Development of a carbon fibre composite body for a radio controlled car through a PBL approach

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INTRODUCTION

Knowledge is exciting and learning, in general, should be enjoyable. This includes learning experience in the University. Furthermore, technical skills at the last years should be highly interdisciplinary, close from the industrial reality where students should be able to make their own decision based on their background. Problem or Project Based Learning (PBL) has been proposed as an active and effective approach to achieve these skills (Barrows,1980). Academic objectives and industry needs are also to keep in mind when defining the project. Thus, the selection of the project aim is a key point in order to motivate both, students and staff.

Automotive is a driver industry in the Basque Country, traditionally based on metallurgy, which employs a lot of engineers from Mondragon University. However, driven by the lightweight priority, carbon fibre reinforced composites´ design and manufacturing skills are demanded from these industries. Fortunately, several research groups from the University are involved in projects related with such technologies, and their state-of-the-art facilities can be used to transfer this knowledge to our students. The confluence of the academic, industrial and research activities gives the students the opportunity to have a holistic experience that could be very useful in their professional career.

So, the aims of this project is to combine PBL approach with the development of a carbon and glass fibre composite 1:18 scale structure of a radio-controlled automobile model in order to motivate students to achieve deep learning and highly specific skills.

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1 PROJECT DEFINITION

PBL is a student-centred methodology in which students learn about a subject through the experience of problem solving in teams (Graaff & Kolmos, 2003). *"Learning is the process whereby knowledge is created through the transformation of experience"* (Kolb, 1984).

PBL is active learning. Students work as self-directed, active investigators and problem-solvers in small collaborative teams. The goals of PBL are to help the students develop flexible knowledge, critical thinking, effective problem-solving skills, effective collaborative skills and innate motivation; in fact, the aim of PBL is the development of self-directed learning (SDL) skills (Loyens, 2008).

Another important aspect of PBL is that teachers adopt the role as facilitator of learning, guiding the learning process and promoting an environment of inquiry. In PBL the teacher changes his role from the traditional lecturer position to become a facilitator who helps the team find their way towards the solution to a problem.

According to Mondragon University educational model, the semester includes different subjects and each subject has its own learning outcomes which impact in the acquisition of different competences (*Table 1*). At the same time different subjects can have an impact on the same competence, so the PBL becomes an interdisciplinary project empowering students to relate these subjects in order to solve the problem. It is a real life simulation of their future work as engineers.

Table 1. PBL definition based on acquiring competences

Semester	Learning Outcomes	Competence 1	Competence 2	Competence 3	Competence 4	...	Competence 9	Competence 10
Subject 1	1	x			x			
	...			x			x	x
	5	x						
Subject 2	6			x				
	...						x	x
	10	x						
...	...				x			x
Subject 5	...							
	n							

In the studied case, defining this PBL involves selecting certain technical competences of Industrial Engineering Master Degree, which are:

- To develop work planning and human resource management skills.

- To be able to manage innovation, development and technology innovation.

- To be able to design and test machine using dynamic analysis methods, geometric verification and applicable standards.

- To be able to calculate and design structures using analytical and numerical methods (specifically, finite element method).

- To able to plan, calculate and design integrated manufacturing systems, optimizing the manufacturing processes best suited to different industrial sectors, taking into account the features of polymeric, metal and composite materials.

Apart from these technical competencies the students learn also soft skills, such as teamwork, communication, decision making and conflict management, which are very much needed in order to work well as a team. Anyway, the most important fact is that they obtain the learning goals better by learning from each other (Peer Learning).

The 47 students of the last course of Industrial Engineering Master Degree have been organized in eight teams to work on this project during the last semester. Each team mixes students from different specialties of Industrial Engineering in Mondragon University, which are *Structural Mechanics* and *Materials and Manufacturing*. This way, their different knowledge is complemented in order to solve the problem in a holistic approach.

2 PBL PROJECT ASSESSMENT

The assessment of the project has been based on the execution of each different phase, such as: achievement of the objectives, meeting deadlines, handing in update reports, a video showing the whole process, a final report and a final written defence.

The use of level descriptors during the assessment, such as the ones defined in Biggs' SOLO taxonomy (Biggs, 1982), provides a powerful tool to assess the learning outcomes that encourage deep approaches to learning and can be used to improve effectiveness. SOLO taxonomy provides a simple and robust way of describing how learning outcomes grow in complexity from surface to deep understanding (*Fig. 1*).

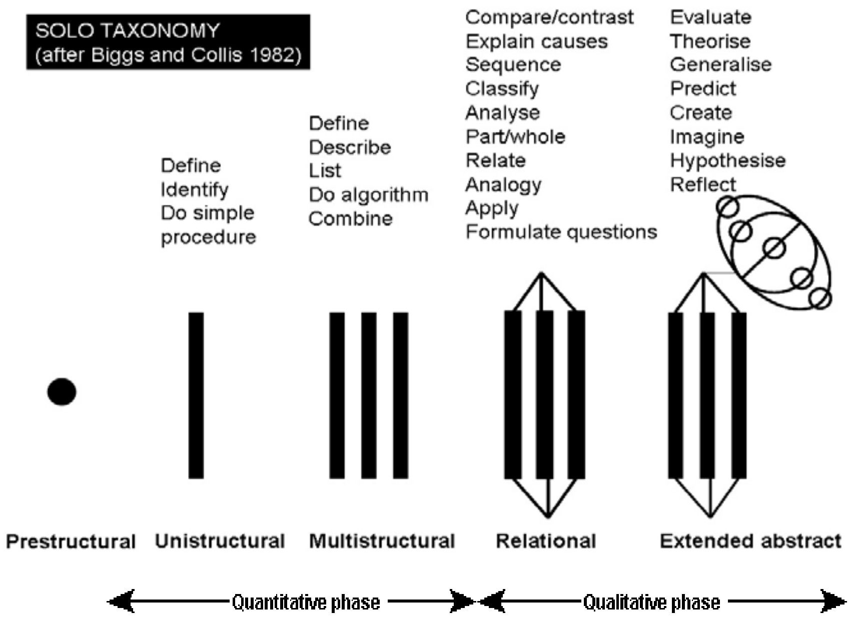


Fig. 1. SOLO Taxonomy (Biggs & Collis, 1982)

3 PBL APPROACH AS AN EFFECTIVE LEARNING METHOD

Marton and Säljö (1976) found that students´ approach to learning could be divided into two distinct groups: those that took an understanding approach to learning and those that took a reproduction approach to learning. These are more commonly referred to as deep and surface approaches to learning, respectively (*Table 2*).

Surface learners are characterized by focusing and memorizing whereas deep learners engage in an active search for meaning.

Table 2. The attributes of deep and surface learning (Marton & Säljö, 1976)

	Surface learning	**Deep learning**
Knowledge	An increase in knowledge or information about subject acquired by gathering unrelated facts and without integration with what is already known.	An increase in understanding of a subject involving grasp of underlying principles.
Application	An ability to apply new knowledge to particular tasks and problems but without transferability.	An ability to apply newly understood principles in a variety of different contexts and situations.
Endurance	An ability to recall new information but usually only short term.	Long-lasting personal change.

The more recent work by Biggs (1987) supports this theory. Deep learning is effective learning, marked by a deliberate intention to learn. Effective learning concerns the construction of knowledge rather than the reception of knowledge, which lies at the heart of constructivism (Savery, 1995). So, deep learning is encouraged through applying knowledge, and motivation is the key factor in improving deep learning as Illeris (Illeris, 2003) has stated.

Biggs conceived his SPQ questionnaire (Study Process Questionnaire) to determine individuals' approach to learning. Later his revised version R-SPQ-2F (Revised two-factor Study Process Questionnaire) included Motive and Strategy factors in the questionnaire (*Table 3*) (Biggs, 2001).

Table 3. SPQ dimensions, motives and strategies (Biggs, 2001)

	Surface	**Deep**	**Achieving**
Motive	Fear of failure	Intrinsic interest	Achievement
Strategy	Narrow target, rote learn	Maximise meaning	Effective use of space and time

One of the many advantages of the PBL approach is that it empowers students in deep learning. PBL students tend to adopt a deep approach rather than a surface approach, which is in line with the assumptions behind PBL. Dolmans (Dolmans, 2010) adapted the Biggs´ questionnaire to a PBL approach, which is known as PBL-R-SPQ. The values in this questionnaire range from 1 to 5. The 18-item PBL-R-SPQ provides a valid and reliable tool to measure students' learning approach in PBL.

4 PBL PROJECT DEVELOPMENT

The PBL´s main objective is to develop a product designing and manufacturing a carbon and glass fibre composite body of a radio-controlled automobile model car. The PBL project has been developed following the next steps (*Fig.2*).

To begin with, each group has defined a positioning considering the car styling, which has to deal with aesthetics, as well as other specifications of the car such as the consumption, prize, stiffness, crashworthiness, ergonomics… At the end of this task each team has obtained a 3D model in a CAD system.

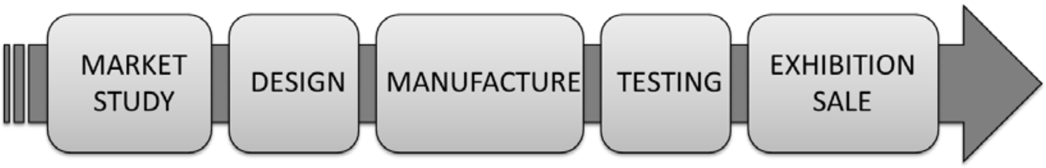


Fig. 2. New Product Development Process

Although the design proposed could be anyone, the materials that can be used for its manufacturing are limited to four types of tissues: two types of carbon fibres (unidirectional and bidirectional) and two types of glass fibres (bidirectional and mat). Epoxy is the unique resin admitted for every material. With the aim of obtaining the best rate of torsional stiffness and weight, the specific material, amount of layers and the fibre directions must be optimized by doing simulations with a FEM software.

After that, the manufacturing process started, which includes three tasks: production of the car's body on reinforced epoxy, manufacturing of auxiliary complex elements (spoilers, bumpers…) by a 3D printer, and assembling all the parts and finishing the model. At the same time, manufacturing the car´s body in reinforced epoxy material has three steps. To begin with, the moulds have been manufactured using CNC programs that are obtained by means of CAM software, based on the 3D models previously obtained. The moulds have been produced in an easy-to-cut material which is proper to produce prototypes (*Fig. 3*) and measured in a coordinate measuring machine.

Fig. 3. Moulds machining

Fig. 4. Positioning fibre patterns

According to the results of FEM simulation, the teams prepared the layers and their own resin, impregnated the laminated by a brush and a roller and finally hermetically sealed the mould with a plastic bag doing a vacuum packing (*Fig. 4*).

Fig. 5. Auxiliary parts manufactured in a 3D printer

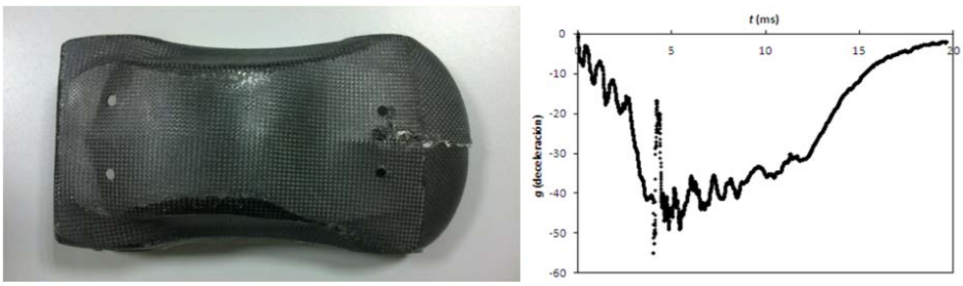
Fig.6. Assembled car body

The most complex and high definition level parts (spoilers, bumpers, diffusers...) have been produced in a 3D printer (*Fig. 5*), which have finally been assembled to the car´s body (*Fig. 6*). Having finished with this, the surfaces were polished, painted and decorated.

As a final task, technical aspects have been evaluated. The idea is to compare the results predicted by the FEM simulations and the experimental results. These comparisons are focused on the specific torsional stiffness, the crash safety and the system´s natural frequencies.

The applied load in the torsional stiffness test has been 20 times the car´s body mass, and the output result has been the rotated angle. Each team has to report the result, the deviation from the FEM simulations and the deviation sources.

The second evaluated aspect has been the crash safety. A frontal crash against a post is simulated in an instrumented mass falling machine, with impact energy of 50 J (5 kg from 1 m height). The impact´s load-time curve is registered to evaluate the deceleration (*Fig. 7*). There are two assessment criteria: the intrusion level (the impactor cannot enter the passenger´s space) and the resulting maximum deceleration (the risk of having serious brain damage is very high for decelerations over 20 g).



(a) (b)

Fig. 7. Result of crash test; (a) intrusion level, (b) deceleration curve

Finally, the natural frequencies of the car´s body are experimentally measured and compared to the ones predicted by FEM simulations.

One of the main tractive forces during the whole project has been the motivation of the students. A car race competition held at the end of the project has helped to keep this motivation, where each team drives their own car in a circuit (*Fig. 8*).

Fig. 8. The car race; (a) general view, (b) starting grid

5 RESULTS AND DISCUSSION

After finishing the PBL project the students in Industrial Engineering Master Degree responded to the Dolmans´ PBL-R-SPQ questionnaire and the results are shown in *Table 4*. It can be concluded that by means of PBL students' approach to learning is closer to deep learning than to surface learning. Thus, PBL ensures effective learning.

Table 4. Dolmans´ PBL-R-SPQ questionnaire results

Learning approach	Average	σ
Deep learning	3.3	1.17
Surface learning	2.52	1.13

The standard deviation in both approaches was quite high compared to other references (e.g. Dolmans, 2010). This could be due to the different learning experiences while learning different subjects or due to the assessment of different facilitators. This is a factor to take into account in future works.

It is important to highlight that throughout the whole process, the students are being given continuous feedback based on their update reports which facilitates the constant improvement of their own learning process and making sure they acquire the expected learning outcomes.

The final written defence confirmed that students reached relational and even extended abstract level in SOLO taxonomy, considering their ability to analyse, compare, relate, justify, predict… aspects related to the project.

After asking students to obtain feedback about their experience in the PBL their answers confirm the initial expectations of this project. A high percentage of them ensured they really liked the problem they were assigned and that the problem reflected a real-life situation. This aspect evidences the motivation of the students when carrying out the tasks of the project and helps to achieve the stated aims.

Students have expressed that the teaching way had nothing to do with classical blackboard teaching. Also they realized that they were forced to learn new things to solve the problem. It is sure that this new knowledge will be long-lasting thanks to the deep learning achieved.

Most of the students admit they have participated in a lot of discussions and that they felt themselves leading the project while the supervisor was just a facilitator. Moreover, they feel the atmosphere of the classroom has given them the freedom to use their own judgement and they have been able to make their own decisions. All these aspects show that soft skills are developed together with technical skills.

6 CONCLUSIONS

Considering the answers of Dolmans´ questionnaire, the level reached in the written final defence, centred in the quality phase of SOLO taxonomy, and the students´ experience in the project it can be affirmed that PBL leads to an effective learning in which the students´ motivation has been the engine of the process.

It must be remarked that it is very important that during the whole process facilitators build good rapport among themselves, starting from the definition of the project, along its development, continuous feedback and until the final assessment to ensure a minor standard deviation in the results of PBL-R-SPQ questionnaire.

7 ACKNOWLEDGMENTS

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