New Methodology for Integrating Teams into Multidisciplinary Project Based Learning*

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This paper describes the collaboration among students and professors in four different subjects, to develop multidisciplinary projects. The objective is to simulate the conditions in a company environment. A new methodology based on student interaction and content development in a Wiki environment has been developed. The collaborative server created an 'out of the classroom' discussion forum for students of different subjects, and allowed them to compile a 'project work' portfolio. Students and professors participated with enthusiasm, due to the correct well-distributed work and the easiness of use of the selected platform in which only an internet connected computer is needed to create and to discuss the multidisciplinary projects. Quality of developed projects has been dramatically improved due to integration of results provided from the different teams.

Keywords: PBL; active learning; collaborative work; multidisciplinary approach; mechanical engineering hands on teaching

1. Introduction

Complex engineering projects are usually carried out by the assimilation of different work teams, which could be located geographically distant. Collaborative Web environments have proven to be ideal knowledge repositories in Academia and in Industry applications. The work presented reproduces the organization of actual engineering projects, and brings it into the classroom.

Mechanical & Industrial Engineering students at the School of Industrial Engineering (ETSII) of the Universidad Politecnica Madrid (UPM) receive an in-depth knowledge in mechanical design and manufacturing processes. The increasing importance of systems integration in this field induces the need to include multidisciplinary knowledge that will allow students to develop complete designs of new products. This experience facilitates their subsequent assimilation into multidisciplinary engineering teams in industry.

In the production area, it is frequent to develop a manufacturing project according to a scheduled plan that comprises actions in design, drafting, drawing, process planning, and plant layout. These actions are done by manufacturing staff from different points of view of the manufacturing process.

Project enunciates were proposed with their particularities for two different subjects from the Mechanical Engineering Curriculum, one subject from the Industrial Engineering Curriculum, and one voluntary subject in all specialties. *Mechanical technology* (TEC) and *Simulation in Mechanical Engineering* (SIM) are subjects in the Mechanical Engineering curriculum at the ETSII and they are taught in the sixth semester while *Manufacturing* (FAB) is part of the Industrial Engineering program taught in the eighth semester, and finally *Computer Aided Design* (CAD) is a voluntary subject in all specialties.

Students of the four implicated subjects have traditionally carried out different application projects, but the new methodology induces collaboration between multidisciplinary teams in different areas of expertise. It has provided the students new types of problems involving the assimilation and development of a project and it has generated important evaluation reports to detect bad team behaviour and delays in the teamwork process.

The use of Project Based Learning (PBL) that allows students to participate in complex projects is a well-established method. Examples of these experiences can be found in many areas, with a positive evaluation particularly in the case of learning in engineering [1–2].

2. Structure of the PBL

The methodology undertaken was based on the fact that the assembly designed by the students in CAD should correspond to the size and constructional specifications of the manufacturing cell proposed by the students in TEC. This automation system was to be integrated into a specific manufacturing process proposed and planned by students in FAB. The feasibility of one or more components had to be checked by dynamic simulation by students in SIM.

Figure 1 shows an example handling problem in a saw cutting machine. The difficulty of the projects proposed is rather uniform, but the work sequence

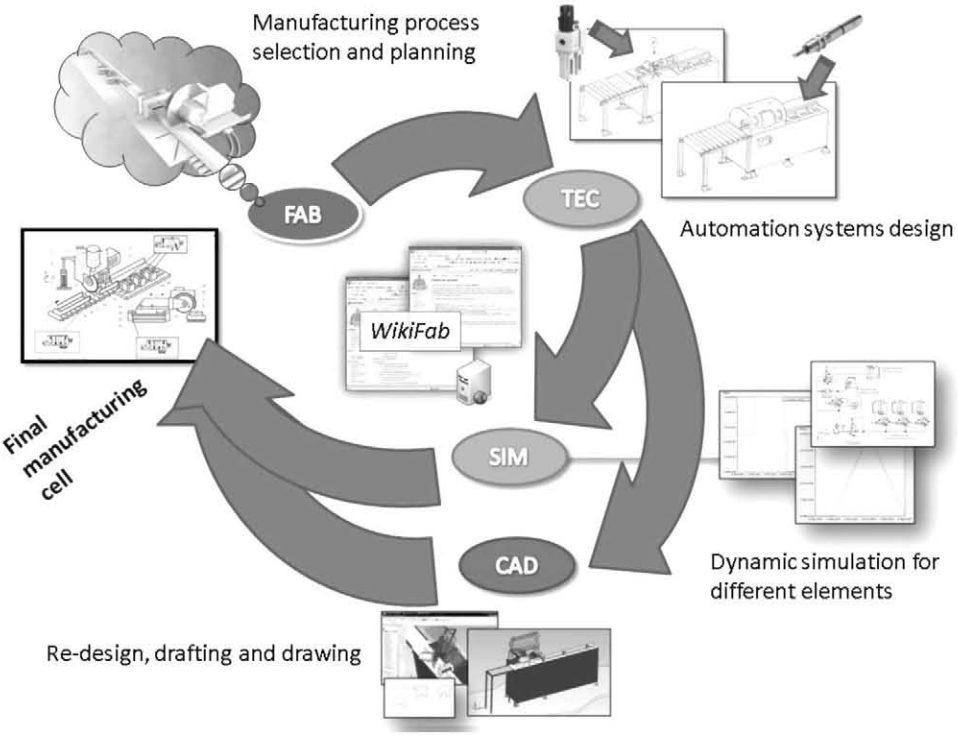


Fig. 1. Team's integration in the same project (in figure saw cutting machine).

and other specifications must be coordinated in advance for each topic. The saw cutting machine represented in this figure was developed by teams having four different points of view. Subsequently its solution would be composed of four different teams' approaches.

This new way of developing 'Project Work' documentation and encouraging discussion has helped the students to combine topics from different subjects, programs and courses with their own interests, and has been considered as an easy alternative to promotes active learning, not only in this area but in other courses.

One of the goals of this experience has been to collect a set of projects developed by students, mainly in the area of automation engineering, where the students have to work in cooperative groups of three students, and have to contrast their results with other groups from different subjects. Students have employed a Wiki server named WikiFab collaborative Web (acronym of Wiki Fabrication) [13] to share and prepare their work content. This server compiles the information available from all projects with the following advantages:

- 'Out-of-the-classroom' discussion with the ensuing improvements in students' ability to conceptualize.
- A simple, homogeneous compilation of the documents contributed by students.
- The chance to improve knowledge in other areas of interest.

The use of collaborative Web environments is now commonplace in university education [3–4]. The new technology platforms such as Blogs, Wikis, and RSS feeds are proving to be invaluable educational tools that satisfy the constructivist theories of active learning [5]. Some experiences are specifically oriented towards teaching in engineering and many are suited to collaborative work [6–7].

Some authors emphasize the creation of case study portfolios to promote an efficient understanding of concepts by students [8]. These case studies give rise to different ideas and have been proven to be an ideal mechanism for stimulating conceptualization.

The Wikis are in fact, an excellent environment for creating knowledge repositories, and many experiences have been developed in teaching [9–10] and in industry [11]. The use of Wikis can help to improve students' reasoning abilities. Their interaction with the Web can be done outside the classroom, as previous experiences have shown [12], where work on a collaborative project is considered as a complementary way for students, to improve knowledge acquired in theoretical classes.

In this case, MediaWiki 1.13 was chosen for its simplicity of configuration, its popularity (it is used in Wikipedia) and its powerful Wiki functionality, derived from third-party extension applications.

3. Team organization

This educational initiative has been applied in four subjects, directly affecting 110 students (2 students on each CAD team, 3 in MEC, FAB and SIM). Additionally, 44 students contributed with part of the work in some groups; in the FAB and TEC subjects, the rest of the students enrolled in these courses also worked to provide additional information to the PBL participant groups. This distribution of students was calculated taking into account the necessary time in ECTS to develop the final work associated with each subject.

The students in FAB manage complex actions in which interact with people that work on product design (the manufacturing cells that are studied in each case), product drawings, and product automation and simulation. Also, their actions usually involve multidisciplinary knowledge, in a wide field that, for example, includes cost and time estimation, plant layout design, choosing commercial equipment, or designing special purpose equipment (conveyors, tracks, lifts . . .), assembly plans, warehouses and logistics, etc.

The interaction of these students with those of the other related areas is probably more necessary, because involves many definitions that must be validated by the other actors. This is one of the most attractive and difficult of the actions proposed. It resembles the collaboration needed in modern industry where there are many subcontractors working together in any plant.

A collection of ten different types of manufacturing cells were proposed for study:

- Parts manipulation in injection moulding process (DPPMI);
- Machine to make pipe ending bezels (MBFT);
- Panel manipulation (MP);
- Can packing machine (EL);
- Saw cutting unit (US);
- Quality control for trays (CCB);
- Glass sheets positioning (PC);
- Tubular parts feeder (APT);
- On demand storage feeding unit (AM); and
- Adhesive application station (AA).

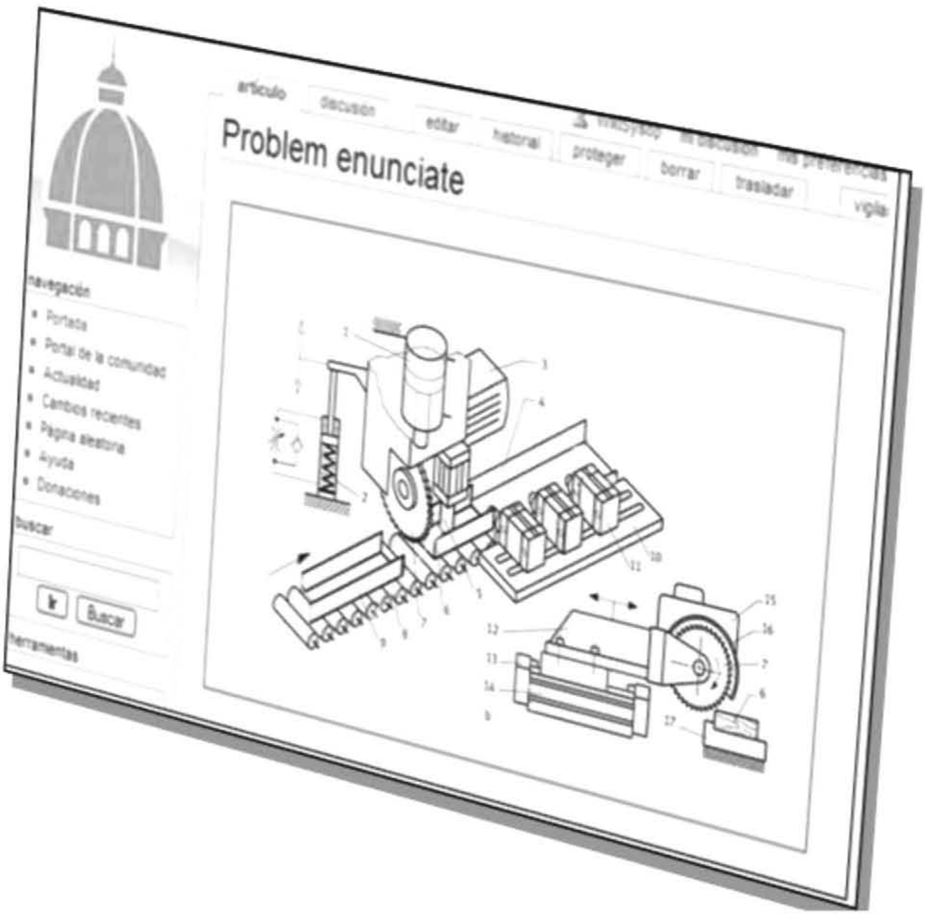


Fig. 2. An example of the type of project proposed (in figure saw cutting machine).

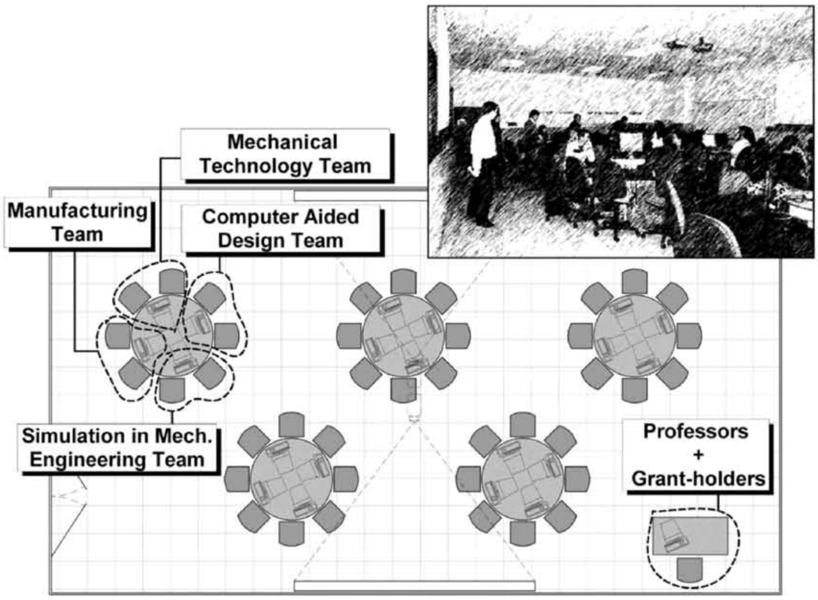


Fig. 3. Team coordination meetings

After developing intermediary results, students must then proceed with the publication and discussion on the collaborative Web.

Professors involved in this experience organized fortnightly coordination meetings in order to adjust course content timetables.

Once a week, collaborative meetings took place in a special designed classroom, where two or three members from each topic team were together and could exchange information face-to-face or solve problems that could not be sufficiently clarified by the Wiki discussion. Figure 3 shows the distribution scheme of these Multi-group exchange meetings in which professors from the four subjects involved answered any query and analyzed how the projects were progressing.

4. Wikifab collaborative web

When each team has defined their particular area of contribution, the collaborative Web begins its task, which is basically to serve as an integration tool for all the information. Published student contributions are visible to other teams, with the purpose of enhancing the overall quality of the results produced.

Figure 4 shows a solution to the formulation of the problem established in Fig. 2 carried out by the CAD team, chosen for publication in WikiFab collaborative Web. It is important to note that the recommended style for publishing solutions is a graphical format. This aspect forces students to train their synthesis skills, to express the objectives

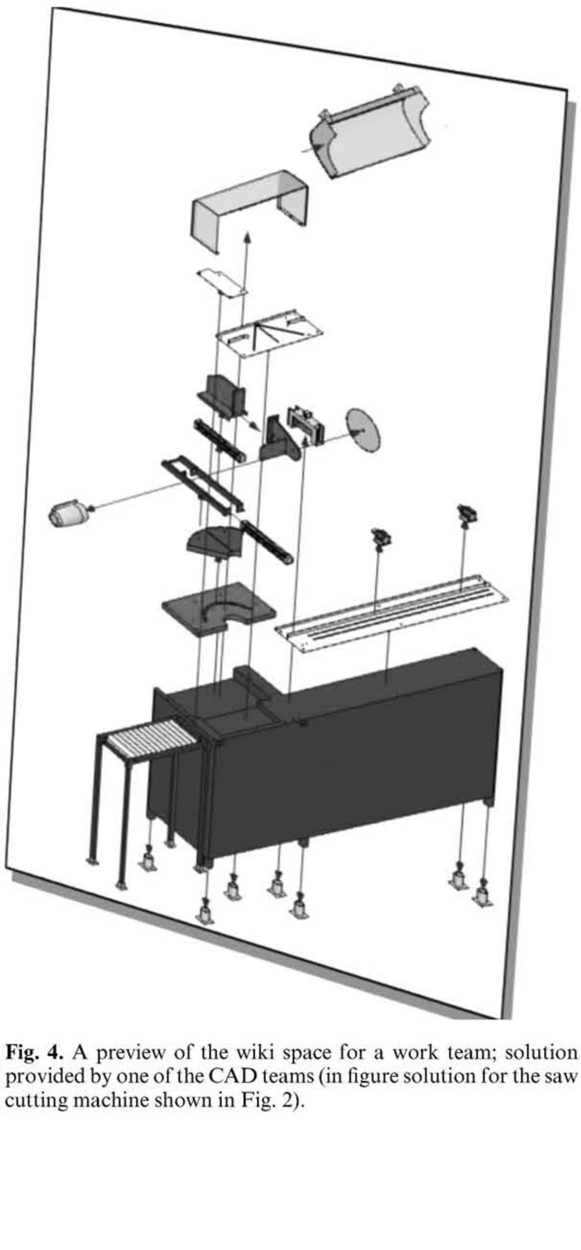
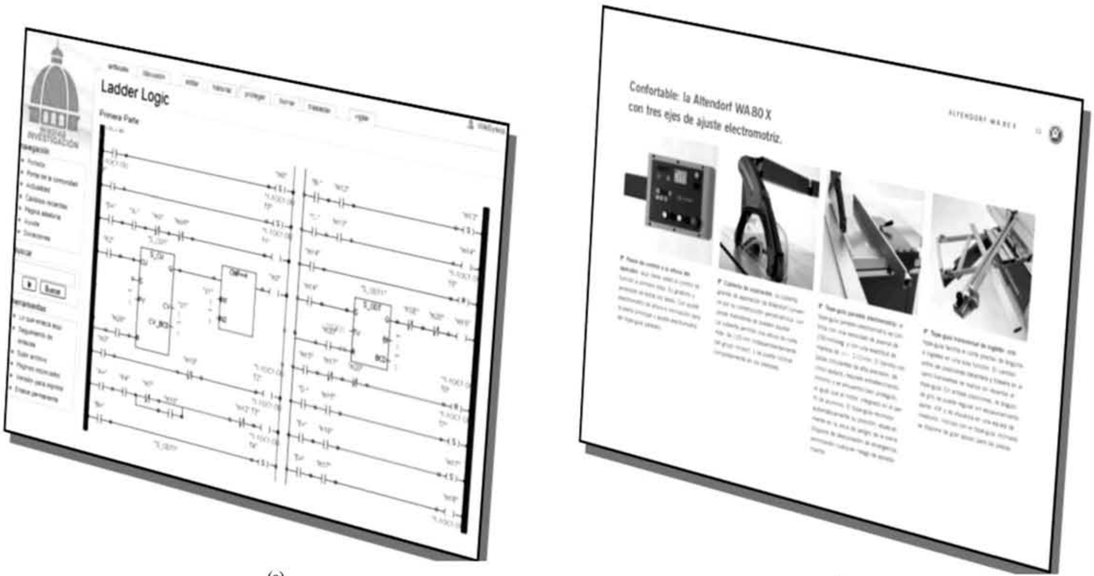


Fig. 4. A preview of the wiki space for a work team; solution provided by one of the CAD teams (in figure solution for the saw cutting machine shown in Fig. 2).



(a) (b)

Fig. 5. Different approaches to the project. (a) from the Mechanical Technology subject TEC, (b) from the Manufacturing subject FAB.

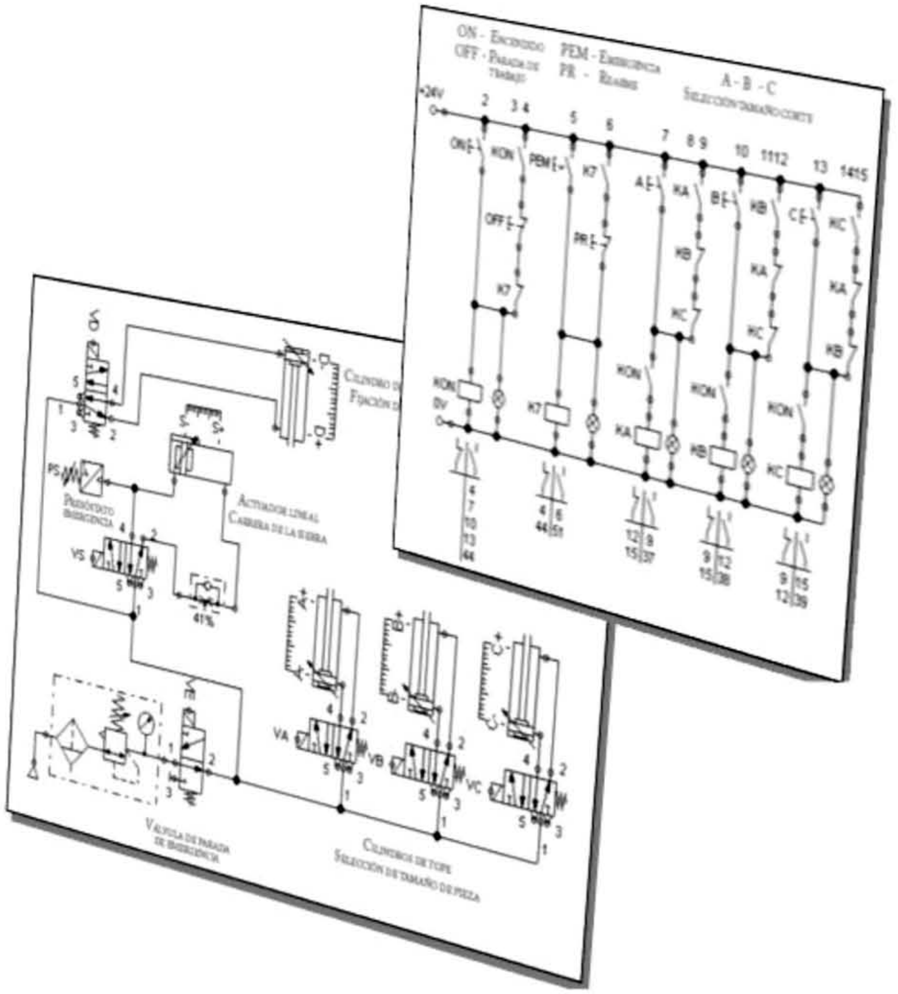


Fig. 6. Solution for the proposed model from TEC.

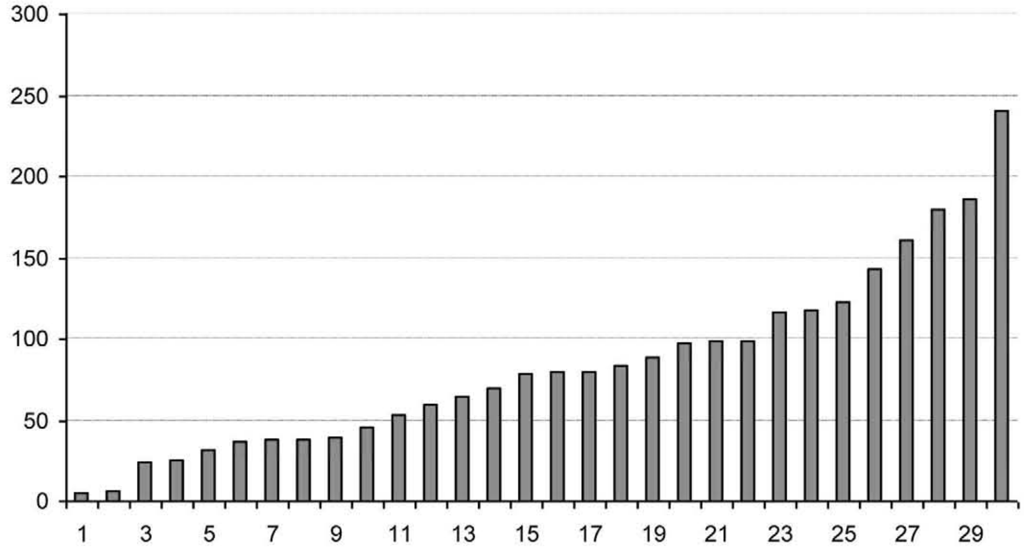


Fig. 7. Wiki editions counter variable for TEC topic.

of their models through schematic outlines or diagrams.

In this Wiki, students must improve the different issues that arise in the project. The discussion page contains everything related to project evolution and the starting conditions, such as the parts references provided by the manufacturers or any of the various design changes. Team members discuss all of this information, but they can also receive comments from other teams.

Figures 5 and 6 show different approaches to the proposed project model and the solution adopted respectively.

The discussion site, allowed the interaction with the professor and other team members to discuss the details of the proposed solution.

Figure 7 shows the Wiki editions counter for the TEC subject, for the 30 students directly participating. From previous experiences, the number of editions needed to create an average quality article, is approximately 50. The mean value for students in this subject was 83.6 during the current experience, and 100% of students actively used the Wiki server.

Note that Wiki use was mandatory for the students in TEC, but the results can be compared with SIM students Wiki participation, in which Wiki use was not mandatory, and students could interchange documentation in other formats. The SIM results showed that only 23.3% of the students generated Wiki contents; although the editions count average was 41.71. Furthermore the Wiki content was very high quality. For students in FAB subject, wiki use was not mandatory. Moreover, students were required to present results in a different format (*.doc or *.pdf) to their professor. 54 students actively used the Wiki server, although edit count average fell down to 14.01. The reason could be that these students mainly used the Wiki server as a file repository server, and did not use it, as a publishing tool for their results. The same behaviour was found in CAD students, with an edit count average of 12.93.

5. Teamwork progress

Every week, the students had to fill forms to describe team progress, interaction with other members, and the problems that they encountered, during the compilation of the project. These evaluation reports were prepared using Google Docs forms. Professors employed these reports to detect dysfunctions and delays in the teamwork process.

As shown in Fig. 8, SIM and CAD teams were usually more delayed because they need the TEC and FAB team specifications, to start their work.

Two general checks were also made at midterm and at the end of semester to evaluate general satisfaction and improvement of the student competencies.

5.1 Influence on the marks of the subjects involved

Figure 9 shows the average mark obtained by all students who took part in this Project Based Learning experience, and those who did not. It can be seen that there is a difference between the two groups in all the subjects as well as in the improvement of the student competencies developed.

Figure 10 shows the global mark for each project and the contribution to it from the different teams. The information about the weekly progress was compiled by a coordinator in each team. This coordinator was chosen by the team members.

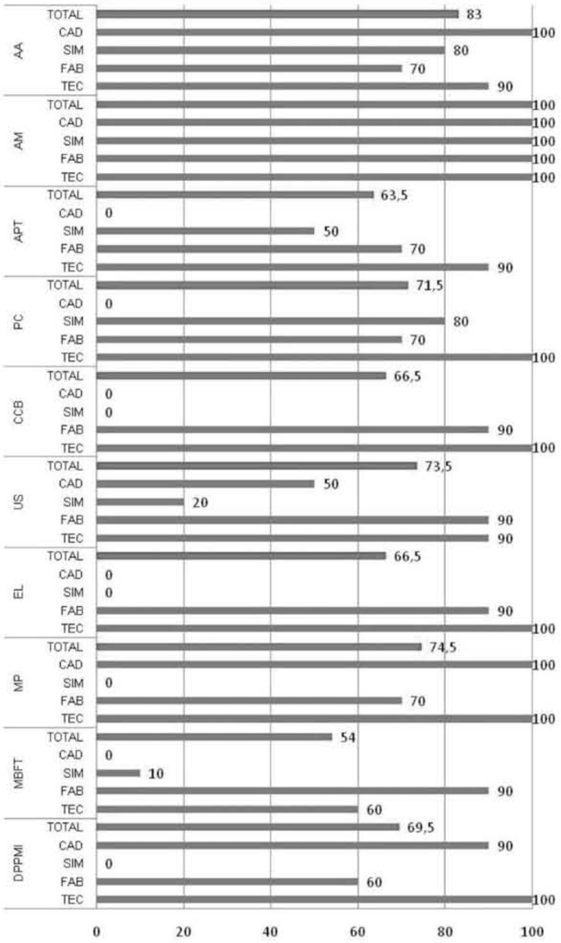


Fig. 8. Development of each project in the 14th week.

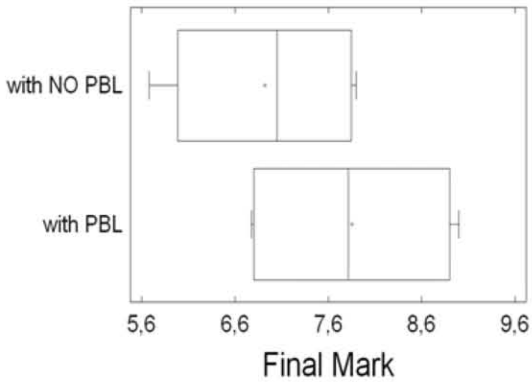


Fig. 9. Comparison between students that follows the PBL method and those who did not.

CAD and SIM teams obtained excellent marks because they knew perfectly the kind of task and design they needed to simulate and design.

5.2 Follow-up checks

The twelve questions contained in the survey shown in Table 1 were scored on a scale of 0 (complete disagree) to 5 (complete agree).

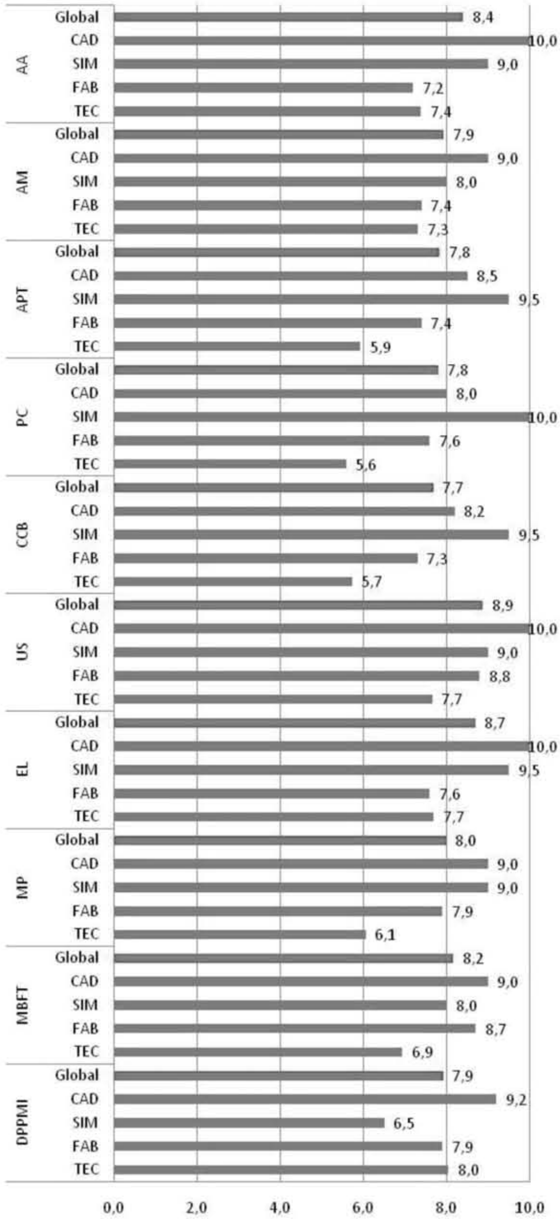


Fig. 10. Marks obtained in each projects and their decomposition in mark teams.

Q1 referred to the subject where the student was participating in the PBL experience.

Q6 had not numeric answer, the answers could be 'Yes', 'No', or 'I don't know'.

6. Statistical analysis

154 students answered the surveys: 23 students were enrolled in the CAD subject, 53 students were in TEC class, 28 students were working in SIM and 50 students in FAB. Table 2 shows that at the end of the semester the scores had a visible improvement in competencies, although not in a significant way, because from the start of the programme students

Table 1. Survey questions

Number	Text
Q1	Select your subject.
Q2	The 'multidisciplinary' work method is preferable to classic 'teacher-delivered lectures'
Q3	I think that my work assessment method is correct
Q4	The professor recognises the extra effort required to work out of the classroom
Q5	The effort made to take part in the project is worthwhile. It would be a mistake not to take part in this experience.
Q6	Would you recommend it to a friend?
Q7	Score the WikiFab environment
Q8	I have improved my ability to work in multidisciplinary teams
Q9	I can estimate work execution times more accurately
Q10	I have become more precise in the work that I carry out
Q11	I have improved my ability to work with different teams by having to exchange information.
Q12	I have more leadership ability

Table 2. Questions average results from Q2 to Q12

	Q2	Q3	Q4	Q5	Q7	Q8	Q9	Q10	Q11	Q12
Average Midterm	3.6	3.4	3.3	3.6	3.7	3.6	3.3	3.8	3.5	3.6
Average Final	4	3.7	3.6	3.8	3.9	3.8	3.7	4	3.9	3.8

Table 3. Questions standard deviations from Q2 to Q12

	Q2	Q3	Q4	Q5	Q7	Q8	Q9	Q10	Q11	Q12
Std. dev. Midterm	0.92	0.90	0.89	1.03	1.07	0.83	0.99	0.87	1.01	1.01
Std. dev. Final	0.92	0.90	0.89	1.03	1	0.86	0.95	0.82	0.95	1.08

perceived a positive improvement in their competencies. The multidisciplinary method used compared to the traditional one is scored very favourably (Q2). Table 3 shows that there are no important deviations related to the taken sample.

Regarding question Q6: 'Would you recommend it to a friend?' the results in Fig. 11 were obtained. It can be deduced, from the midterm check, that students were doubtful about the benefits of the programme. However, at the end, they were satisfied.

A Chi-square test of the data was made and was found a p-value = 0.001 (< 0.1), so the hypothesis that rows and columns are independent at the 99% confidence level can be rejected. Therefore, the observed value of Q6 shown in Fig. 12, in the midterm survey is related to its value for its subject.

Q6 question was studied in the final survey again, obtaining a clear correlation between student and subject membership. Performing the Chi-square test, revealed the p-value = 0.0056 is less than 0.01. The hypothesis that rows and columns are indepen-

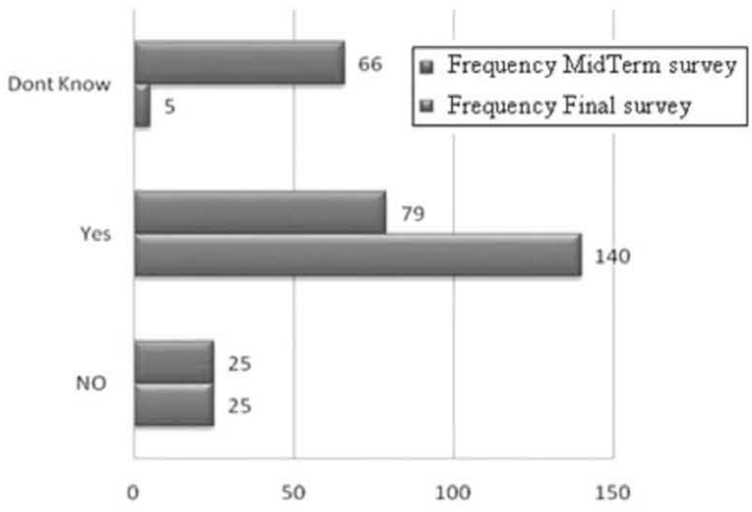


Fig. 11. Histogram corresponding to Q6 results.

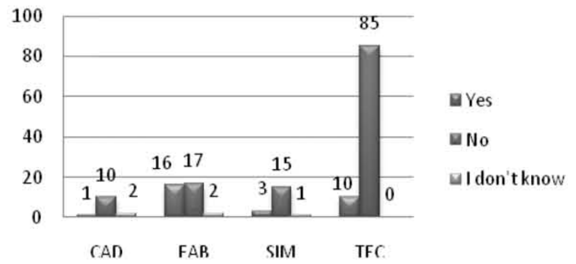


Fig. 12. Q6 results in the midterm survey (analysis by subject).

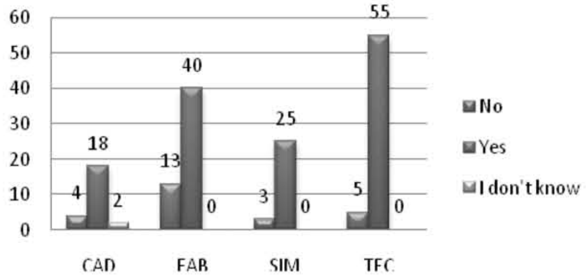


Fig. 13. Q6 results in the final survey (analysis by subject).

dent at the 99% confidence level can be rejected. Therefore, the value of Q6 in the final survey, shown in Fig. 13 is related to its value for the applied subject.

The ANOVA analysis shown in Table 4 was made from the different student opinions regarding the topic they were studying. These findings refer to the final survey conducted in the semester. An F-Test

Table 4. ANOVA Analysis of the final check out

Source	Sum of squares	Df	Mean square	F-ratio	p-value	if P-value of the F-test is greater than or equal to 0.05. there is not a statistically significant difference between the means of the 4 subjects at the 95.0% confidence level
Analysis of variance for Q2.						
Between groups	7.9322	3	2.64407	3.16	0.0252	< 0.05
Within groups	220.143	263	0.837043			
Total Corrected	228.075	266				
Analysis of variance for Q3.						
Between groups	19.5228	3	6.50758	8.13	0	< 0.05
Within groups	210.545	263	0.80055	9.19	0	
Total Corrected	230.067	266				
Analysis of variance for Q4.						
Between groups	3.78784	3	1.26261	1.58	0.1952	
Within groups	207.269	259	0.800267			
Total Corrected	211.057	262				
Analysis of variance for Q5.						
Between groups	16.0204	3	5.34013	5.28	0.0015	< 0.05
Within groups	266.099	263	1.01179			
Total Corrected	282.12	266				
Analysis of variance for Q7.						
Between groups	36.0482	3	12.0161	12.86	0	< 0.05
Within groups	245.825	263	0.934694			
Total Corrected	281.873	266				
Analysis of variance for Q8.						
Between groups	5.77447	3	1.92482	2.84	0.0384	< 0.05
Within groups	178.882	264	0.677584			
Total Corrected	184.657	267				
Analysis of variance for Q9.						
Between groups	12.0309	3	4.01031	4.47	0.0044	< 0.05
Within groups	236.82	264	0.897045			
Total Corrected	248.851	267				
Anaysis of variance for Q10.						
Between groups	9.14847	3	3.04949	1.74	0.0031	< 0.05
Within groups	169.878	264	0.643476			
Total Corrected	179.026	267				
Anaysis of variance for Q11.						
Between groups	2.58755	3	0.862517	0.91	0.453	< 0.05
Within groups	246.469	261	0.944326			
Total Corrected	249.057	264				
Anaysis of variance for Q12.						
Between groups	7.1993	3	2.37664	2.19	0.09	
Within groups	242.988	224	1.08477			
Total Corrected	250.118	227				

Table 5. Project Work ECTS distribution

	ECTS	Class hours/ week	Weeks per subject	Total class hours/ subject	Extra study time	ECTs min (1ECTS = 25h)	ECTS max (1ECTS = 30h)	Hours per Project Min.	Max.	Min. hours per week	Max. hours per week
CAD	3	3	14	42	10	75	90	23	38	1.6	2.7
TEC	4.8	4	14	56	10	120	144	54	78	3.9	5.6
FAB	4.8	4	14	56	10	120	144	54	78	3.9	5.6
SIM	4.8	4	14	56	20	120	144	44	68	3.1	4.9

was used to determine meaningful differences between the teams of SIM, FAB, CAD, and TEC subjects.

The response to Q2 shows discrepancies between the averages of CAD and TEC groups.

Because the p-value = 0.0252 of the F-test is less than 0.05, there is a statistically significant difference between the means of the teams at the 95.0% confidence level.

The answers to Q3 have a p-value = 0 <0.05 and from the Multiple Range test, FAB teams are not homogeneous with the other team subjects.

Q4 shows a homogeneous distribution for all groups. The answer to Q5 shows discrepancies between the FAB and TEC groups with p-value = 0.015. The FAB students did not score positively the extra effort required to conduct the multidisciplinary work. These students are members of the Industrial Engineering program, so they probably needed to work harder given their non mechanical specialization.

Question Q7 showed more disparate performance. The SIM and TEC students score it very positively, which was not the case with the other groups. The SIM students found the Wiki to be a very useful environment for developing their work and the TEC group, moreover, was driven by a professor who was highly enthusiastic about its use and deployment.

The CAD students did not perceive so much improvement in their work in multidisciplinary teams (Q8) compared to the other groups.

The TEC and FAB groups felt they had improved their time estimation ability to carry out jobs (Q9) better than the other teams.

Students from CAD also did not perceive much improvement in the precision adopted in the resolution of the projects, as can be deduced from the study of Q10.

Regarding Q11, the ability to exchange information was compared to other teams. All the means were above 3.5 points with the FAB teams giving the highest scores.

The FAB teams had the best score for leadership ability (Q12). The CAD teams did not feel that they had improved their leadership abilities.

Table 5 shows the ECTS estimation for the subjects in the experience. The workload varies in the range of 23–38 hours to 54–78 hours depending on the subject. The regular exam was not mandatory for those students who accomplished successfully the project work.

7. Conclusions and future trends

A multi-disciplinary experience for a large number of students in four subjects related to the Mechanical & Industrial Engineering programs has been described and documented. Students involved in these programs had to work in the design of ten manufacturing cells. Their viewpoints depended on which subject they were enrolled in. The use of a collaborative Web environment made it possible for students to work in multidisciplinary teams out of the classroom. Students performed a divergent thinking process for analysing and discussing with their partners to decide on the best solutions to be adopted. This new methodology has enabled the students to approach the same problem from four different points of view and to adapt their contributions in accordance to other contributions from students working on different subjects.

The Web environment will let an important compilation of manufacturing cells case studies to be collected in a homogeneous style that may become a virtual reference space in this area.

This new way of carrying out the project-work in coordinated subjects has been very enthusiastically received by the student body and by the teaching staff which consider it to be a simple alternative for promoting multidisciplinary tasks between different groups.

For future terms, professors are designing new manufacturing cells that can also be built by students. These little mock-ups will be realized using and combining Lego Power functions and Lego Mindstorms [14], and will reproduce a miniature prototype of the real ones. These experiences will promote not only, the students' ability to design, calculate and simulate, but also to build an actual manufacturing cell.

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