Project/Problem Based Learning in Civil Engineering: the Ciudad Real (Spain) Experience

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Abstract — *The creation of a civil engineering school in 1998 at the University of Castilla – La Mancha (UCLM) was done with the intention of being complementary with the seven existing and more traditional ones. This paper presents the limitations of the more traditional teaching system used in Spain, experiences from different countries using Project Based Learning, and the experience at UCLM at Ciudad Real. Project Based Learning can be a good alternative to conventional educational approaches, or at least, a good complement, as there is always the necessity of conventional courses to give students the required basic knowledge. There are interesting experiences in universities that will be briefly presented. In some cases the system is used in a very extended way (Aalborg), and in others has different objectives along the educational process (Trondheim). The paper compares these two systems with the one developed at UCLM, in which students are confronted with a group project every semester, from second to fourth year and with an individual one during the final year.*

Finally, the paper will explain some of the projects that have been done at UCLM, the problems and limitations that have appeared that are helping in improving the methodologies and the general organization of the studies..

Index Terms — *Civil Engineering, Comparison between Curricula, Project Based Learning, UCLM.*

FRAMEWORK FOR A NEW SCHOOL OF CIVIL ENGINEERING IN SPAIN

The preparatory studies for the creation of a new School of Civil Engineering at the University of Castilla - La Mancha (UCLM) were undertaken between April 1997 and April 1998, the School was formally created in June 1998, academic activities started in September 1998. At the time there were seven Universities where Civil Engineering could be studied at the equivalent of Master level, all located in major Spanish cities. The challenge for a new School in a smaller city (Ciudad Real has 60.000 inhabitants) with little tradition on University studies was considerable.

On top, the Spanish Professional Institute of Civil Engineering was reluctant on new schools for two reasons: more civil engineers at a time when unemployment was rising from a traditional full employment situation, and because two of the last previously created schools were considered low quality ones. As a consequence of the above mentioned and of the civil engineers characteristics demanded by prospective markets, it was decided that the new school will seek to be a high quality academic institution and to develop different teaching and specialization approaches from the existing schools. These resulted in the following objectives (Ureña, 1998):

- A school specialized in:
    - Environmental and spatial aspects of civil engineering.
    - Conservation, rehabilitation and quality management.
    - Information technologies, with a student/computer ratio of 2.5.
- A Project Based Learning system from second to fifth year.
- Learning to work in groups, communicate and innovate.

Since the UCLM School has existed it has resulted that students entering have comparatively higher grades than the ones entering the other schools and come from six different Spanish regions, an important percentage being from outside the Ciudad Real province. Spanish Universities decide the number of students admitted for each degree and are obliged to intake the students on the sole criteria of the *Selectividad* mark (average of the High School marks and a national exam). The

"cutting mark" is the *Selectividad* mark for the last admitted student in each School. The School of civil engineering at UCLM has had the highest "cutting mark" of all civil engineering schools in Spain.

In Spain all University Degrees are nationally regulated by minimum subject requirements. The 5-year civil engineering degree was regulated by the *Real Decreto* 1425/91. The universities degree of freedom in civil engineering curricula is around 25% of total credits which is used for two academic activities: optional courses chosen by students from the ones specifically offered by the school and compulsory courses decided by each university. Thus, in Spain, the real level of freedom by each university is quite reduced in civil engineering curricula.

In edition, the number of hours dedicated to the core technological subjects of Civil Engineering in Spain could not easily be reduced at the new school due to danger of being considered by the Institute of Civil Engineering and by the other Schools a low quality one. Since the actual load of these subjects in the curricula in most schools is bigger than the nationally required ones, the level of freedom was even smaller.

At the School of the UCLM the real flexibility was used for the following:

- A small percentage for Optional courses
- The introduction of PBL in second, third and forth years
- -The introduction of compulsory courses in Ecology, Landscape and Environmental Impact Analysis and Management of Public Works

There are two other important framework considerations for Spanish engineering university programs. First, most students have great problems in being able to get an adequate level in the first years mathematics, physics and some other courses. In relation to this the new School decided to offer a pre-entry intense course of four weeks duration on mathematics and mechanics, which up to now is followed by more than 50% of the new students. Second, most Spanish engineering students do not have real vacations since they have exams after them. University teaching period is October to June, ordinary exams happen early February and June, Christmas vacations are December 22 to January 8 and summer vacations last from early July to end of September; but re-sitting exams are in September. Vacation periods are used for a mixture of leisure and study and most engineering students are unable to do other activities during their vacations, which diminish their global maturing process and reduces their value as professionals. The UCLM school decided to change the semester periods to be able to have all exams prior to vacations and which is meaning that 60% of third and forth year students use substantial parts of their summer vacations for internships in building or consultancy companies.

PROBLEM/PROJECT – BASED LEARNING

Usually, PBL means Problem Based Learning and is defined as any learning environment in which problems drive learning (Woods, 1996). PBL first began at McMaster University Medical School in the early seventies and today is starting to be used in a large number of Universities. In Spain, this learning methodology is slowly beginning to be used in new studies and Universities.

In many cases, the acronym PBL is also used for Project Based Learning, sometimes to emphasize a word, project, that "provides a longer term, and multi-faceted problem to allow an exploration of the breadth and depth of the stimulus material" (Jorgensen and Howard, 2000). In Aalborg University, the system is called Project-oriented Problem-Based Learning (Kjersdam and Enemark, 1994). This is also the focus of the Civil Engineering School of Castilla – La Mancha University (UCLM). Although the differences between Project and Problem based Learning is a matter of debate in which positions may differ very much (Kaisler, 1999), we also consider the word Project, as the origin of the problems our students deal with, real civil engineering projects.

As defined by Thomas (2000), Projects "are complex tasks, based on challenging questions or problems, that involve students in design, problem-solving, decision making or investigative activities, give students the opportunity to work relatively autonomously over extended periods of time; and culminate in realistic products or presentations".

Thomas (2000) also defines the five criteria that a project must achieve to be considered as Project Based Learning. First, PBL projects are central, not peripheral to the curriculum, so PBL must be a decision of the whole institution, not just some teachers experiencing on their own. Second, PBL projects are focused on questions or problems that drive students to encounter (and struggle with) the central concepts and principles of a discipline. Third, Projects involve students in a constructive investigation. New knowledge is necessary to solve the problem (not only to use the things already learnt), so students are responsible for reaching new skills and understandings. Fourth, Projects are student-driven to some significant degree and teachers must renounce to continuous supervision and leave some freedom and autonomy to the student to lead their own work. Finally, Projects must be realistic, not school like. If projects are real, students will be deeply involved and their results will be better as they feel solving a real problem.

PBL problems must be complex and have no unique solution. On the opposite, they must be flexible and allow different approaches. The final solution should be found throughout discussion, alternative testing, failure and success, improvement

and correction of previous solutions, instead of finding solutions in a straight and unique way. Civil engineering projects fit very well in this methodology.

In comparison with the traditional method, PBL is good in motivating students, as they understand the need of learning. As the Chinese proverb says (Kjersdam and Enemark, 1994), "*tell me and I will forget, show me and I will remember, involve me and I will understand, step back and I will act*", the quality of the acquired new knowledge is better than in the traditional method, as each new concept is related to a personal experience, and will be easily recalled later for solving new problems.

Most times, projects are approached in groups (cooperative learning), of about five students. In these situations, students learn from each other and one of the teachers' main tasks is to promote discussion in and out of the groups. They also learn to work together, sharing responsibilities and tasks, to discuss and to take advantage of their individual abilities and skills, instead of competing for the highest marks. As projects must be solved by students, they develop active and participative attitudes.

Teachers must adopt a new role as coach/facilitator, and sometimes this can be difficult (Woods, 1996). They must avoid being the only reference for the students, the expert always available. In a way, the best facilitator could be a non-expert in the subject although it is necessary someone to keep the right technical level.

PBL IN THE CIVIL ENGINEERING CURRICULUM AT UCLM

PBL, except for the Final Individual Project that is normally required in all Spanish Engineering Schools, is totally new in Spanish Civil Engineering curricula. There have been several reasons for the adoption of PBL in the Civil Engineering curriculum at UCLM:

- To introduce students in an evaluation framework in which the response to questions are not sectorial, unique and exact. In Spain most evaluation of engineering courses is done through written exams with sectorial questions of unique and exact answers. In engineering there are no sectorial unique and exact solutions, on the contrary there are always several options with different advantages and disadvantages for each multidisciplinary problem.
- To introduce students in an active learning environment. Spanish engineering graduates have good abstract knowledge, very submissive and have poor entrepreneurial capabilities and this seems related to their learning environment.
- To introduce students to team activity. In Spain most learning activities are individual, students receive many lectures (not less than 25 hours per week), go home and study what the teacher has explained, with little contacts with their colleagues and use of university facilities. In professional work most activities are done in teams and with extensive use of materials and facilities.
- To set students soon in contact with engineering related topics. In Spain most Civil engineering curricula use the first two years only in basic sciences (mathematics, physics, chemistry, drawing, materials science, fluid mechanics, etc.). PBL activities allow student contacts with quasi real engineering activities.

The Civil engineering curriculum at UCLM is composed of five years, each one divided in two semesters, with the 2nd, 3rd and 4th year so called "*trabajos proyectuales*" (PBL). These "*trabajos proyectuales*" take between 25 and 32 % of student work load (see table 1) from second to forth year. At the end of their studies, every student has worked in six group projects plus an individual final one.

TABLE 1
PROJECT WORK (PBL) DISTRIBUTION IN CIVIL ENGINEERING AT UCLM

Year	Compulsory Courses	Optional Courses	Number of Projects	% of PBL time	Project theme	
					1st semester	2nd semester
1st	10	0	0	0	---	---
2nd	8	0	2	25	Road related environment	Water related environment
3rd	6	1	2	32	Land – use planning	Transportation
4th	6	1	2	32	Building	Hydraulic infrastructure
5th	4	5	1	17	Final Project (individual)	

The second year projects are basically oriented in developing concepts on drawing and cartography, some learned during the first year, others newly introduced. The other four group projects are centered in the main civil engineering themes: land – use planning, transportation, building structures and hydraulic infrastructures. This thematic approach was adopted in order to have a similar amount of time dedicated in each engineering subject than the other schools.

Each class of about forty to fifty students will be working in groups of three to five students with the support of three faculty members. Each class has one or several spaces for the PBL activity, with assigned areas for each group, with computer facilities. These spaces are accessible to students 24 hours per day, seven days per week.

These projects serve as a link between the different departments and faculty members, as they are multidisciplinary, and students must develop and integrate knowledge acquired in different courses and from different sources (Castillo, et al., 1999).

PBL IN THE CIVIL ENGINEERING CURRICULUM AT NTNU AT TRONDHEIM

The Faculty of Civil and Environmental Engineering at the Norwegian University of Science and Technology (NTNU) at Trondheim started to introduce a PBL string in 1997, as a result of a review of the curriculum and also of a prolongation of the study period from 4,5 to 5 years.

Each class with around 100 – 150 students will be working in groups of 4 – 5 students, to which professional and technical input is given by various means (lectures, exercises, reference literature, internet, etc.). During the starting phases of each PBL activity inputs from the teaching staff are considerable.

Each PBL activity has a responsible professor and all PBL activities have a PBL coordinator. Normally several teachers will be involved in each PBL unit (typically 3 to 5 professors and 7 to 9 assistant students per PBL unit). Active student assistants, in a well-designed learning environment, will significantly reduce the need of input by teachers, without a loss in quality.

The first five PBL activities are organized on a project progress process, from the planning phases, through the building phases, to the organizational phase:

Physical Planning and the Environment. Insight into physical planning in an environmental and sustainable development perspective. Including: planning, assessments and comparison methods, planning system and law, environmental issues related to the built environment and traffic, water supply and discharge systems.

Environmental and resource engineering. Understanding and practical insight into major civil engineering challenges related to the environment and the use of resources. Including: global environmental issues, environment and use of resources in buildings, water resources, use, pollution and discharge, and waste sector and waste re-use.

Building Materials. Improve foundation for choice of materials and constructive solutions related to new buildings, maintenance and rehabilitation. Including: understanding of production, composition, structure and use of building materials, use for specific functions and joint action between different materials.

Design of Buildings and Infrastructure. Practical training in design of various types of buildings and facilities. Including: buildings, structures, roads and water/discharge facilities, sub-processes related to design and individual and societal considerations.

Organization and Economy in Building and Construction Projects. Understanding of subjects related to economy and management in building processes. Including: assessment of budgets, profitability analysis, bid calculations, contract processes and building process organization.

The two last PBL activities are organized in a specialization environment:

Experts in Team. Understanding the processes of working in teams with professionals from other disciplines. Each student, from several disciplines, joins a Student Village (or area of interest) composed of 20 to 36 students, one village professor, 3 to 4 assistant students and several external resource persons. Each village divides in several interdisciplinary groups, each with a different approach of a common interest, and organize its work on the basis of one day per week.

Specialization Project. Each one related to one of several specialization fields that are offered at NTNU.

PBL IN THE CIVIL ENGINEERING CURRICULUM AT AALBORG UNIVERSITY

Aalborg University (Denmark) was founded in 1974 with Project-organized Problem-Based learning in all faculties, "The Aalborg Experiment" (Kjersdam and Enemark, 1994) shows the learning methodology used for more than 20 years.

Civil engineering curriculum at Aalborg is five years long. The first year, students learn basic theories and methods and also to work in groups. Fist year is mainly common for all engineering students. Next year and a half (three semesters) are common in the civil engineering curriculum and PBL work is Design-oriented; this means that students have to solve problems with the knowledge they have acquired in lectures. The final two years and a half are different for each specialization (construction, planning, energy, etc.) and PBL work is mainly Problem-oriented, where students deal with unsolved problems within science and profession.

Fifty per cent of the curriculum is PBL, the other 50 % is divided equally between courses related to the project and to the curriculum. The curriculum is organized into themes that last for a semester, and have an associated project and its related lectures.

The splitting of time along the semester is very interesting. In the beginning, lectures take more time than project work, and towards the end, the opposite happens. During the first weeks of each semester students get some of the information they need for the project, and at the end, they concentrate in developing the project, writing the report and preparing for the evaluation. There are two kinds of courses, project courses, which relate directly to their semester project, and subject courses, which are not.

Each project group is supervised by at least a faculty member and are self selected groups and the same happens with projects within themes and disciplines. *The teacher has the responsibility of guiding students to complete the project work in time, and in defensible way according to Methodological and scientific requirements* (Kjersdam and Enemark, 1994).

Audited by the Danish State Parliament, Aalborg University appears to have the most effective educational system of all Danish engineering educational institutions (about 80 % of the students pass their examination in the prescribed time). Its graduates have no difference in quality or level from traditional educational institutions, but they are stronger in problem solving, communication, cooperation and general technical knowledge, while traditional graduated were stronger in specialist knowledge and technical methodology (Kjersdam and Enemark, 1994).

COMPARISON OF THE PBL ACTIVITIES IN UCLM, AALBORG UNIVERSITY AND NTNU

The civil engineering curriculum main characteristics of PBL in UCLM compared to the frameworks used in Aalborg and NTNU derive on the following similarities and differences (see Table 2):

1.- At UCLM there is no PBL activity during the first year while there are in Aalborg and NTNU. In Aalborg the first year is mainly common for all engineering studies while in UCLM and NTNU they are specific for each engineering degree.

2.- The percentage of PBL in the total student workload is smaller in UCLM, around 27 %, and in NTNU around 18%, than in Aalborg, where the percentage of PBL activities is around 50%.

3.- The relation of PBL activities with the other ones taking place in the same semester differs in the three cases. In Aalborg 50 % of courses are related to the project, while in UCLM this is only 25 % and not in every semester, and in NTNU this only happens in two semesters.

In the case of Aalborg the total curriculum is organized as a PBL activity, which means that PBL is the center and keystone in the curriculum; the other activities (courses, seminars, etc.) are defined and organized to help PBL activities. The curricula at UCLM and NTNU are a mixture of PBL and traditional lecture activities, the percentage of PBL and the relation between PBL activities and the other ones are also different to the Aalborg case.

At UCLM, the first two projects (second year) are intended for the students to explore the environments in which civil engineering activities normally take place (a road related environment and a water related one) and to develop concepts and procedures learned during the first year cartography, topography, drawing techniques, ecology and geology. (There are some similarities with the two first projects in NTNU). Each one of the semesters of the 3rd and 4th year at UCLM are focused in one subject, around 32% are PBL activities and another 18% is a course in the same subject.

At NTNU, PBL activities are organized along two criteria. First, the criteria of project progress which is used for the first 5 projects; in this process the traditional learning activities are related to PBL only during the 4th semester. Second, the criteria of specialization in which PBL activities are quite related to the traditional learning activities.

4. Some of the PBL activities at NTNU do not have previous traditional courses that introduce students to each subject (for instance no Planning course before the Environmental Planning Project, or no Building Materials course before the Building Materials Project). At UCLM there are always previous courses on topics being considered in the PBL activities.

5. In the three cases environmental and spatial aspects are dealt by PBL activities.

TABLE 2
PBL FRAMEWORKS OF CIVIL ENGINEERING CURRICULUM AT UCLM, AALBORG, AND NTNU.

ASPECTS OF PBL	UCLM	AALBORG	NTNU
Moment along the Curriculum	All years except first year of 5 years	All years	First 2.5 years and 8th and 9th semesters of 5 years
Type of projects	Thematic	Very concrete (first ones more applied "know how", last ones more scientific "know why")	Sequential and thematic
% of total student work load	27%	50%	17,5%
% of year student work load when existing	Between 16 and 32%	50%	25%

Relation to other subjects in semester	Certain specialization of 5th, 6th, 7th and 8th semesters	Subjects are organized for the project topic	Only in 4th and 9th semesters
Number of projects per semester	All students work on the same subject with different projects only occasionally	Several projects to choose from	Several projects to choose from
Involvement of faculty	Several faculty from different scientific areas in each project	Each faculty responsible for small number of groups of students	Several faculty from different scientific areas in each project

IMPLEMENTATION OF PBL ACTIVITIES AT UCLM: RESULTS AND PROBLEMS FROM THREE YEARS OF EXPERIENCE

The Civil engineering school of Ciudad Real is only four years old, so the experience in PBL is still small. Second year projects have been taught in three occasions, while fourth year projects only once. In table 3 the 2001- 2002 academic year PBL activities are summarized.

TABLE 3
PBL ACTIVITY IN UCLM DURING THE 2001 – 2002 ACADEMIC YEAR.

Project	Year	Sem.	Hrs.	Title	Students	Groups	Teachers	Areas	Individual Assignments	Group Asigm.	Public present.
1	2nd	1	100	Rural Roads Plan in Manzanares.	54	10	3	A,B,H	3	4	2
2	2nd	2	100	Hydraulic Regeneration of a small lagoon in Caracuel.	40	8	4	A,C, D,E	3	8	4
3	3rd	1	120	Railway in Puertollano: - City access - Rail station neighborhood - Railway station surroundings	39	8	4	B,B, G,H	1	3	4
4	3rd	2	120	Ciudad Real airport connection to the road network	41	8	2	G,H	2	7	2
5	4th	1	120	Three optional subjects: (1) - Pedestrian bridge in Lérida - Health center in Madrid - Sports center in Barcelona	15	6	2	F	0	2	1
6	4th	2	120	Water resources management of Almonte river	15	4	2	E	2	3	5

Faculty areas:
A: Drawing and Cartography
B: Land – Use Planning
C: Ecology
D: Geology and Geotechnics
E: Hydraulics.
F: Structural Engineering
G: Transportation
H: Profesional Collaborator

(1) There are four previous small projects (two of prestressed concrete. a building and a bridge) with four individual and group assignments

From this table it can be deduced that in second year projects there is more multidisciplinary faculty than in the rest, as the subjects of the last years projects are more technical and specialized. This could be a problem to be conscious of.

Faculty have certain flexibility to organize the project work, so there are differences between the number of assignments and of individual versus group work assignments. Public presentations indicated in the table are main ones; there are many small presentations during the critics with the faculty.

Experience makes evolution, and for example, after three years, the first project in the curriculum has slightly changed, in order to have more conditioned problems. Last year (2001 – 2002), the selected topic was a municipal rural road network. Also, a historic "sheep way" had to be restored and a resting and exhibition area had to be organized, with certain degrees of freedom, but clear limits, orientation, etc. In this way, the students proposals were much more conditioned and thus, less arbitrary. Obviously, one of the main issues is the right selection of the project site, which must be as real as possible, well defined, and with factors to condition the proposals.

The second project dealt with water table recharge and small lakes, a very important problem for the Mancha region from an ecological point of view. The third one focused on discussion between, by studying different scales (city, neighborhood and surroundings) for the same problem, railway and city integration. In this way, proposals have been more varied, and a big number of students have worked in the same problem without repetitions. In the fourth one, with the collaboration of a consultancy company, specific software developed by the company for navigating inside of the project

documents in a computer environment, instead of a paper one, is being used and developed. In the fifth, students have been able to choose between three possibilities for their main project: a pedestrian bridge, a sports arena and a building. Previously, they have worked in four small projects to learn the structural calculation of a building, a bridge, and two cases of prestressed concrete. Finally, the last project has dealt with a complete river system, developing parts: dams, power plants, water supplies, river restoration, etc. As the total number of students was small, it was possible to work all together in the same proposal, developing each group, different aspects, in coordination.

These four years of experience have highlighted the importance of carefully distribute the students workload and to have a good coordination between PBL and traditional courses, since it has been found that students usually spend a lot of their time in projects, because they like this learning methodology. On the other hand, third and fourth year projects are quite related to conventional courses dealing with the same subjects, and it is very important to program the contents in order to avoid unnecessary repetitions.

CONCLUSIONS

Prestigious Universities and programs, not only newly established ones, are starting to consider the introduction of PBL in substantial parts of their engineering curricula.

The new academic approach of the Civil Engineering School at UCLM is producing an enhanced demand of high quality students and motivated new faculty, which decide to study or work at Ciudad Real, a small city with little university tradition.

The Spanish framework for civil engineering university education does not facilitate new academic approaches. Even though, at UCLM it has been possible to reorganize periods of teaching, number of students and facilities so that learning becomes more appropriate and it has also been possible to introduce substantial Problem/project based learning at the same time as traditional lecture approach learning.

The PBL activities developed in the Civil Engineering curricula at the Universities of NTNU (Trondheim), UCLM (Ciudad Real) and Aalborg are representatives of three prototypical PBL models. Aalborg represents a curriculum based completely on PBL activities, UCLM represents a curriculum based on related traditional and PBL activities, and NTNU represents the introduction of a self-coherent PBL string in a traditional curriculum, with very little relations between both methodologies.

Adequate spaces and facilities (computers, library, etc.) are critical for PBL. An adequate approach and new activities are required to be undertaken both by faculty and students to make PBL fully useful.

The UCLM proposal of a combination of related PBL and traditional teaching activities have advantages and disadvantages. Students with specialist knowledge and technical methodologies at the same time as strong problem solving capacities are the positive aspects. A certain uneasiness by students between their preference on PBL activities and their lesser willingness to dedicate time and effort to traditional lecture type activities are the disadvantages.

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