS were assigned to Linear Algebra, whose content is the standard one: vector spaces, linear applications, Eigen values and eigenvectors , Euclidean space and transformations (orthogonal and similar). The face-to-face teaching (5 hours per week) is divided in to two hours of formal lectures, two hours for practical sessions and one hour of computer laboratory or tutorials.

Students' personal work includes the solving of problems posed by the instructor and the drafting of a project in which some concepts of Linear Algebra seen during the course are used. Both activities are done by groups of 3-4 students. The project contributes 10% to the final grade.

The students are free to choose the project topic, although the professors offer a guiding list including: *Kirchoff laws for circuits, discrete dynamic systems, matrices and cryptography, sets of linear equations and magic squares, distribution of temperatures in equilibrium on a square plate, the Fibonacci sequence and the golden ratio, Leontief economic models, applications of eigenvalues to genetics and population growth*.
All groups of students chose some of the projects quoted in the above list.

Some characteristics of the experience:

- A list of books, articles or web sites, together with the instructions about the project, has been provided for the students.
- The number of hours estimated for dedication to the project was 15-20.
- The students were able to attend tutorials with their instructor as often as they felt necessary in order to check the progress of their work and make the requisite consultations for the elaboration and understanding of the topics of the project and the best way to present it. Some of the groups never took advantage of these tutorial activities.
- The work had to be presented in class and the students had to contribute a Power-Point presentation and a report in Word or PDF format (10-15 pages).

Some conclusions from the experience:

- The difficulty of the projects was not homogeneous. In some of the projects the students were asked to provide a previous study of the problem to be analyzed or technical knowledge that is not usually available to first-year students.
- The presentations and the quality of the projects were very inhomogeneous and there was a fair degree of correlation between the quality of the work and the other grades obtained by the students. There was also a tight relationship between the grade obtained by the groups of students and the number of tutorial sessions they attended.
- Instructor proposed questions after the presentation, for guarantee the minimum aims for all members of the group.
- Taking into account the questions proposed by the students in the tutorial sessions we can conclude that the greatest difficulty found by the students in certain projects was the modelling of the problems and their translation to concepts in Linear Algebra.

Project experience in the subject applies mathematics I

Since 2009-2010, Salamanca University (Zamora Polytechnic School) has been offering a Degree in Construction Engineering. Its curriculum includes the subject of Applied Mathematics in the first semester. This subject is worth 6 ECTS and it has a fairly generalist content, mainly oriented at the fundamentals of Calculus in a single variable. The degree is offered to 130 students, divided, for formal lectures, into two groups of 65 students each.

The initial mathematics training of the students is highly heterogeneous and the course essentially serves to achieve common training objectives, supported by a very exhaustive tutorial system with the students who have basic initial deficits in their knowledge.

The autonomous work of the students (organized in groups of no more than 3) involves the solution of different problems related to the course contents, doing practical work on the computer, and the drafting of short projects in which some mathematical technique related to the course contents is used. The final grade is obtained with autonomous work (60%) and individual written exams (40%).

Each of the quoted projects involves work lasting about 15 hours and the electronic document should address different aspects related to the problem posed: a historical overview of the problem, the mathematical modelling and solution, the industrial or technological solution, and the sources used in the work. The students attend an initial tutorial with the instructor to receive additional information about the project chosen and a final tutorial to solve any doubts that might have arisen while the project was being prepared.

Below we analyze the results of our experience gained over the past two years with two projects from the list of projects proposed to the students in their first year: *The golden ratio in constructions* and *Why TV antennae are parabolic*?

The above projects were addressed by 10 groups of students, with a total of 25 students involved. The mean grade was 7.23 (none of the groups failed) and all the students who performed these works successfully passed the subject at the end of the course.

Regarding positive aspects, the following are of interest:

- The students were comfortable working as a team and were able to share out the various tasks under the supervision of the instructor.
- The students were happy that the learning process was linked to “real situations” and worked more enthusiastically. Motivation was easier.
- The students attended specific tutorials with a different spirit and participated more willingly.
- The students were able to extract appropriate information from very different sources: books, photos, videos, etc.

The negative aspects would be as follows:

- The students had great difficulties in handling a scientific text processor. In some cases, the tutorial sessions were confounded because of the student’s lack of knowledge of the specific technologic applications.

- The knowledge deficits of the students have made a difficult task the selection of the possible projects. Not all the projects proposed had the same mathematical difficulty and, above all, many of them were not directly related with engineering problems.
- The students try to choose the most attractive project according their professional context and the simplest one from the mathematical point of view.

Finally, there are two problems that must be addressed. The first refers to the work of the instructor, and the second to the work of assessing the students.

Regarding the instructor's work, the compilation of a suitable list of projects (attractive, accessible and with adequate mathematical level) is difficult (more difficult than setting problems and exams) and generates much more work for the instructor (only one instructor for 130 students).

Regarding assessment of the students' work, the numbers involved does not allow them to report their findings in the classroom or the instructor to ask questions aimed at elucidating the true participation of each of the members of the groups. As well as the quality of the work presented, the only indirect assessment instruments that we use are the active participation of the students in the tutorials performed in relation to the projects.

The exposed conclusions were obtained through enquiries (designed for the teacher and general inquiries of the University) with the involved students. Also different feeling about motivation of students and tutorials activities has been appreciated by the teacher.

The main detected problems have been: a correct election of the proposed projects and the design of a personalized evaluation system using projects realized in teamwork.

A project experience in calculus for computer engineering

This experience has been carried out, in the academic years 2009-10 and 2010-2011, at Polytechnic University of Madrid, with students of a first-year course of the Degree of Computer Engineering. The subject Mathematical Analysis includes 1 ECTS devoted to several topics related with Integral Calculus: Indefinite Integrals, Riemann Sums, Definite Integrals, Fundamental Theorems of Integral Calculus, Numerical Integration, etc. The last topic (Numerical Integration) has not been addressed in formal lectures and a small-project was proposed to the students.

The aim of this activity was to develop generic competences (teamwork, use of technology, self-learning and problem-solving) and specifics competences (the use of appropriate mathematical language to describe algorithms and define concepts and the ability for applying knowledge of Integral Calculus and Numerical Methods in a world-real problem).

The students' tasks for the project included:

- To use integration for modelling a problem (different for each students group).
- To autonomously learn two algorithms on numerical approximations of integrals (Composite Trapezoidal rule and Composite Simpson's rule) using references as (García *et al*. 2008), and write a theoretical report.
- To program the appropriate functions to implement these algorithms using the CAS Maxima (Gaertne 2005).
- To test the programmed functions by means of a comprehensive test battery.
- To solve the proposed problem.

The previous experience has been used to improve the project evaluation model and contrast that the estimated work time for the project (10 hours) was consistent with the actual time reported by students. We provide an assessment rubric of the project for clearly showing the student how their work will be evaluated and what is expected. Each group submits a report and a Maxima-file for which they receive a mark. This mark contributes (10%) to the final grade of the subject.

Results: Last year, the above project was addressed by 15 groups of two or three students, with a total of 36 students involved. The average mark in the project was 6.25, very similar to the average final grade for the same students (6.29). Only one student with a mark greater than 6 in the project does not pass the course. The following graph shows the marks obtained in the project.

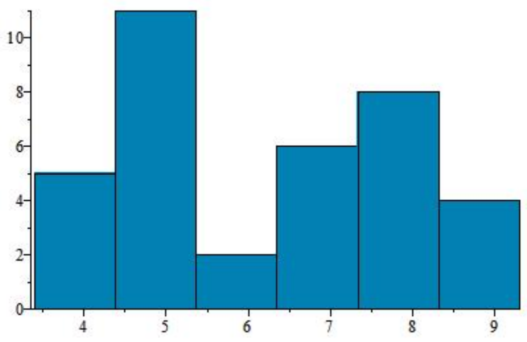

Figure 1: Histogram of the marks obtained in the project

Conclusions and proposed model

In addition to analyzing the experiences carried out in their own universities, the authors of this paper have organized and participated in several meetings in Spain, for exchanging information and opinions with other teachers (I Congreso Internacional sobre Metodologías de Aprendizaje Colaborativo a través de las TIC www.cimac2011.blogspot.com, held in Salamanca in June 2011 or Workshop for Innovative Education at basic subject for Engineering held at the Polytechnic University of Madrid in January 2011)

As results we found:

1. Enhance a mathematics course with some small projects allows students to increase their motivation, improves their understanding of course concepts and a greater satisfaction is obtained.
2. Some students decline to participate in these projects because the contribution of the marks obtained in the final grade is small in relation with the time spent in the work.

Taking into account the literature (see for example Henderson *et al*. 2008 and Hmelo-Silver *et al*. 2006) and our previous experiments detailed in previous sections, we have developed a proposal for future action, focusing on methodological issues, logistics, guidelines and content of a project and evaluation aspects.

The methodology for a course of Mathematics for Engineering students must combine lectures, work sessions, in which students solve problems (sometimes using a CAS) under the supervision of the teacher, individual student work and small collaborative projects.

The basic concepts and skills are taught with a traditional methodology, some specific contents are devoted like a part of the time student work, to develop certain competences, through autonomous cooperative work in small projects.

The framework for projects is:

- Each group (2 to 4 students) must do at least two different small projects in a course of Calculus or Linear Algebra.
- The title of each project must include a driving question anchored in a real-world problem or in a professional practice.
- The problems must be well chosen to be accessible and stimulating for learners (see Wertz *et al.* 2005).
- The selection of the topics involved in the project should balance the understanding of the problem, the motivation and the difficulty for solving the proposed problem.
- For appropriate working in the project students should use essential contents and skill and learn something new.
- Each project should take between 5 and 10 hours of student work.
- The instructions must be clear and precise, including timing, format and tools for using (bibliographical references, mathematical software, etc.)
- Feedback and revision are necessary. Then, for each project at least two tutoring sessions are required: The first one, at the beginning, for organizing the work, and the second one when half the work has been done, for supervision of the project.

Students' work on every small project must include:

- The work planning, defining clearly the tasks to be performed and separate those that are distributed among the members from the ones to be conducted jointly.
- The mathematical modelling of a real-world problem.
- The self-learning of an algorithm or some concrete result of those collected in the course objectives.
- The application of mathematical concepts and results studied for solving the problem (using software if necessary) and the answer to the driving question.

In our model summative and formative assessments are contemplated, together with continuous feedback to students during the academic year. With the projects, the assessment of the application of knowledge when solving problems is the heart of the mater. Then, we propose:

- Projects must contribute at least 20% to the final grade.
- The use of the co-responsibility principle: all student of a group are responsible of the group work. Therefore, we propose an oral presentation, with questions, when possible, or alternatively a small validation test to ensure that all students have achieved the minimum targets.
- A variety of assessment tools is preferable to a simple tool (Macdonald *et al*. 2004)

As a final remark we point that this methodology requires a significant effort of the teachers in order to conceive problems and projects which would lead to significant learning.

REFERENCES

García, A., García, F., López, A., Rodríguez, G. and De la Villa, A., 2008, *Cálculo I. Teoría y problemas de Análisis Matemático en una variable* (Madrid: CLAG).

Gaertne, B., 2005, The Computer Algebra Program Maxima – a Tutorial, http://maxima.sourceforge.net/docs/tutorial/en/gaertner-tutorial-revision/Contents.htm [29-05-2011]

Henderson, S., Keen, G. and Ahadi, P., 2008, Mathematics for 21st century engineering students, Carrick Institute for Learning and Teaching in Higher Education, http://maths.anu.edu.au/DoM/Teaching-Maths/Math-CoS-2008-01/DBI_Report.pdf [29-05-2011]

Hmelo-Silver, C. E. and Barrows, H. S., 2006, *Goals And Strategies Of A Problem-based Learning Facilitator*, Interdisciplinary Journal of Problem-based Learning, **1**, 21–29.

Kirschner, P. A., Sweller, J. and Clark, R. E., 2006, *Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery,* *Problem-Based, Experiential, and Inquiry-Based Teaching*, Educational Psychologist, **41**, 75–86.

Macdonald, R.F. and Savin-Baden, M., 2004, A Briefing on Assessment in Problem-based Learning, http://www.heacademy.ac.uk/resources/detail/resource_database/id349_A_Briefing_on_Assessment_in_Problem-based_Learning [29-05-2011]

Perrenet, J.C., Bouhuijs, P.A. and Smits, J. G. M., 2000, *The suitability of Problem-based Learning for Engineering Education: Theory and Practice*, Teaching in Higher Education, **5**, 345–358.

Segers, M., Dochy, F., Corte, E., 1999, Assessment practices and student's knowledge profiles in a Problem-based curriculum. Learning Environments Research 2, 191–213.

Strobel, J and Barneveld, A, 2009, *When is PBL More Effective? A meta-analyses comparing PBL to conventional classrooms.* Interdisciplinary Journal of Problem-based Learning. **3**, 44-58.

Sweller, J., 2006, *The worked example effect and human cognition*, Learning and Instruction, **16**, 165–169.

Wertz, V., Ben-Naoum, K., Delsarte, P., 2005, PBL in Mathematics: What is a "Good" Problem? Proceedings of the International Conference on Problem-Based Learning, University of Tampere, Faculty of Education and Lahti Polytechnic, Finland.