MODEL DESIGN AND CALCULATION WITH POLYMERIC AND COMPOSITE MATERIALS THROUGH PROJECT-BASED LEARNING

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Abstract

The new educational paradigm requires new active methodologies to fulfil the market demanding needs. Students need to join the competitive labor market with optimal skills to achieve all their professional objectives. That is why the current teaching-learning process requires disruptive changes through the implementation of innovative methodologies such as the Project-Based Learning (PBL). The PBL is a methodology that allows students to acquire the key knowledge and skills through the elaboration of a project that gives response to a real problem.

According to the Edgar Dale's Cone of Experience (Dale, 1946) the PBL is an active methodology since it is located at the basis of the pyramid in the layer of: 'Direct Purposeful Experience – Go through a Direct Experience'. Based on Dale's results, students will remember 90% of what they do as they perform the project. In light of this, and with the main goal of prepare suitable professionals, in the Mechanical Engineering Degree of the Universitat Politècnica de València, a PBL model has been defined. This model involves the following three subjects: (i) Polymer Matrix Composite Materials Engineering; (ii) Manufacturing processes of polymer matrix composite materials and (iii) Advanced design with polymers: Project with composite materials. All these subjects are taught in the second semester of the 4th year of the Mechanical Engineering Degree. The PBL model, which consists of the design and calculation of a pressure tank by using CAD/CAE tools such as SolidWorks, will be developed concurrently among the three subjects. In this article, the PBL model is defined as well as the steps and considerations that have been followed and taken into account for its definition.

Keywords: Project-based learning, mechanical engineering, composite materials, Computer Aided Design (CAD), Computer Aided Engineering (CAE), Computer Aided Manufacturing (CAM), materials selection.

1 INTRODUCTION

The new educational paradigm requires new active methodologies to fulfil the market demanding needs. Students need to join the competitive labor market with optimal skills to achieve all their professional objectives. Current engineering students and future professionals require a general training to involve the complete practice of the technical areas of all types of companies to solve technical problems, design and implement new technologies, processes, products and mechanisms to enhance companies production process-related issues. Therefore, engineers require all the necessary skills to know where to find the solution and how to apply it to solve a specific problem.

These new educational requirements promote the research in new educational methods to try to fulfil the current engineers' education needs. That is why the current teaching-learning process requires disruptive changes through the implementation of innovative methodologies such as the Project-Based Learning (PBL). The PBL is a methodology that allows students to acquire the key knowledge and skills through the elaboration of a project that gives response to a real problem.

The project-based teaching and learning are part of the field of "active learning". Within this field, besides PBL methodology there are others active ones such as task-based learning, problem-based learning, discovery learning and the challenge-based learning. All these teaching and learning strategies make a difference from direct teaching because, among other things [1]:

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- Knowledge is not the lecturers' possession that should be transmitted to students, but rather the result of a work process between students and teachers whereby questions are asked, information is sought, and this information is processed to draw conclusions.
- The role of students is not limited to active listening but it is expected to actively participate in higher-level cognitive processes such as: problem recognition, prioritization, information collection, comprehension and interpretation of the data and/or information collected, establishment of logical relationships, proposal of conclusions and/or critical review of pre-concepts and beliefs.
- The role of the lecturer expands beyond the exposition of contents, the main function of lecturers is to create the learning situation that allows students to develop the project, what will involve search for materials, locate sources of information, manage group work, assess the development of the project, solve difficulties, control the pace of work, facilitate the success of the project and evaluate the result.

According to the Edgar Dale's Cone of Experience [2] (Figure 1), the PBL is an active methodology since it is located at the basis of the pyramid in the layer of: 'Direct Purposeful Experience – Go through a Direct Experience'. Based on Dale's results, students will remember 90% of what they do as they perform the project.

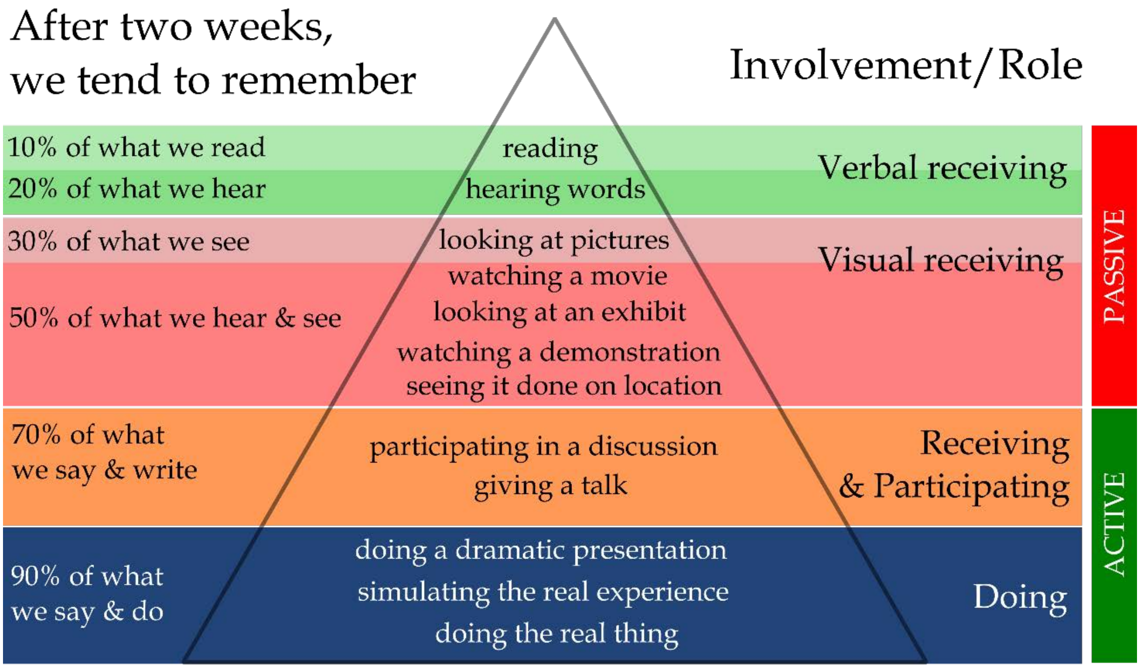

Figure 1. Dale's Cone of Experience (Adapted from [2]).

In light of this, it seems that PBL is an adequate methodology addressed to engineers' training since learning by doing through a project provides the sufficient cognition to instruct in practical technical skills and prepare suitable professionals. In this case, the PBL will be defined and implemented in the Mechanical Engineering Degree of the Universitat Politècnica de València. The model involves the following three subjects: (i) Polymer Matrix Composite Materials Engineering; (ii) Manufacturing processes of polymer matrix composite materials and (iii) Advanced design with polymers: Project with composite materials. All these subjects are taught in the second semester of the 4th year of the Mechanical Engineering Degree. The PBL model, which consists of the design and calculation of a pressure tank by using Computer-Aided Design/ Computer-Aided Engineering (CAD/CAE) tools such as SolidWorks, will be developed concurrently among the three subjects.

After exposing the utility of this active methodology, the aim of this article is to define the aforementioned PBL model addressed to Mechanical Engineers to provide a real use case with two twofold objectives. Firstly, the definition of the PBL model will provide a prospect to other lecturers who are in the same circumstances and are not highly experienced about how to define PBL models and secondly, the model will also serve as a common thread in the coordination of the different subjects involved in the model, so that students appreciate the continuity in the learning process.

2 METHODOLOGY

The methodology used to define de PBL in Mechanical Engineering, the following elements must be considered [3]:

a) Students. Defining the control group.
b) Lecturers or involved knowledge areas.
c) Involved topics.
d) Acquired transversal skills.
e) PBL definition. Scope and subjects.
f) Standardizing notation.
g) Definition of the software platform to develop the PBL project.
h) Sequence of contents (what to explain and when to explain).
i) Stablishing the links/interactions between the sequenced contents and subjects.
j) Feedback with students.
k) Periodical meetings with the involved lecturers.
l) Tutorship tasks during the project developed by the students.
m) Exposition and evaluation.
n) Analysis of the usefulness of the PBL compared to regular teaching-learning process.

Following, all these issues will be discussed. The involved lecturers in this PBL project, are in the initial stage to define the scope, despite some previous experiences can help in succeeding.

3 DEFINITION OF THE PBL

All the above-mentioned issues can be structured into four main levels that are linked all together to give an overall project:

a) The framework of the PBL.
b) Defining the scope of the PBL.
c) Development of the PBL.
d) Validation of the usefulness of the teaching-learning process by PBL.

3.1 The framework of the PBL

This first level includes students, lecturers or knowledge areas and subjects involved in the PBL, and the overall skills the students will obtained after the PBL. This PBL will be implemented in a specializing block corresponding to the Degree of Mechanical Engineering and will involve a total number of students of about 20. It is evident that to evaluate the usefulness of the PBL *versus* traditional teaching-learning methods, the lecturers involved in this PBL will consider a control group of one half the total number of the students that will follow the regular methodology as done in previous years, and the other half will follow the PBL methodology to cover some topics included in different subjects.

On the other hand, to give optimum results, it is necessary that lecturers from different knowledge areas are involved in this new methodology. As we are working on a PBL in Mechanical Engineering, the following knowledge areas will be involved to enrich the outcomes of the PBL.

- Mechanical Engineering.
- Manufacturing Processes Engineering.
- Materials Science.

It is evident that the use of new methodologies requires the lecturer is motivated in using these new teaching-learning tools. To overcome this restriction, we plan to define a protocol/methodology that could be used in the future independently of the current leading lecturers of this project.

On the other hand, the Universitat Politècnica de València (UPV) is pioneering a macro-project to define transversal skills that students acquire during their formation period, in addition to the regular subjects. These transversal skills are gaining relevance at UPV and are the following (**Table 1**), and every conventional subject works on one or two of these skills in the list. Nevertheless, with the PBL, it will be possible to cover a wider range of transversal skills and, subsequently, complete the acquisition with other conventional subjects.

Table 1. List of transversal skills defined by UPV and skills that will be involved by the PBL.

Transversal skills at UPV	*Involved in PBL*
Comprehension and integration.	✓
Application and practical thinking.	✓
Analysis and solving problems.	✓
Innovation, creativity, and entrepreneurship.	
Design and project.	✓
Teamwork and leadership.	✓
Ethical, environmental, and professional responsibility.	✓
Effective communication.	✓
Critical thinking.	
Knowing contemporaneous problems.	✓
Permanent learning.	
Planning and time management.	✓
Specific instruments.	✓

Some of these transversal skills will be acquired or reinforced during the PBL (marked with a green check arrow). Just by reading the name of the transversal skill involved its contribution to a PBL almost is self-explaining. PBL methodology requires, comprehension, establishing relationships, practical thinking and solving complex problems, teamwork (and all the issues related to this, such as leadership), effective communications (oral exposition of the project), planning sequences and time optimization. Therefore, the scope of this PBL not only convers technical issues but also acquiring transversal skills.

3.2 Defining the scope of the PBL

As above-mentioned, this PBL is intended to be applied in the Degree on Mechanical Engineering. This degree is structured into eight semesters (four years, each 60 ECTS). One particularity of this degree is that almost all optional subjects are included in the 7th and 8th semester (4th year), but what is most important, these optional subjects are gathered in different specializing blocks.

- Design and vehicle engineering.
- Design and calculation with polymer composite materials.
- Design and manufacturing machines and prototypes.
- Project Engineering.

All these specializing blocks have an average number of 20 students per year. The PBL we propose corresponds to the "**Design and calculation with polymer composite materials**", block, which is composed of the following subjects.

Table 2. Characteristics of the subjects included in the "Design and calculation with polymer composite materials".

Name	***Type***	***Semester***	***ECTS***
Technical Office	Compulsory	4A	6
Polymer Matrix Composite Materials Engineering	Optional	4B	6
Manufacturing processes of polymer matrix composite materials	Optional	4B	6
Advanced design with polymers: Project with composite materials	Optional	4B	6
Engineering of polymeric materials	Optional	4A	6
Manufacturing processes with polymeric materials	Optional	4A	6
Project and engineering parts with polymeric materials	Optional	4A	6

As can be seen in **Table 2**, Technical Office is compulsory for all students in the last year (4th year). On the other hand, all subjects included in this specializing block are optional and correspond to the 1st semester of the 4th year (4A), or to the 2nd semester of the same year (4B). As one can see, there is homogeneity between the subjects in 4A semester, mainly focused on polymers and the subjects included in the 4B semester (all them related to composite materials).

To define the limits of the PBL, it is important to determine the scope of the project. In this case, the PBL, will be applied to subjects included in the 4B semester which are related to the characteristics, design, calculation and manufacturing with polymer composite materials such as epoxy+carbon fiber (EP/CF), unsaturated polyester+glass fiber (UP/GF), among others. These composite materials have become a real innovation in the field of materials as the combination of a polymer matrix such as epoxy (EP), unsaturated polyester (UP), vinylester (VE), among others, with a reinforcement fiber (short fiber, 2D fabric, unidirectional, among others), such as carbon (CF), glass (GF), aramid (AF), and so on, leads to high performance materials widely used in high tech-applications. Therefore, the PBL in this field can be very advantageous to the students and could provide them with a competitive advantage with regard to other specializing blocks since they will work with high-tech materials.

An important think to be considered is that all lecturers involved in this project use the same notation and units to avoid confusion or misunderstanding, *e.g.*, strength (σ_m) and modulus (E_t for tensile and E_f for flexural) in (MPa), forces (F) in N, plane directions x-longitudinal; y-transversal; z-normal, and so on.

Currently, the software used in each of the involved subject is different; therefore, we propose the use of a unique software platform which includes all the topics to be covered by the project, i.e. material selection, computer aided design (CAD), computer aided engineering tools (CAE) such as the finite elements method and, obviously computer aided manufacturing (CAM). After the initial meetings of the lecturers involved in this PBL, SolidWorks has been selected for several reasons. On one hand, all students have full access to this software and can work both at University and home by a VPN connection. On the other hand, despite it is not as powerful as other CAD/CAM/CAE tools such as ANSYS or NX, SolidWords has a very fast learning curve and all the students are used to work with it because if the software selection for CAD subjects [4].

Moreover, students develop a small project in each subject to evaluate some particular topics. What we propose it is not a full change in the methodology since most of the theory and practical sessions will be evaluated as currently done (tests, reports, and so on), but is this small project that will become into a large project (PBL) covered by the three considered subjects and will be evaluated globally.

This large project will contain issues related to all three knowledge areas and will be related to topics explained in each of the subjects as indicated in **Table 3** [5,6]. As all subjects are assigned to the 4B semester (last semester) it is complicated to define a sequence (this has more sense in subjects corresponding to different years and semesters). In the case we propose, theoretical sessions and practical sessions will contain all the relevant information students need to develop a coordinated project. This project will be launched the last month since they will have received all the relevant theoretical and practical concepts. During the regular sessions (theoretical or practical), the corresponding lecturer will indicate the relationship of the explained concept with some other concepts corresponding to other subjects or knowledge areas, so that, the student can see these relationships and conceive the project as the interaction between the three subjects and not as isolated concepts. As can be seen, the superscript letters [a], [b] and [c], represent individual knowledge areas and almost all topics from a knowledge area are somewhat related to some topics from other knowledge areas.

Table 3. Definition of the basic topics that each subject will cover to develop a coordinated PBL.

Knowledge area	***Main topics to be covered***
Mechanical Engineering [a], [7,8]	- Composites in engineering applications [b,c]. - Micromechanical models as a base to design and calculation with composite materials. Inputs from materials [c]. - Mechanical resistant and elastic properties of a composite ply [c]. - Classic Laminate Theory. Input parameters and output properties [c]. - Using SolidWorks as a CAD tool to design parts/assemblies [b]. - Failure criteria and modes in composite materials [c]. - Using SolidWorks as a CAE tool to optimize parts/assemblies [c].
Manufacturing Processes Engineering [b], [9,10]	- The relevance of manufacturing with composite materials [a,c]. - Manufacturing with composite materials. Open mould [a,c]. - Manufacturing with composite materials. Closed mould [a,c]. - Design for manufacturing [a]. - Using SolidWorks as a CAM tool for engineering [a,c]. - Cost estimations [c]. - Surface finishing of composite parts/assemblies [c].
Materials Science [c], [11,12]	- Scope of composite materials in engineering [a,b]. - Adhesion for load transfer [a,b]. - Polymer matrices: types, properties, and characteristics [a,b]. - Fiber reinforcements: types, properties, and characteristics [b]. - Micromechanical models [a]. - Linear elastic orthotropic materials [a]. - Analysis of micromechanical models [a]. - Mechanical properties of a composite ply [a]. - Working with composite materials in SolidWorks [a]. - Classification and nomenclature of composites [a,b].

3.3 During the development of the PBL

As previously stated, it is worthy to note the relevance of the student/lecturer communication to get the optimum results in this PBL experience. For this reason, all three lecturers will be available during the last month (development of the project), to guide students in the right direction to achieve the goals. During this period, lecturers will reinforce the interaction between the topics studied in the three subjects.

All the drawbacks, doubts, and problems identified by the students and transmitted to the lecturers, will be treated as a high-quality information to continuously improve this PBL experience with future students.

Additionally, all involved lecturers in this PBL experience will have periodical meetings to coordinate the PBL project. These meetings will not be focused only on the final stage (last month, development of the project), but also during all the semester to check if things are going well or need some adjustment depending on students, motivation, and so on.

As indicated previously, the current system considers three mini-projects developed in each subject. With this new proposal, that would be launched in 2020-2021, these three mini-projects will convert into a real problem related to the use of composite materials in engineering applications. For example, students could develop a project related to a pressure vessel design by selecting materials, designing and optimizing the geometry, using CAE tools to simulate the actual working conditions and, finally, define the optimum manufacturing process by taking into account geometry, number of parts to be manufactured, and so on.

Students will use teamwork and all required tools to give their solution to the project and, finally they will have to do a written report and an oral presentation to evaluate the quality of the developed project. All students will be present during the presentations and the three lecturers, as well. The evaluation for this project (which could represent 30-40% of the final mark), will be carried out though a checklist with items related to both the written report and the oral presentation.

3.4 Validation of the usefulness of the teaching-learning process by PBL

To assess the advantages of this new methodology of PBL in Mechanical Engineering, the outcomes of all the students (with regular methodology and with PBL methodology) will be compared and statistically analyzed. These results will provide lecturers with high-quality information about the usefulness of the proposed methodology versus traditional methodology.

Moreover, a questionnaire will be given to students involved in the PBL experience with questions related to all things related to this new methodology: advantages, disadvantages, satisfaction with the final marks, problems and doubts arisen during the development, evaluation of the tutorship activities with lecturers, and so on.

All this information will be vital to define/adjust the PBL methodology for upcoming students, with the main aim of PBL represents a real alternative to traditional methodologies in Mechanical Engineering.

4 CONCLUSIONS

The project we propose is the use of a Project Based Learning (PBL) approach in the Degree on Mechanical Engineering. Since almost all the optional subjects are offered in the 7th and 8th semester (4 year), the PBL we propose involves participation of lecturers from different knowledge areas such as mechanical engineering, manufacturing processes engineering and materials science. We think students in their last semester have enough motivation to face a real project related to their previous knowledge in Mechanical Engineering. Despite the use of new methodologies are directly related to the lecturer motivation, with this PBL, we would like to give a step forward and completely define an optimized and well defined methodology that could be used by other lecturers in the involved subjects as usually, new lecturers are assigned to these subjects. The PBL experience we propose must be able to define in a clear way the following issues.

Table 4. Planning of a PBL new methodology in the Degree on Mechanical Engineering.

Topic	***Sub-topics***
The framework of the PBL	- Students. Defining the control group. - Lecturers or involved knowledge areas. - Involved topics. - Acquired transversal skills.
Defining the scope of the PBL	- Students. Defining the control group. - Lecturers or involved knowledge areas. - Involved topics. - Acquired transversal skills. - PBL definition. Scope and subjects. - Standardizing notation. - Definition of the software platform to develop the PBL project. - Sequence of contents (what to explain and when to explain). - Stablishing the links/interactions between the sequenced contents and subjects.

Topic	Sub-topics
Development of the PBL	- Feedback with students. - Periodical meetings with the involved lecturers. - Tutorship tasks during the project developed by the students. - Exposition and evaluation.
Validation of the usefulness of the teaching-learning process by PBL	- Analysis of the usefulness of the PBL compared to regular teaching-learning process.

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REFERENCES

[1] J. Larmer, & J.R. Mergendoller. *The main course, not dessert.* Buck Institute for Education, 2010.

[2] E. Dale. *Audio-visual methods in teaching*. New York: The Dryden Press, 1946.

[3] L.P. Martiqua, S.A. Brandt, D. N. Barlow. *Introduction to Engineering: A Project-Based Experience in Engineering Methods*. AIAA American Institute of Aeronautics & Ast., 2017.

[4] L. Habeeb, M. Ahmed. *Solidworks for Mechanical Engineering: for beginner and intermediate level*. LAP LAMBERT Academic Publishing, 2016.

[5] K.K. Chawla. *Composite Materials: Science and Engineering*. Springer, 2012.

[6] D. Gay. *Composite Materials: Design and Applications*. CRC Press, 2014.

[7] K.L. Yin. *Composite Materials: Materials, Manufacturing, Analysis, Design and Repair*. K.L. Yin, 2015.

[8] R.E. Gibson. *Principles of Composite Material Mechanics*. CRC Press, 3rd edition.

[9] S.V. Hoa. *Principles of the Manufacturing of Composite Materials*. DEStech Publications, 2009.

[10] S.K. Mazumdar. *Composites Manufacturing: Materials, Product, and Process Engineering*. CRC Press, 2001.

[11] D.D.L. Chung. *Composite materials. Science and applications*. Springer, 2010.

[12] R. Kumar. Polymer-Matrix Composites: Types, Applications & Performance. Nova Science Publishers Inc., 2014.