Learning by doing in Project Management: Acquiring skills through a collaborative model

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Abstract— **This paper presents a teaching approach for an undergraduate course of project management under the learning by doing paradigm. The course experience as a whole is presented, including planning aspects for all scheduled activities, are provided later. The definition of the project is provided, as well as its specific details for practical project work, the main educative instrument of the course, in order to bring out the most relevant aspects of the approach. These include improving the learning process by means of a collaborative model and details of the assessment process that make continuous improvement possible. Detailed research to evaluate the effect of students' previous work experience of this learning model is also considered in this paper.**

Keywords-project management skills; collaborative groups; interdisciplinary groups; engineering education; learning by doing formatting.

I. INTRODUCTION

This paper presents a 'learning by doing' approach related to a course in the project management of engineering projects, which is offered in the final academic year of the Industrial Engineering Degree at Universidad Politécnica de Madrid.

The teaching approach involves a combination of several topics in an endeavour to reinforce the learning process itself. These topics are:

- Practical work focused on managing a real project, mainly in its beginning stages (preliminary scope of the work, feasibility analyses, technical and tactical scope of the work, design, documentation and customer presentation).
- Competition among teams of students.
- Transforming theoretical course material from a time-oriented presentation to a practical presentation of contents that enables them to become of direct use in practical work.
- Combining different roles and responsibilities within each student team in order to improve the learning process that results from internal discussions in which students adopt different roles.

The subject of the project was chosen to ensure that:

- Several disciplines are involved.
- Different solutions are possible.
- Integrative solutions must be found in order to present a coherent solution to the customer.

The teacher has two different roles in order to foster student learning from the training. The first role is that of an external consultant to the student team. The second role is as a customer representative, who is able to negotiate (i.e., make decisions or agree to compromises on behalf of the customer), if required.

For much of prehistory, educational methods were largely informal. Children imitated the behavior of others or modeled their behavior on that of their elders, learning through observation and play. In this sense, the children were the students, and the elder was the teacher. A teacher creates the course materials to be taught and then puts them into operation. Pedagogy is usually defined as the different methods by which a teacher can teach. It is the art or science of being a teacher, generally referring to strategies of instruction or style of instruction.

There are several methodologies available for teaching engineering courses, but, according to ANECA [1], the agency in charge of monitoring the educational system at the university level in Spain, more than 90% of engineering courses uses a delivery strategy based on lectures. The purpose of a lecture is to clarify information for a large group in a short period of time. Lectures require a great deal of time for preparation and need to be supported by various audio-visual materials. The lecture is an instructor-centered methodology.

Although the lecture strategy has such advantages as productivity in content delivery and its suitability for specific topics like project management, it also presents difficulties. These difficulties are related mainly to the knowledge, which has a high degree of practical application, and specific context skills, such as leadership skills, negotiating skills, etc., which are usually perceived by students to be abilities that are acquired or developed outside of school. In addition, students of engineering greatly prefer technical content to managerial content, which they perceive to be potentially useful, but provided only after they have completed the educational process. All of these elements serve to strengthen students' passive attitude.

In order to manage this context, some particular improvements have been designed [2], implemented and tested. They were motivated by a desire to foster a greater engagement of students as well to reinforce the learning process itself [3]. These special add-ons included the immediate use of most of the theoretical components presented, team competitions, team work, and negotiation [4].

As described later in this paper, this study can be viewed as the construction of an applied learning environment [5] under a paradigm of learning by doing [6] in which concepts and tools are required to develop practical work in a competitive context. A convenient conceptual framework is provided before theory class is runned under a discussion approach. The purpose of a discussion is to solicit student participation and involve the student in content transmittal. Discussions are usually limited to small groups and require considerable time. However, the discussion method requires little audio-visual support. It promotes understanding and the clarification of concepts, ideas, and feelings. There are numerous variations. The discussion method can vary from a teacher-centered approach to a student-centered approach. Examples of specific methods that can be employed include role playing, debates, panel discussions, reviews, supervised study, brainstorming, buzz groups, idea incubation, tests, show-and-tell, worksheets, conferences, and interviews. In this particular teaching approach), a role playing approach was usually selected, although the relatively high number of students to manage was a challenge. An additional reason to use the role playing approach is that students must become very accustomed to these concepts for immediate practical application in competitive practical projects. In creating a suitable environment in which to use the acquired knowledge, specific asynchronous events that impact a project's lifecycle are introduced [8].

All scheduled activities need to be estimated in terms of student effort in accordance with ECTS criteria. Satisfying this requirement for the project management course produced the following distribution, assuming duration of 14 weeks per course (Table I).

TABLE I. DISTRIBUTION OF STUDENT EFFORT IN THE PROJECT MANAGEMENT COURSE

Task	In class effort (Per week)	Out of class effort (Per week)	Total effort (Per course)
Reading course material	0 h	2 h	28 h
On line quiz relative to theoretical reading material	0 h	0,25 h	3,5 h
Class discussion	1 h	0 h	14 h
Individual work	0 h	1,5 h	21 h
Software practical class	0,5 h	0 h	7h
Practical project Development	0,5 h	5 h	63 h
Public presentation	0,05 h	0,1 h	2,1 h
Test	0,25 h	1h	17,5 h
Total	2,3 h	8,85h	156,1h

Like the time distributions of other courses and, because the course has been given a grade of 6 ECTS and one ECTS means 27h at Universidad Politécnica de Madrid, the total time available is 162h. This includes a float of 4% as a safety factor since the estimate was based on averages.

Investigating the outperformance of teams according to their internal structures [7] was of additional interest. In order to investigate the effect of previous work experience in developing the real project, two different teams were created, the first consisting entirely of young students who had no previous work experience and the second consisting of students who possessed significant previous work experience.

An additional interest for this research is to measure the instructor's effort. In such way, specific activities for theoretical learning processes and practical ones are presented (Table II).

The rest of this paper is focused on presenting the relevant aspects of the development of a practical project, as the latter is the driving force of the PBL approach chosen. Firstly, previous experiences in teaching project management by use of a 'Project-based learning' methodology is recalled, as this is the easiest way of identifying innovations to include in the learning approach presented here. This is the objective for section II.

Later, the project definition and implementation details are presented, bringing up the most relevant aspects of the experience, like details of assessment of the process to make continuous improvement possible or improving the learning process by a collaborative approach. This is the goal of section III.

The next section is dedicated to a discussion of the results of the experience, including learning planning, learning development, a comparison to classical lecture-based learning models and an overall score. Also discussed is how these results are transformed into learned lessons as feed-back. Finally, the last section presents the main conclusions and future plans.

TABLE II. DISTRIBUTION OF INSTRUCTOR'S EFFORT IN THE PROJECT MANAGEMENT COURSE

Task	Theoretical effort (Per week)	Practical effort (Per week)
Preparing and updating course materials (syllabus, quiz and case studies)	3h	
Class discussion	1h	
Scoring four individual assignments	4h	
Test definition and evaluation	1h	
Practical case definition		1h
Monitoring the project evolution and reporting		2h
Scoring the practical work including public presentation		2h
Individual mentoring	3h	3h
Total	12h	8h

II. Project-Based Learning and Collaborative Teamwork in Project Engineering

There is a shift in emphasis in engineering education from professional skills to process skills [9]. These skills include problem analysis and problem solving, project management and leadership, analytical skills and critical thinking, dissemination and communication, interdisciplinary competencies, intercultural communication, innovation and creativity, and social abilities. PBL has proved to be an excellent method for development of new forms of competencies [10][11].

Research has shown that students retain minimal information in the traditional didactic teaching environment and frequently experience difficulty in transferring the acquired knowledge to new experiences [12]. A PBL environment enables students to draw upon their prior knowledge and skills, brings a real-world context to the classroom, and reinforces the knowledge acquired by both independent and cooperative group work [13].

PBL is a model in which learning opportunities are organized around projects [14]. According to the definitions found in PBL papers, projects are complex tasks that are based on challenging questions or problems that involve students in design, problem-solving, decision making, or investigative activities. They give students an opportunity to work relatively autonomously over extended periods of time and culminate in realistic products or presentations [15] [16] [17]. Other defining features of projects that have been found in the literature include authentic content, authentic assessment, teacher facilitation without direction, explicit educational goals [18], cooperative learning, reflection, and incorporation of professional skills [19].

Several criteria define what a project should have in order to be considered an instance of PBL [20]. The five criteria are centrality, a driving question, constructive investigation, autonomy, and realism. The first criterion is that PBL projects must be central, not peripheral, to the curriculum. In PBL, the project is the central teaching strategy. Students encounter and learn the central concepts of the discipline by means of the project. The second criterion is that PBL projects must be focused on questions or problems that "drive" students to encounter the central concepts and principles of a discipline. The definition of the project (for students) should be so crafted that a connection is formed between activities and the underlying conceptual knowledge that one might hope to foster [21] [22]. The third criterion is that projects must involve students in a constructive investigation. An investigation is a goal-directed process that involves inquiry, knowledge building and resolution. Investigations may take the form of design, decision-making, problem-finding, problem-solving, discovery, or model-building processes. However, in order to be considered as a PBL project, the central activities of the project must involve the transformation and creation of knowledge (by definition: new understanding, new skills) on the part of students [23]. The fourth criterion is that projects must be student-driven to a significant degree. PBL projects incorporate a good deal more student autonomy, choice, unsupervised work time, and responsibility than traditional instruction and projects. Finally, the fifth criterion is that projects must be realistic and not school-like. Projects should have characteristics that give them a feeling of authenticity to students. These characteristics can involve the topic, the tasks, the roles that students play, the context within which the work of the project is carried out, the collaborators who work with students on the project, the products that are produced, the audience for the project's products, or the criteria by which the products or performances are judged. Reference [24] was the first to make a distinction between academic challenges, situation challenges, and real-life challenges. PBL incorporates real-life challenges where the focus is on authentic (not simulated) problems or questions and where there is a possibility that solutions will be implemented.

In PBL, the project is the central teaching strategy. Students encounter and learn the central concepts of the discipline by means of the project. There is a longstanding tradition in schools of "doing projects," incorporating "hands-on" activities, developing interdisciplinary themes, conducting field trips, and implementing laboratory investigations [25].

Research on PBL can be undertaken to: (1) make judgments about the effectiveness of it (collective evaluations), (2) assess or describe the degree of success resulting from implementation or performance of Project-Based Learning (formative evaluation), (3) assess the role of student characteristics in PBL effectiveness or appropriateness (aptitude-treatment interactions), or (4) test a proposed feature or modification of Project-Based Learning (intervention research) [20]. Moreover, there are at least three traditions from which PBL research and practice seem to emerge. They are: (1) Outward Bound wilderness expeditions [26] [27], (2) postsecondary models of PBL [22] [28], and (3) university-based research in cognition and cognitive science applications [29] [30] [31].

The inclusion of real-world problems in engineering education reinforces concepts and improves learning in ways not available with traditional lecture methods or predefined case problems [32]. Students develop problem solving skills, project management skills, communication and teamwork skills, and a sense of professionalism from such experiences.

III. Experiment and Assessment Plan

A. Project definition

The learning approach presented here concerns the development of a real engineering project by groups' competitive assignments. The main purpose of *playing to manage projects* is to move on from simply learning contents by heart to understanding, discussing and sharing in order to learn from experience.

The project proposed is multidisciplinary and unifying. Students come from nine different specializations: industrial management, manufacturing, energy, electronics, chemistry, construction, materials, mechanics and electricity. Each team member plays a different role, according to his/her specialization, skills or preferences. Each group appoints a project manager who has the authority to assign responsibilities and acts as the team spokesperson to communicate with the project's owner(s). The professor will play two different roles during the process – that of the project owner's representative who is ready to make decisions when required and also as an external consultant during the project follow-up meetings.

Each team will study the fundamental notions of Engineering Project Management and apply them to actual cases. Students will be required to define the scope of the project, assess its technical and economic feasibility, prepare a schedule and budget, and assume responsibility for cost management, conflict management, documentation management, follow-up controls, quality management, communication management, and, finally, completion of the project and the main conclusions.

In this study, the project owner is a European investment trust that is highly committed to the preservation of nature and the avoidance of any negative impact on the environment as a result of its investments.

Following an exhaustive analysis of the different investment opportunities, the trust has decided to embark on the construction of a non-hazardous industrial waste management plant. This new plant will be located in a highly industrialized area and will address the potential demand of nearby companies for waste disposal services. The project owner would like to see an analysis of the different alternatives for the construction of the plant, bearing in mind that the plant will be operated for a minimum of fifteen years and a maximum of twenty five years.

The strength of the proposed solution will be considered in the final assessment, as well as its conformity to existing legislation and the potential for waste treatment (the higher the better). Both the cost of the complete solution and its operating expense must be included in the budget. Finally, the engineering fees also must be included.

With regards to methodology, the students have at their disposal the theoretical materials needed to cause the project to move forward. In this learning experience, theory is subordinated to the requirements of practical sessions, both in sequence and content. The learner studies the contents and completes a questionnaire about the subject before a lecture or a project meeting takes place. For each knowledge area, the student submits an individual assignment about planning the scope, preparing an offer or taking a stance on a current topic in Project Engineering. All of these activities have been assigned specific time "costs" that count towards the final evaluation of the subject.

Two project teams were created for the case study that is under consideration, the teams are populated by ten to twelve members in order to have a fit management workload. Each project team represented a different consulting firm that had been asked by its client (the lecturer) to undertake an assessment of the project. In this context, the students apply the project management methodologies and techniques that they learned during the course to enable them to make a sound proposal that meets the client's terms (in time, resources, etc). The technical quality of the proposal, excellence of the presentation of the offer to the client and the team's performance in managing the project will count towards the final evaluation of the subject.

This participative model shifts the active role to the student, given the fact that he is the one who needs to solve the problem after he has validated his approach. Once the simulation of this collaborative, multidisciplinary model has been completed, it becomes clear that the proposed learning dynamics promotes the development of diverse knowledge competencies required to manage engineering projects: reach management, time management, resource management, cost management, communication management, risk management....In addition, the model fosters the development of collective skills, such as teamwork, conflict resolution skills, negotiating skills, leadership skills, self-control, creativity, commitment, motivation, etc. In short, the model permits the student to put into practice those skills that a project manager should possess. Finally, the student's impressions of this learning model with regards to planning, development and assessment are presented, as well as the methodology, resources employed and changes proposed to enhance the usefulness of the subject.

B. Development of the learning experience.

Each project team must meet for half an hour each week during which time the project manager reviews the work performed during the previous week that the plan had required. Also, tasks for the current week are agreed upon and scheduled.

All team participants must claim their hours spent in execution of assigned tasks. The project manager is responsible for managing the work to be done and reporting the hours used by all team members - 600 in this particular case. The efforts spent can also be reviewed. The limited time available for the weekly team meeting reinforces the need for skill in conducting meetings and leadership.

The Work Breakdown Structure, as well as internal deliverables (e.g., documents or products created by the team) are freely determined by the team itself with the only constrains being the total effort available and final products to be provided as a result of the work. This particular design improves the creativity and reinforces the contribution of the interdisciplinary groups to the common project, even when the interests that the students have in the project differ.

The role of the teacher is perceived to be that of an external consultant-agent, due mainly due to the effort expended in maintaining both profiles (consultant and owner representative). The specific management of the owner representative is an issue for team leaders. Team members' week-by-week progress in their work is the result of a combination of effort, use of their technical skills and the growth of group competencies (e.g., leadership, teamwork). This is an excellent way for monitoring the development of these competencies.

This approach puts emphasis on an active role for the students who must present a solution for a problem, after discussing it to assure them that it has been well thought out. During the learning experience, specific knowledge is applied by the students and various skills are reinforced, such as scope management, time management, resource management, communication management, both formal and informal, and risk management. The proposed approach also improves group competencies like teamwork, conflict management skills, self motivation, negotiating skills and competitiveness.

In order to evaluate the dynamic capabilities for quick answers by the teams, specific asynchronous events are introduced. For example, this might be an environmental regulation change that affects the project under development or a customer crisis that precipitates a sudden reduction in the size of the investment budget, which necessitates a significant change in the size or scope of the project. Such unexpected issues force the team to manage the situation by redefining the scope of the work, re-planning the work to be done or adjusting the previous plan It is an excellent way to see how the team manages a situation that can lead to loss of motivation, frustration, contempt for the customer or renewed motivation, or any combination of these elements, in order to win the competition. There is a possibility of observing a direct relationship between the attitude of team managers and internal team atmosphere. Obviously, there is a relationship between the team's internal atmosphere or morale and its productivity and the quality of the products that it delivers.

As the team needs to work in a multidisciplinary way, and nearly all team members have specific schedules due to their other engagements, it is appropriate to provide tools that allow for easy group work activities. To aid teams in this approach, a model [33] site was established, although teams are free to adopt other approaches, such as specific Google-groups. The model system provided is configured as group courses arranged in such a way that the contributions of one team are concealed from the members of other teams. These additional tools contribute towards improving members' skills for technological uses in the execution of projects.

The approaches carried out by the teams differ greatly. The team consisting of young students who lack professional experience invests a great deal of effort in devising the right scope and formulating logical alternatives. It functions as a real team with discussions, a common vision of the solutions and high commitment to project objectives. The other team, which consists of students who have previous professional experience, adopts a more individualistic approach. Only matters of coordination are handled at team meetings. The scheduling of individual tasks is conditioned in great degree by the experience of the participants. Significantly less time is given to developing the team. The homogeneity of people in teams and tasks was observed. It is noteworthy that some team members divided their attention between their employment and their studies. This makes it much more difficult to develop the team in ideal fashion.

IV. RESULTS AND FEED-BACK

A confidential survey was carried out during the last course week. Several groups of related questions were reviewed and scored on a Likert scale 1 to 5 (from fully unsatisfactory till fully satisfactory). As it is allowed to no answer some questions, 0 values mean no answer to that specific question. One chapter of the survey takes into account particular aspects related to the concerned methodology.

It becomes clear (Figure 1), that students prefer to read by themselves and to get their own feedback prior to attending a common discussion (answer X7_1) or to provide their own opinions in personal essays (answer X7_3). There is agreement in having an opportunity to develop a real project solution (answer X7_4), as well as activities like negotiation role plays (answer X7_5). Finally, greater support for the methodology used was obtained than for the more classical methodology, which is based on theoretical concepts plus some individual practical tasks, each of which is two hours in duration.

In addition to considering the feelings of students in regard to methodology, resources, services from teachers, the learning process and learning planning, a specific evaluation of the quality of the product was conducted.

X7_1. I agree with reading class material before the class and use that time for concept discussion.
X7_2. I agree with using the theory as a toolbox for development of practical projects.
X7_3. I agree with individual tasks that allow me to express my own opinions.
X7_4. I agree with the development of a practical project.
X7_5. I like to perform specific tasks like negotiation simulation.
X7_6. I like to learn specific software tools for project management.
X7_7. Overall, I prefer the current methodology, instead of the classic approach, which is much more oriented to lectures.

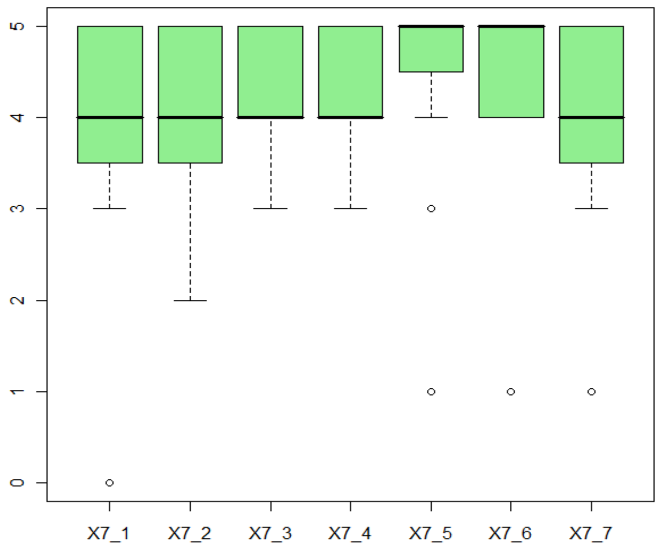

Figure 1. Boxplot of specific aspects of methodology.

From a technical point of view, both solutions were far removed from the professional viewpoints, due mainly to a lack of specific knowledge of the specific field. This can be used to introduce the subject of technology transfer solutions or, at least, to visit different solutions related to current problem. Another problem is the great differences between real costs and estimated costs for most cost categories. As most of the time was consumed in defining the problem and identifying alternatives, there was not enough time spent on the task of cost analysis.

A common strategy that the teams employed was to attempt to keep the owner's agent far from their design and solutions. The main drawback of this strategy is that, since the customer was not involved in intermediate decisions, the risk of a failure to fulfil customer's expectations becomes higher as the project nears its end. This was an important lesson that was learned.

By far, the most important problem identified by the students concerns the amount of time that the teams spent, although the number of hours claimed individually is consistent with the initially planned time (600 hours in this particular case).

Another specific problem not identified directly by students, but reported by teachers, is the project manager's lack of skills (i.e., the student acting in that role usually had more interest in technical questions than in managerial matters). This unfocused management normally leads to wasted efforts as the Work Breakdown Structure is produced later and there is no close tracking. A visible effect is a lower rating for teachers in practice classes (Figure 2).

It becomes clear that students are more comfortable with a fixed environment. They assign a lower rank to a noisy environment (Q3), (i.e., practical sessions where there is less structure and where time is managed by a project manager without the benefit of a plan provided by the teacher (see in Figure 2, answer for X6_3 against those for X6_2 and X6_4).

X6_1. There are enough teachers
X6_2. Teachers of theory do good work
X6_3. Practical class teachers do good work
X6_4. Overall, I agree with the performance of the teaching team

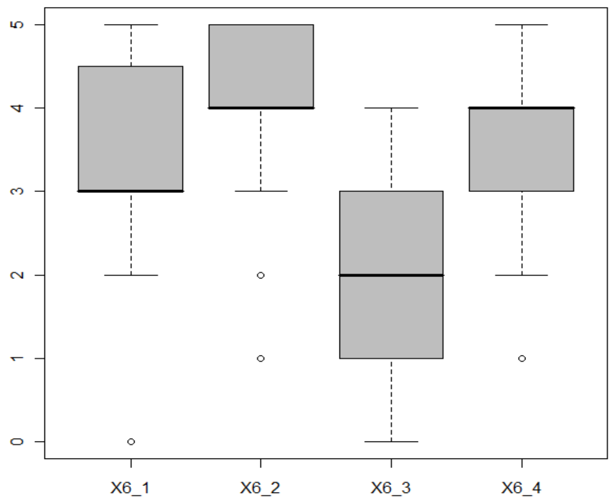

Figure 2. Boxplot of the perceptions of teacher performance

V. CONCLUSIONS AND FUTURE PLANS

As demonstrated, PBL is a method of instruction that challenges students to learn how to work cooperatively in groups in order to seek solutions to real world problems. These problems are used to engage students' curiosity and initiate the learning of the subject matter. PBL prepares students to think critically and analytically and to find and use appropriate learning resources (see Figure 3 below and particularly the answers to X4_5, X4_6 and X4_7).

This provides students with an opportunity to prepare for a professional life by practical training in coordinating a work group and working effectively as a member of a team. The independent research and learning aspects of the PBL provide the students with the skills necessary to identify, research and fill in the missing knowledge for the types of problems that they may encounter during their professional lives.

The purpose of this practice was not only to enable students to acquire technical knowledge, but also to open their minds and see what engineering project management is really about.

This experience has demonstrated that project-based learning is an effective way to effect student learning in the subject area of project management. In addition to detailed technical knowledge and performance skills, successful project management requires engagement, motivation, creativity and understanding. Interdisciplinary team projects offer many learning opportunities related to complex problem-solving, conflict resolution, and decision making, among others. The opportunity to develop these skills often is unavailable to students until they become employed. Introducing students to such experiences earlier can foster the development of these abilities.

X4_1. The real effort expended equals that of the theoretical one.
X4_2. The evaluation is consistent with the rules presented at the beginning of the course.
X4_3. The evaluation processes measure knowledge correctly as well as competencies.
X4_4. The evaluation components are coherent with the activities scheduled.
X4_5. I learned concepts, tools and techniques that are new and valuable to me.
X4_6. I learned to do things related to this matter that are useful and completely new to me.
X4_7. Overall, I support the evaluation system for this course.

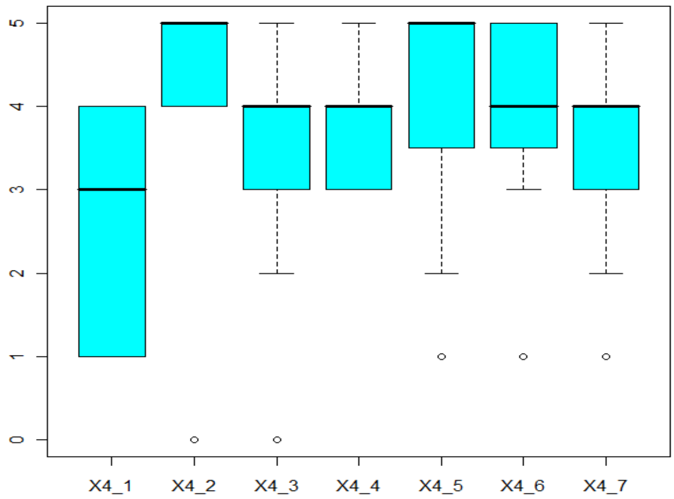

Figure 3. Boxplot of learning opportunities

A comparison of inexperienced and experienced students also reveals aspects that require special management. Young students are much more reluctant to make practical assumptions that are not directly related to specific mathematical formulas. In contrast, the students who possess previous work experience make assumptions naturally. However, because of their individualism and empowerment, they require a much more experienced manager. Management that has strong leadership attributes is clearly required here to avoid providing various fragmented solutions to the customer, instead of one well-focused approach.

When the project manager fulfills his role, the solutions provided are more practical than those generated by inexperienced students. This analysis supports the relevance of work experience as an additional skill provider to formal knowledge with an impact on student performance. When the project manager doesn't fulfill his role, the risk of project failure is much higher than in the other case. This is also a lesson that was learned, demonstrating its relevance for the profession of project manager in real life.

The perception of both the students and teachers is that the learning approach tested was valuable and more productive than lecture-oriented approaches, despite the fact that it required greater effort than the classical method, in which most of the effort is spent as examinations approach.

This does not mean that the learning approach presented is in an optimal state because, according to the lessons learned, there are improvements to consider making to the lessons. The easiest improvement to implement would be to design some 'gates' for practical projects to help project managers to have individual goals to refer to concerning the progress desired.

One issue is the number of class students as some scheduled tasks are class size-dependent, including the blended learning tools.

These tools were rated as very relevant for both students and teachers as they make possible direct feedback from an individual's reading, as well as an individual's work. Also, they make non-synchronous work possible by means of common repositories, forums with email alerts and many other useful tools.

The experience could be adapted to other courses by changing the project area to one that aligns with the subject of the course concerned. Our immediate plan is to complete the experiment by comparing the work of the teams. The following step will be to study and measure how technical information about project management improves the execution of practical work. In order to accomplish this, specific objective measurement looking for effectiveness of this learning approach will be established. Also, scalability characteristics will be analysed by running the approach with nearly two hundred students integrated into sixteen different teams.

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