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Project Based Learning Methodologies Applied to Large Groups of Students: Airplane Design in a Concurrent Engineering Context

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Abstract: This article presents a college course experience taught in the final academic year of the Aerospace Engineering program at the University of Seville, in which students design an airplane taking the specification submitted by the instructor, following the Project Based Learnig (PBL) methodology. Students are organized into groups forming "companies" that have to defend their proposed design with the "client". The article presents the usual steps of the PBL methodology showing the feasibility of applying this methodology to large workgroups.

The complete design of an aircraft is the result of a compromise between knowledge, experience and teamwork in a collaborative environment. The students need to understand that each of the different areas are necessary pieces of the larger puzzle of aircraft design, and they need to find the key that solves this puzzle. The main objective of this course it to provide instructions to complete that puzzle by introducing concurrent engineering and PBL methodologies.

Keywords: project-based-learning; large groups; concurrent engineering; aerospace.

1. INTRODUCTION

The complete design of an airplane marks the end of the education of many aeronautical engineers. Students, during their educational journey, acquire a series of training tools that they will use once the move up to their better life: working in the industry. The problem is that these tools are just pieces of a quite complex puzzle, that in the context of airplane design, range from aerodynamics, structural design, propulsion, performance, systems engineering, stability and control, and modeling and design, that although are not the only aspects that contribute to the aircraft design, they are the most important.

The following sections describe the teaching experience of Aircraft Design which uses the project based learning (PBL) methodology. This methodology provides solution to one of the main teaching-learning needs that appear in the European Space of High Learning Education concerned with the need of creating education environments with capabilities of providing the future engineers with the necessary competences (Feisel 2005).

Throughout the duration of their academic training, students rarely receive the instructions of how these pieces of the puzzle are put together in order to understand the context that they will enter once they move to the industry. The main objective of the course presented in this article, Cálculo de Aviones, is to provide students with the instructions that will allow them to understand the aircraft design process. For simplicity of reading, from now own the course will be refereed in the text by Aircraft Design.

The following sections describe the teaching experience of Aircraft Design which uses the project based learning (PBL) methodology. This methodology was first introduced in the Aerospace Program in the 2006-2007 academic year, and the results here presented cover the experience until the last year of implementation in the 2013-2014 academic year. It's important to note that the experience here described focuses on the results of the five-year extinct aeronautical engineer degree, and also important to note that this same methodology has been implemented in the four-year degree program currently implemented in the Spanish University system due to the Bologna process (Musselini, 2004). The following sections will describe the experience, placing first the course within the context of the Aeronautical Engineering curricula at University of Seville (US), explaining the objectives of the course, the methodology employed, and finally, presenting the results of applying the PBL methodology, with special attention to how it is applied to large group of students.

2. AIRCRAFT DESIGN

2.1 Aerospace Engineering Degree

To understand the context in which the PBL experience presented in this article is framed, it is interesting to present the Aeronautical Engineering Curricula at the Escuela Técnica Superior de Ingeniería (ETSI) of the US, which comprises two cycles without intermediate qualification, and is structured in courses spread over five courses, with a total of 390 credits (1 credit being equivalent to 10 hours of

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course). In order to obtain their degree, students need also to conduct a Final Project. The first cycle of Aeronautical Engineering consists of disciplines structured in two academic years of 152.5 course credits, where 97.5 credits correspond to core subjects, 39 credits to mandatory subjects and 16 free election credits.

The second cycle of Aeronautical Engineering is structured in three academic years of 237.5 course credits, where 112.5 credits correspond to core subjects, 43.5 credits to mandatory subjects, 52.5 credits of optional subjects, 23 credits of free election subjects, and 6 credits to Final Project.

Aircraft Design is one of the core subjects of the Aeronautical Engineering degree at the ETSI. The number of credits of this course is 4.5 and is taught during the second semester of the 5th year. This subject is the responsibility of the Aerospace Engineering Department. The subject has a workload within the curriculum of Aeronautical Engineering, 42 teaching hours and about 68 hours of student work. The course content is similar to that taught at the equivalent subjects in many other universities in Spain, but with a very different teaching focus by using the project based learning philosophy being used in the best universities around the globe.

The teaching project presented here is highly influenced by educational programs based on PBL, in which the students are oriented to conduct independent learning and cooperation among themselves. This teaching philosophy for Aircraft Design is being used at numerous leading aerospace university programs in countries as UK, USA, Germany, Holland, and Italy, to name a few. It should be noted that the experience presented here has been designed by the authors as to meet the qualification requirements of the Aeronautical degree at the ETSI in Seville, taking into account the limitations of credits given, so although the methodology exhibits many similarities with the methods used in other universities, it has been adapted so that both faculty and the students are able to meet the needs of the subject.

Given the complexity associated with the design of a system like an airplane, it is necessary that students acquire a series of aeronautical technical skills such as propulsion, aerodynamics, structures, flight mechanics, stability and control, and finally, the capability of organization and management of large scale projects. It is also important to emphasize that students must also possess basic mathematical skills as calculus, algebra, geometry, and Computer Aided Design (CAD), so the location of this course in the second quarter of the last year is ideal to ensure that students are able to study a large number of subjects with cross competences. The following sections will describe the PBL teaching experience on the Aircraft Design course.

2.2 Aerospace Engineering Degree

The design of an aircraft is the result of a compromise between knowledge, experience and teamwork of students who are organized in different design groups that have to undertake the task of designing an airplane. These design groups are made up of very diverse areas of specialization, particularly in the ETSI of the US, focus on only six areas of expertise: aerodynamics, structures, performance, propulsion, stability, and finally, design and systems. It is natural to understand that each of the different areas of design are equally important when designing an airplane, but this is not unimportant, since students often are not aware of this obvious, and they think that their area of responsibility is more important than the other areas, which could cause to the wrong design methodology as seen in the famous idealization of the CW Miller "Dream airplanes" (Sohler 1948) Figure 1, which describes what could happen if each of the areas involved in the design of an airplane was considered the most important when undertaking the design of an airplane.

Figure 1. Dream Airplanes. C.W. Miller.

Working in a concurrent engineering environment teaches the students to work in a coordinated and cohesive environment, allowing them to integrate the different areas in a more efficient manner. This will be possible if they understand that they are necessary pieces of a larger puzzle, and that they need to find the key that solves this puzzle.

This task falls to the instructor by applying the PBL methodology so that students can convey the degree of interconnection between each of the areas, and thus create a cohesive concurrent engineering environment. To achieve these objectives the teacher uses theory sessions and tutorial sessions (which will be explained in more detail below) to transmit to the whole group the degree of interaction between the six working areas, always emphasizing that each group is responsible for maintaining communication lines between each of the areas to ensure the completion of the aircraft design puzzle.

In this environment of coordinated work, students learn to manage individual responsibilities in a workgroup environment, where the emphasis is on the need to promote effective communication between the different components of the groups, so they are able to convey their ideas, listening to the ideas of others, accepting criticism, and analyze the "feedback" provided from other groups in the various reviews and forums.

The teacher needs to emphasize that students must learn to rely on the work of members of their own group because of the need to divide tasks, and in return, this should also create in their minds the commitment to share responsibility with their peers, as it happens in the industry. Students are also encouraged to organize and work in a coordinated environment to fulfill the deadlines, thus forcing them to practice real life engineering tasks. It is quite important to emphasize that the task of the instructor is to actively convey these ideas to the students during the specific sessions used through the course, which are described in the following section.

3. METHODOLOGY

Students are divided into small working groups (between 6 and 12 depending on the number of students), and are faced with the challenge of designing an aircraft that needs to comply with certain specifications described in a Request for Proposal (RFP) presented by the instructor. The RFP not only presents aircraft requirements, but also deadlines for partial design goals, and the evaluation criteria always within the context of market opportunity. These RFPs are primarily motivated by the competitions of aeronautical designs promoted by "The American Institute of Aeronautics and Astronautics" (AIAA 2014) to universities around the world based on the PBL methodology, which are modified by the authors according to the needs of the current academic year (Esteban 2015a).

The chosen teaching methodology makes emphasis in the need of regularly monitor the progress of each design group through regular in-progress presentations. This monitoring presentation allows the teacher to ensure that they are able to meet all deadlines. This system of self-management milestones promotes responsibility among the students, as each working group must be able to manage their own resources to meet both the partial, and the final goals at the given deadlines.

Regular monitoring is enhanced by splitting the professor in three figures that perform different, but at the same time, coordinated tasks. This methodology allows to divide the responsibility of the teachers, and the teaching structure of the course into three distinct blocks: THEORETICAL SESSIONS, CONTROL SESSIONS, and TUTORING SESSIONS. In each of these in session, the teacher will represent a different figure (INSTRUCTOR, CONTRACTOR, and CONSULTANT respectively), allowing students to experience all phases appearing in aircraft design in the industry.

The peculiarity of this methodology is that the three figures (INSTRUCTOR, CONTRACTOR, and CONSULTANT) are clustered in the figure of the same person (the teacher), which permits to infuse a touch of realism to the educational experience for both students and the teacher. The teacher must be able to move from one figure to the other depending on the educational context. This PBL methodology aims to provide the students with a close-to-real working environment experience. The following three points describe briefly the teaching methodology (Esteban 2015b):

1 THEORY SESSIONS: the lectures are chronologically divided into three blocks: preliminary design, detailed design, and advanced design. Between each block, a concurrent engineering session is delivered, where the teacher explains the guidelines for the theoretical sessions of the following block, and provides also the degree of interconnection between each of the areas. In these sessions the teacher shows the figure of the INSTRUCTOR.

2 CONTROL SESSIONS: given the nature and the difficulty associated with airplane design, designs need to be monitored regularly by in-progress presentations. Three control sessions are scheduled (motivated by three blocks of the theory sessions), where progress of the project is evaluated through both presentations, and preliminary technical reports that need to reflect the degree of compliance with the RFP. The control sessions are open to questions not only to the teachers (CONTRACTOR), but also to the other groups, which are encouraged to question the results presented by the rest of the groups. In addition to the three control sessions, a last control session (final exam) consisting of a final exhibition in which each group makes a final presentation of their projects to the CONTRACTOR.

3 TUTORING SESSIONS: these sessions wrap the monitoring cycle of the tasks performed by the different design groups, by providing to the students the “instructions” to complete the aircraft design puzzle. These sessions are conducted during the days after the control sessions, and have a confidential nature between the teacher (CONSULTANT) and each group. Two main objectives are addressed in these sessions: resolve any doubts presented by both the CONTRACTOR, and the other competing groups during the control sessions, and help the group to orient their working efforts towards ensuring achieving goals and fulfilling deadlines. These tutoring sessions help the teacher to ensure that the students in each group understand the importance of concurrent engineering methodologies.

The learning experience presented in this article is not limited to the students, since teachers need also to learn to improve their teaching skills by analyzing their own teaching experiences. By integrating new and diverse learning strategies within a real problem frame, such the one presented in this PBL experience, both the students satisfaction, and their performance are improved (Gibbs 2001). Additionally, the three hats methodology permits the teachers to participate in the educational experience by "learning to think as a teacher, to know as a teacher, to feel like a teacher, and to act as a teacher", and most important, in a more student-centered environment, rather than a teacher-centered environment (Gibbs 2001).

4. EVALUATION METHODS

Throughout the course each design group should present three technical reports (associated to each of the control sessions), and a final technical report during the final presentation session.

The overall evaluation criteria is provided to all the students at the beginning of the course in a matrix of compliance with more than 200 elements that assigns values to each of the RFPs design criteria in a similar way is conducted in the industry to all the companies that are competing to win the contract. These elements comprise not only technical aspects such aerodynamics, structures, propulsion and performance, design, or systems, but also organization, business case, style and presentations. The final grade for each student is compromised by the sum of four areas:

1. Part associated to the individual work conducted by each student (i.e aerodynamics). This part accounts for approximately 35% of the final grade.
2. Part associated to the overall group work. This part accounts for approximately 40% of the final grade.
3. Quality of the final presentation. This part accounts for approximately 10% of the final grade.
4. Quality of the control sessions presentations and technical reports. This part accounts for approximately 15% of the final grade.

As an additional evaluating tool, the students are asked to evaluate the performance and contribution of each one of the members of their design group. This tool is used to identify anomalies in the overall grade of the group associated to students not committing to the course objectives.

5. CAN PBL BE DONE WITH LARGE GROUPS OF STUDENTS?

The first aircraft design course at the ETSI was taught in the academic year 2006-2007 with just 34 students. This permitted a reasonable number of group designs (6 students each), which in return turn out to be a reasonable working load for the teachers, since the number of groups defined the number of control and tutoring sessions. As the number of students increased (up to 141 students in the academic year 2013-2014), but not the number of teachers, it was obvious that new solutions and tools needed to be introduced to be able to maintain the PBL methodology.

Evolving to improved methodologies was easily implemented given the context in which the course is conducted: a concurrent engineering environment where competition between different "companies" (each design group) is similar to the context that these future engineers will face when jumping to the real world. In order to deal with overcrowded classes, the number of students for each of the areas within a design group was increased to three during the 2013-14 academic year. This increment in the size of the design groups was dealt as an improvement in the diversity of each area, introducing the concept of task revision among each area. In addition to the inherent engineering duties of each student within their own areas of design, an in order to facilitate the coordination among the areas of each design group, the figure of area coordinator was created. This person was in charge of maintaining a constant communication channel between each of the areas within each design group, thus ensuring the realization of the concurrent engineering philosophy (see Figure 2 for details).

This person, in addition to the existing design group coordinator, has strengthened the coordination between the different areas, improving the collaborative nature of the educational experience. This evolution was complemented by the extensive use of Information Technology and Communication (ICT) tools, which in addition, permitted to meet two critical aspects in order to make this a successful teaching experience:

1 Provide students with the necessary tools for the monitoring and management of the course and the capability of meeting deadlines.

2 Provide the teacher with tools that will permit to extend the PBL experience to the students in a self-learning context.

In order to accomplish both objectives, over the last eight years several tools have been incorporated into the batch of academic resources used in the course to improve the teaching experience. These tools are available the page of the course (Esteban 2015c) and the US Web Course Tools (WebCT) (http://ev3.us.es).

This material includes slides used during the theoretical sessions, other support materials, RFPs proposed in previous years, aircraft comparisons similar to those proposed in the RFPs, presentations of works defended in previous years, additional information on other educational aircraft design programs, and useful generic and specific aircraft design software. Among the specific aircraft design software, it is important to remark the software tools created specifically by the author through final degree projects of students that have taken the aircraft design course. These tools are intended to help students during the aircraft design process in the areas of aerodynamic, structures and stability and control (http://www.aero.us.es/sesteban/pages/RL_Airplane_Design.htm).

To enhance an effective and rapid communication between teacher and students, a series of discussion forums are used (using digital tools available in the US). Four types of forums depending on the context in which they are used are distinguished. The first three are focused on providing channels of communication between the CONSULTANT and different groups to answer questions concerning the teaching materials, design requirements, or RFP:

1. COMMON DISCUSSION FORUM: answer common questions to all areas;
2. GROUP DISCUSSION FORUM: Each group is assigned a forum for direct discussion with the instructor, so you can communicate directly and confidentially without the other groups aware of the information addressed;
3. AREA DISCUSSION FORUM: A single forum is created for each of the design areas, and each student is assigned to one of these forums, so that the instructor can use the forum for communications concerning those areas.

The fourth forum is developed immediately after the various design groups have made final presentations (final exam). At that time, the teacher opens a panel in which students express their thoughts regarding the course, propose amendments to the course aiming to improve the educational experience, address different aspects of the course such suitability of the deadlines, RFPs, teaching methodology, structure, communication channels, etc.

This is the most important discussion forum from the point of view of improving the teaching methodology of the course, since the instructor receives a direct feedback from students regarding the teaching methodologies. Most of the improvements and modifications applied to the course over the last years, have been introduced in this fourth forum, and has been of invaluable help in order to improve the PBL experience.

6. RESULTS AND ASSESMENT

The methodology described has been implemented since the first academic year in which the course was taught (2006-2007), so there is no comparative data with other methodologies. After 7 years, the experience can be considered a good one. The feedback from students is the best indicator of the success of the used methodology, and students they have repeatedly expressed the satisfaction that an important course within the aeronautical curricula is taught using PBL methodologies oriented in a real-life concurrent engineering context, which promotes self-learning.

The degree of responsibility acquired by the students throughout these seven years has been quite high. The collaborative methodology used in this course teaches the students to share both, their learning responsibilities, and the overall assessment of their final grade. The fact that the grade of each student depend largely on their level of commitment to their design group (Esteban 2015b), has added a sense of overall responsibility among the students. Students have understood that this commitment is the same that they are going to experience in the industry, therefore, they have seen this educational experience as a first simulated-contact with the industry.

The innovative teaching format of a teacher who brings in the same person the figures of INSTRUCTOR, CONTRACTOR and CONSULTANT, has been well received among students. This “three-hat” methodology has created a complicity between the teacher and the design groups, since, the same person that teaches, is the same that demands clarifications at the control sessions, and at the same time, provides them with solutions and tools that will allow them to progress in the design, which has been proven to increase the degree of commitment of the students with the course.

It is important to note that, during the first weeks of the course, the teacher can identify the difficulty that students have to make executive and engineering decisions towards the design process. This competence is necessary to continue the design process, and is the responsibility of the teacher to pay attention to this fact and to provide “instructions” to complete the “puzzle” by providing guidelines that will allow students to avoid getting stuck in any of the different stages of the aircraft design process. By doing so, the teacher promotes the feeling among the students that engineers do solve problems constructively.

One of the most valued aspects by students is the existence of a large amount of educational support material: slides, manuals, forums of Frequently Answered Questions, tutorials, videos. All this material has been gathered over the past years thanks to the collaboration and involvement of students. All these material has been possible thanks to the extensive use of ICT tools through both the web of the course and the WebCT, and the incorporation of these technologies into education experience represents one of the most enriching aspects for both the student and the teachers.

A fundamental aspect of teaching is the ability to explain the same concepts from different perspectives, diversity in the multimedia tools helps to strengthen the learning of a concept. Therefore, one of the objectives of this educational project is the continuous incorporation of new tools to improve the transmission of knowledge.

The US, throughout an independent evaluation office (Centro Andaluz de Prospectiva), has been conducting surveys every year to understand the degree of acceptance of the course among the students and the results are shown in Figure 3. It can be seen the degree of acceptance among the students, where the qualification of the course has been always higher that the evaluation of the area of aerospace engineering, the aerospace engineering degree, or the University of Seville itself.

7. CONCLUSIONS

A teaching experience based on PBL for large groups has been presented. It has been proven that by using all the tools that teachers have at their disposal, along with the right organization means to ensure the learning process of students, PBL educational methodologies can be extended to large groups of students, as in the example here presented up to 141 students.

The added value acquired by students after studying the aircraft design class with the PBL methodology here presented is of great value since allows students to learn to work in a concurrent engineering environment. In addition, this methodology introduces the students to their first experience with the collaborative engineering process that is used in the aerospace industry. This concurrent engineering environment is enhanced by the collaborative learning methodologies because the design of such a complex system as an aircraft requires that all areas interact continuously throughout the design process.

The teaching experience that students have received in this course has helped the students demystify the concept that engineers cannot interact with other engineers. Students have fulfilled the main objectives of the course by learning to share individual responsibilities in a working group as is done in the industry. Students also learn to make quick decisions in the context of a project with goals and milestones, promoting at the same time the concept of an engineer who is dedicated to solve problems constructively. They have understood that both their decisions and their level of involvement with their design group have repercussions not only in their own academic performance, but also in the performance of their peers, which creates promotes an effect of responsibility.

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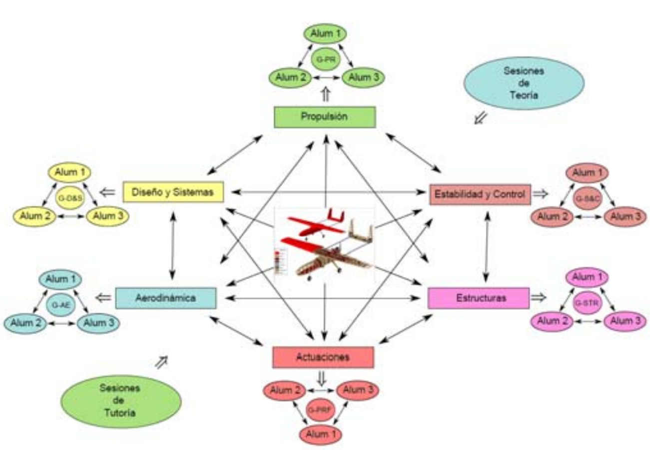

Fig. 2. Interaction between the Areas of Study

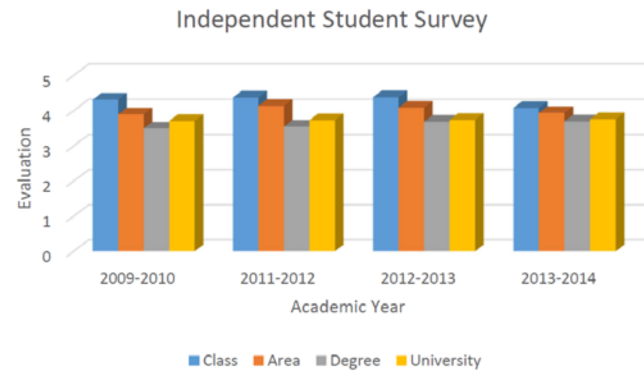

Fig. 3. Results of Student's Survey

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