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Case study of a project based learning course in civil engineering design

Abstract:

This paper describes the use of project based learning to teach design skills to civil engineering students at University College Dublin (UCD). The paper first considers the development of problem based learning (PBL) as a tool in higher education. The general issues to be considered in the design of the curriculum for an PBL module are reviewed. Consideration of the literature on the application of PBL in civil engineering suggests that because of the hierarchical nature of engineering education, PBL is best applied in a hybrid form known as Project Based Learning. A detailed description is given of how hybrid PBL was implemented in the final year of a civil engineering degree programme is then presented. In the final section, the results of an evaluation process designed to gain an insight into students' perceptions of the PBL process are reviewed. The module which was developed at UCD provided an excellent mechanism for developing many skills including, problem-solving, innovation, group-working and presentation skills desired by graduate employers. It was clear that the students enjoyed the peer to peer teaching and increased interaction with staff and external experts which the problem solving nature of the module facilitated.

Keywords: Problem based learning; Project based learning, civil engineering

1 Introduction

Engineering education is in a state of flux with Universities facing requirements from industry to develop graduates with a wider skills base while at the same time a revolution in the availability of information is changing the way that students learn De Bono (1992) suggests that as global competition increases, the key to competitiveness is creativity, and companies must generate added value from their existing resources and assets. Baillie and Fitzgerald (2000) state that employers need transformative employees with the skills to analyse, critique and communicate innovative solutions within a team based work environment. In a recent report, the American National Science Board (2007) noted that one of the consequences of increased globalisation was that basic engineering skills are commodities which can readily be sourced in low-cost economies.

Faced with these external drivers, a number of professional engineering and accreditation bodies have established task forces with a mandate to update and improve the curriculum of engineering programmes. One of the key recommendations the United States Accreditation Board for Engineering and Technology (ABET) guidelines (cited in Prados 1998) was that instruction in design, which included at least some of the following aspects; use of open-ended questions, formulation of design problems, and consideration of alternatives would lead to the development of more innovative engineers.

This paper discussed the development of a project based learning design course in civil engineering developed at University College Dublin. The paper first reviews the application of Problem Based Learning (PBL) in engineering education, and then

describes the design of the specific project based learning module. Whilst the literature contains many valuable epistemological studies to support the application of PBL in civil engineering, few illustrate how the process can be implemented by academics in the field. The objectives of this paper are (i) to identify the most appropriate form of PBL in Civil Engineering, (ii) demonstrate the design and implementation of a PBL course and (iii) illustrate how evaluation can be used to determine the effectiveness of PBL. In addition to the discussion on the means of implementing PBL, example problems are included to illustrate how PBL can be applied in practice.

2 Problem Based Learning in Civil Engineering

Background

Schon (1983, 1987) suggested that in the working environment, engineers reflect in action, and that the skills necessary to do this cannot be taught in the classroom or laboratory (by scientific theory) but in the design studio. There has been much interest in the use of PBL in undergraduate teaching (Boud 1985, Savin-Baden 2000, Kolmos et al. 2007). PBL provides an opportunity to develop teamwork, problem-solving and leadership skills within a framework where the student accepts control of what needs to be learned and how it should be learned (De Graaff and Ravesteijn 2001). The model provides opportunities for deep learning and introduces the students to resources and skills necessary for life-long learning. Well designed PBL courses thus satisfy many of the objectives or learning outcomes specified by accreditation bodies.

The genesis of PBL occurred forty years ago in the medical faculty at McMaster University in Canada when the issue of student boredom at lectures was compared to the excitement generated when they began learning in practice during their residency periods (Barrows 2000). Learning was moved out of the classroom and occurred in a real-life (experiential) setting. The use of PBL has spread rapidly, predominantly in medical education, and also in the spheres of law and engineering (See Barrett 2005, Ahern 2009). The key principal of PBL is that the problem (which the learner wishes to solve) is the starting point of the process (Boud 1985). Kolmos et al. (2007) set out some of the key features of the PBL method:

1. Ill-structured and complex questions based on real world scenarios
2. Student centred active learning occurs
3. Learning occurs in small groups, considering and reviewing solutions to open-ended problems
4. The teacher becomes a facilitator
5. Self-assessment increases the efficacy

Project Based Learning of Hybrid PBL

Perrenet et al. (2000) note that in the traditional PBL model learning is self-directed, and in domains such as medical education (where learning is somewhat encyclopaedic), missing concepts may not preclude the construction of valid theories. However, in mathematics and engineering, which tend to be hierarchical, missing essential concepts may result in a failure to learn. They suggest that whilst the development of meta-cognitive skills (knowing about knowing) will result from PBL, the risk of missing vital concepts and theories suggests that PBL should be used as a

partial solution to develop professional problem solving skills through the application rather than the acquisition of knowledge.

Whilst PBL has proved to be very successful, particularly in medical education, the forms of PBL often practiced in engineering schools (such as Aalborg in Denmark and the National Technical University in Trondheim, Norway) are often described as Project Based or Hybrid PBL. Mills and Treagust (2003) differentiate Project Based Learning (hybrid) and Problem Based Learning in the following ways:

1. Time – engineering project tasks usually take place over a longer period than problems
2. Projects are directed at applying rather than acquiring knowledge
3. Projects are usually run in tandem with traditional lectures
4. Time management is a key issue for projects
5. Self-direction is stronger in project based learning as the learning is directed by the problem

Some of the major problems facing educators who wish to develop PBL courses include (i) the question of how to organise the students into groups, (ii) are good quality, experienced facilitators available?, (iii) is there physical space available outside of lecture theatres? and (iv) how to phrase the problems? Questions (i) to (iii) largely depend on the available resources and may in large part explain the diversity of PBL approaches adopted throughout the world. In general, engineering students are used to working in small (laboratory and tutorial) groups from the time they enter University and the group size appropriate to Project based learning (typically less than six students) is very familiar to them.

The hybrid PBL or Project based approaches can be operated with a floating facilitator (or tutor) as the students are applying knowledge and creating links rather than creating knowledge and therefore need significantly less scaffolding or support. The question of physical space is an institutional issue. However, faculty members should be cognisant of the benefits in providing project rooms in new and refurbished facilities. Assuming that these obstacles can be overcome through resourcing, the perennial issue of the form of problems to be presented is the key to success of any PBL initiative.

The design of challenging PBL problems

Federau (2006) describes the learning climate model which can be used to ensure the preparation of *good* problems. The two-axis model considers the assignment freedom, which is a measure of how open the question is. He describes the example of a bridge design exercise “design a bridge to span from A to B”, which if given to a first or second year student who has not studied engineering materials or bridge engineering, will represent a problem with a high degree of assignment freedom. In contrast, if a final year student is asked to “design a concrete bridge to span from A to B” a relatively low score on assignment freedom would result. The abscissa, Active Drive, is a measure of how motivated a student will be to acquire the knowledge required to solve the problem. Put simply, there is a significant pressure on the first or second year student discussed above to self-educate on the basics of bridge engineering, e.g. what spans are permissible for given engineering materials etc. thus resulting in a high value for active problem drive.

3 Design of PBL Module at UCD

Kolmos et al. (2009) present a PBL model which provides a holistic view of the elements which must be considered in a PBL curriculum. These include consideration of (i) the objectives and knowledge, (ii) types of problems, (iii) progression, size and duration, (iv) student learning, (v) academic staff facilitation, (vi) space and organisation, (vii) assessment and evaluation. The model forms a useful tool to consider the PBL module case studies in civil engineering which is taken by the students in the first semester of the 2 year Master of Engineering (ME) course in Civil Engineering at University College Dublin. This programme which is described by Gavin (2010) is open to students who have completed a 3 year BSc. in Civil Engineering (or equivalent). In semester one a series of 5 ECTS traditional lecture and tutorial based, core Civil Engineering Design courses (CED 1 to 3) are taken which build on the theoretical principles of Structural Engineering and Soil Mechanics developed during the BSc. programme and apply these to real design problems. A 10 credit PBL (Case Studies) is run in parallel with these modules. The UCD ME degree is structured over four semesters with students accumulating 30 credits in each semester. The PBL module thus represents 33% of the credits available in the semester one.

Objectives and Knowledge

The module employs group work and weekly presentations by students to experts in a range of cross and inter-disciplinary projects. On completion the students should be able to:

1. Formulate design solutions to open-ended problems
2. Learn to work in an inter-disciplinary group working environment
3. Develop an understanding of the principle mechanisms through which structures carry load and transfer loads through elements into the ground
4. Consider the wider social and environmental aspects and identify risks associated with their schemes
5. Demonstrate effective presentation skills

Types of Problems

Given the nature of the learning which is required (application rather than acquisition) the problems are well defined following the usual PBL definition. However, they contrast strongly with typical text book problems and are relatively open-ended. To encourage diversification and contribute to a real-world feel, the majority of problems are set by experts from industry and are based on current projects. The format is that a brief is issued to the class each Monday morning whereby they compile a scheme design and present their solutions to their peers, tutor and the external expert on Friday morning in a “question and answers” type, interruptible presentation format. An example problem designed to encourage the students to appreciate the interaction of structural and geotechnical engineering is included in Appendix I.

Progression, Size and Duration

This involves consideration of the progression in terms of the complexity of problems encountered, and the amount of time given to the PBL exercise within the overall curriculum. Because the course is taken only by 4th and 5th year civil engineering students, who have covered the essential theories of structural and geotechnical engineering, all the problems are designed to have a relatively high ranking on both axes of Federau's learning climate model. There are ten problems given in the semester. The first deals with a relatively simple portal frame structure with competent soils. As the semester progresses the structures become more complex (finishing with high-rise buildings and Grandstands) and the soil conditions become more challenging. Inter-disciplinary concepts are promoted whenever possible. Each week calls on the students to recognise the interaction between structural and geotechnical engineers. Problems in traffic engineering (e.g. car-park layouts), hydraulics (e.g. drainage systems for underground car-parks) and other issues arrive. Each year there is one problem which is handled by engineers and architects working together (for example in the current year they designed a footbridge). The use of innovative solutions and materials is encouraged. Students have the freedom to choose the structural form of their solutions and unusual solutions are actively encouraged through the marking scheme. In addition at the end of each session the external expert presents a solution which invariably incorporates details and products that are novel.

Increasing problem complexity at the beginning of the semester is relatively simple. However, in practical terms, the use of outside experts (typically senior engineers from industry) sometimes involves rearranging the pre-determined schedule. Increasing problem complexity at the beginning of the semester is relatively simple.

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Students' Learning

The philosophy, learning outcomes and teaching methods were considered in some depth in the design of the module. However, the student who is in the fourth year of their higher education career will be unlikely to have time to fully recognize this opportunity for self-development. We must therefore provide some supportive guidance to allow them to maximize the potential of the PBL process. This support takes the form of:

- (i) An initial lecture on the PBL process applied, guidance for working in groups and the learning objectives of the module.
- (ii) An open door policy is in operation where the three full-time staff members are available at all times to discuss issues with regard to development of scheme designs.
- (iii) Each Friday morning all the groups present their scheme design to their class and a panel of two staff members and the external expert who designed the problem.

Academic Staff and Facilitation

The role of academic staff is known to be critical in effecting positive outcomes from PBL. Although only one of the three staff members who act as tutors on this module had any formal training on how to organize or facilitate a PBL module, somewhat unusually in modern Universities, the staff members involved have significant

industrial experience which the students view as a significant resource. This is important as the natural tendency for students who have been trained to perform quite sophisticated analyses is to immediately begin to undertake calculations. In fact the critical ability in performing effective scheme design is to develop an ability to see the bigger picture. Students need to develop practical experience of how structures transfer loads and interact with their environment. In a sense we are trying to recreate the relationship that develops in practice between the graduate engineer and their design office mentor. It is essential therefore that the persons providing this guidance within the module have design office experience. In the absence of such experience amongst the permanent staff the author would suggest that the use of adjunct staff would provide a suitable compromise to ensure the effective delivery of any such module.

Space and Organisation

The Civil Engineering department at UCD recently moved into a new building where the ground floor consists of a number of large project rooms (freely available for project work and study for each stage/year) surrounded by staff offices. The environment is therefore ideal for collaborative project work. The UCD campus is within 4 miles of the city's capital and has a very good relationship with industry. We have access to a large resource of visiting engineers to act as tutors in our PBL initiatives.

Assessment and Evaluation

Student performance in the module is assessed using continuous assessment with group marking (worth 30%) and a final (open-book) individual design exam (worth

70%). The students develop significant skills in scheme design and experience of thinking of broader issues which may affect their chosen solution during the continuous assessment process. Whilst problems in the open book exam will have similarities to some of the weekly case studies, because of the open-book nature of the assessment careful consideration of the design of these questions to prevent students transcribing schemes is vital.

Assessment of the course should incorporate both student assessments and evaluation of the course itself. The latter evaluation will be undertaken by staff from the department, industry advisors and the degree programme certifying body. An important first step in this process is student feedback which is considered in some detail later in the paper. In terms of student assessment, lecture driven courses tend to rely heavily on terminal exams backward-looking assessment (Fink 2003) to evaluate student performance. In process based models which use real-life problems, (where possible) it is important to consider a number of critical elements in the assessment procedure in order to enhance the quality of student learning:

- (1) The use of student self-assessment
- (2) Clear description of the assessment, i.e spell out clearly the criteria and standards required
- (3) Clearly demonstrate how excellence may be achieved
- (4) Through the provision of regular, timely, detailed and constructive feedback

A fundamental concept of PBL is that where possible, learning and assessment should occur simultaneously. In this course an obvious example would be project presentations in which the results of a problem are presented by students, where peer

to peer and peer to tutor questioning takes place, and complementary skills such as presentation, public speaking and self-confidence are developed. Each group is subsequently provided with written feedback and therefore can evaluate their own progress through a given problem. Kolmos et al (2007) suggest that questions such as “What did I learn?”, “What further knowledge do I need?” and “how could I approach the problem differently the next time?” should be at the centre of self-reflection. They suggest that a more contentious issue, which is peer assessment, should form part of the process. However, to mitigate problems students should be introduced to this form of assessment using simulated PBL sessions. Continuous assessment (whether in groups or as individuals) is obviously an attractive form of student evaluation and it aligns the assessment with the process of acquiring knowledge. However, terminal exams are also appropriate. Where group assessment is being undertaken as a quality assurance exercise, it is important to get feedback on the efficacies of group working within the PBL environment.

Evaluation of the course itself, of the tutors and of facilitators can take many forms, but should include specifically an evaluation of the curriculum design, facilitation, student experience and effectiveness of learning (Marcangelo et al. 2009). This aspect of the course evaluation is discussed in the following section

Summary

The course as described is in keeping with the five principles identified by Mills and Treagust (2003) differentiating Project Based (or hybrid PBL) and Problem based learning (See section 2). 1. Timing – The problems take place over a short 5 day

period. 2. They are focussed on the application of civil engineering design principles in practice. 3. A special lecture is arranged in each week to address unusual features associated with the problem, 4 Students must orally present their solution each Friday morning and there is no facility for late submission. They therefore develop capabilities to meet rigid and tight deadlines. 5. A consequence of the heavy workload and tight deadlines encourages self-direction.

4 Students Perceptions of PBL Initiative

4.1 Survey Methodology

Continuous evaluation of academic programmes and individual modules is crucial to maintaining academic standards and promoting student engagement. At the programme level, input should (and has been) sought from and industrial advisory committees. Feedback from students can be obtained through a number of channels including; carefully designed surveys (which are now being implemented online through the online teaching environment) and through focus groups. An additional powerful and often over-looked source of evaluation can be derived from student comments, either during the informal interactions which occur during the tutorial sessions or on evaluation forms where space is given to free comment. The use of such feedback is discussed in detail by Barret (2008) and Clouston (2007).

The formal evaluation of the PBL course to date has comprised an end of semester student evaluation form to gain feedback on their experiences. The survey was run at

the end of two academic semesters (Winter 2008 and Winter 2009). Each year the class included 4th year Civil Engineering students and 5th year Structural Engineering and Architecture (SEA) students. The total number of students who completed the questionnaires was 144. This comprised of 76 respondents from the 2008 class, and 68 respondents from the 2009 class, and represented a minimum response rate of 86%. A hard copy of the questionnaire was distributed to students immediately following the last class room based exercise and the students were given 10 minutes to complete the forms which are then collected by a member of the Schools administrative staff. This ensured the high participation rate (100% of students present), where to date student participation in on-line course questionnaires has been poor (typically below 30%). The hard-copy questionnaires were compiled by the module coordinator and simple statistical data was extracted.

4.1 Survey results

The format of the questions required the students to answer in the following form; numerical grading (from 1 being strongly disagree to 5 being strongly agrees), and Yes/No or Open questions (with some including lists of possible answers which students ranked). The numerical grading adopted is in the form of a LIKERT SCALE procedure (see [http:// www.socialresearchmethods.net/kb/scallik.htm](http://www.socialresearchmethods.net/kb/scallik.htm)).

Noting that the course was designed to be a capstone for the lecture based design subjects where students had the chance to apply their design skills, one of the key objectives was to develop inter-disciplinary design and competence in solving open-ended questions and we asked students “Does Problem Based Learning (PBL)

improve your understanding of material covered in your design lectures?" The responses shown in Figure 1 indicate strong agreement that the PBL helped to reinforce the design skills which were taught in a traditional class room setting.

When we asked students

"How would you rate the importance of the following elements of PBL? Please rank in order of importance, (i)1 being most important: Quality of working group; communication skills; competence of individuals; guidance by lecturer; evaluation process; difficulty level of material given; time management; enjoyment of process, and OTHER (please specify)."

The response (shown in Figure 2) from both years was similar in that the quality of the working group ($\approx 23\%$) and competence of individuals ($\approx 21\%$) were seen as being most important for both years the survey was conducted. The perceived importance of guidance from the lecturer is an issue that should be explored further in focus groups, in order to ensure that over-reliance on small-group instruction/lecturing is not taking the place of self-learning. This issue may be seen as an educational issue for both the students and staff (who are used to offering helpful guidance on request).

When asked (with no word prompts) to rank in order of importance, the positives of using the PBL approach over Traditional classroom style learning? Each student typically inserted 2-3 free text words to describe their experience. These were collated and arranged in order of importance (from the first survey results conducted in 2008). The 2008 cohort of students (See Figure 3) identified the importance of the practical

application of their design work and development of teamwork skills as being very important. Whilst both these elements were very important to the 2009 students, this cohort also gave relatively very high importance to elements from the education domain, namely; motivation, thinking for oneself and increasing knowledge. These are very positive findings and demonstrate a clear link between the PBL process and the development of skills which are required by future employers.

When asked to consider the negative elements of PBL (See Figure 4, with the data again presented in the order of importance determined from the 2008 survey), by far the most important issue raised (which is an almost universal complaint from PBL students) was that the process was too time consuming. Consideration of the student comments revealed that the problem with working groups arose when one or more of the group were perceived to be *not pulling their weight* and the issue of group marking and peer to peer evaluation will be addressed in the next semester.

When asked the question “Should peer review be used in this course?” 56 % of students responded that it should not be. Only 22 % of respondents voted in favour of peer review and the remainder had no preference. However, it is worth noting that these students were given very little (or no) educational instruction in PBL. One of the regular verbal responses from students is that they would like more detailed solutions to the problems. This could form a positive driver towards encouraging peer to peer marking and spreading the workload between students and tutors. In addition, peer to peer working group assessment may solve some of the problems identified within working groups.

One of the most positive aspects of the questionnaire results was the overwhelming support for the use of more PBL initiatives in the courses where 71 % of respondents would have liked to have more PBL, with only 20 % of students being against the idea.. It would seem evident from student responses that there is very enthusiastic support for the wider implementation of PBL with enhanced learning, fun and relief from boredom being cited as some of the more positive aspects.

5 Conclusions

A case study of a design based capstone course in Civil Engineering design was considered, where the learning and assessment methods designed were implemented to meet some of the key learning outcomes was presented. A student survey suggests that the course is already achieving many of its stated objectives and it is felt that considering the course design in a more theoretical education framework, where alignment of all elements is considered, should allow for positive development of this course and in the future. The survey clearly demonstrated student satisfaction with the PBL process and that they recognised that key skill required by industry namely; group work, time management and the development of technical competence were enhanced. Notwithstanding the observation that PBL is time consuming, approximately 70% of the students favoured expanding PBL methods into other parts of the curriculum and 90% agreed that it improved their understanding of material delivered in traditional classroom settings. The students perceived that main positive elements of the PBL process were; the application of design skills, teamwork and the

development of their teamwork and communication skills in the context of real-world design problems.

From an instructors perspective the adoption of PBL allowed:

- (i) The use open (less well defined) questions which were useful in testing students understanding of material.
- (ii) An important associated benefit for the School was that the PBL process significantly enhanced increased staff-student interaction and hence benefited relation as a result of one to one and small-group informal sessions. .

The most obvious drawbacks in the application of this PBL initiative were the time input required by both students and staff. It is important that coordination of this time commitment with other modules, particularly with regard to submission dates for continuous assessment work is carefully managed at a programme level. Notwithstanding these difficulties the course has proved to meet its learning outcomes and is widely enjoyed by both students and staff.

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Appendix I Sample Case Study

Joint Structural/Geotechnical Case Study

Due: November 6th 2009,

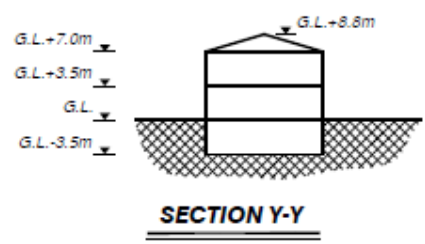
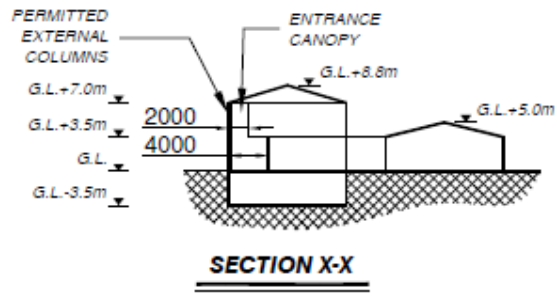
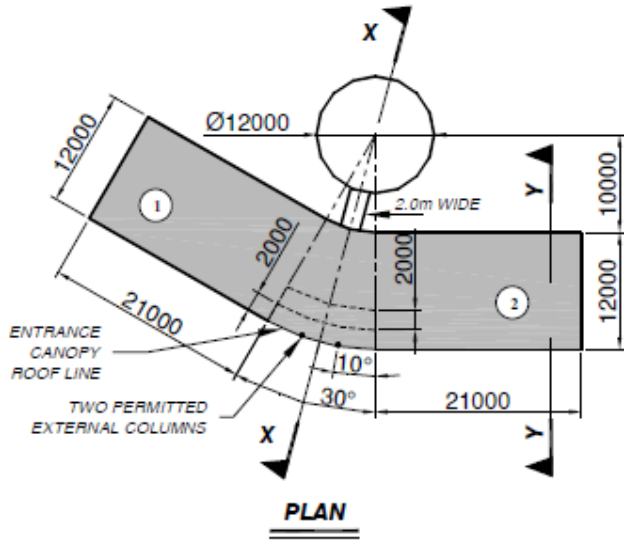
No late submissions accepted

Prepare an outline structural scheme for an office building with basement and cafe. The building layout is given on the next page. Some constraints on the design are:

- Each floor steps out over the entrance canopy a distance 2.0 m, as shown;
- Only two external columns are permitted to the entrance canopy, as shown;
- The basement is for plant and storage use, and extends under the main office building (shown as solid grey hatch);
- No internal columns are permitted on the first floor;
- The roof apex level indicated is not to be exceeded;
- No internal columns are permitted in the café rotunda;
- One lift core, and two fire escape stairs are to be provided.
- The water table is 1 m below ground level

In addition to other relevant information, you must address the following:

- Select a structural material, form of construction, and cladding;
- Sketch the structural scheme showing columns/beams/slabs etc.;
- Address the structure in critical areas such as the roof, entrance canopy, floor overhangs, rotunda structure etc.;
- Indicate approximate sizes for the main structural elements;
- Identify lift/stair core locations, taking into account basic fire escape requirements;
- Identify any expansion joints that may be required and how lateral stability is achieved.
- Suggest a suitable foundation type
- Sketch a form of construction for the basement
- Suggest additional site investigation which may be useful for the purpose of your design



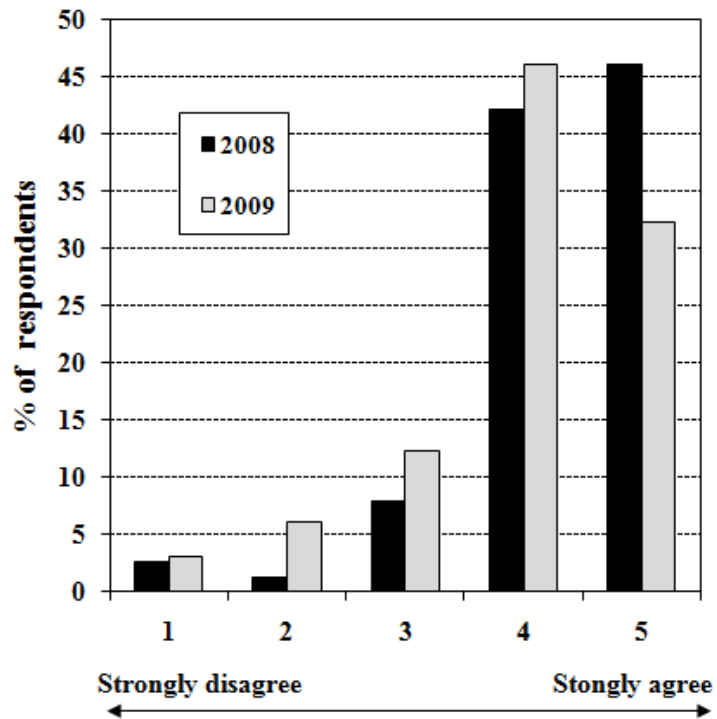


Figure 1 **Response to survey question 1 - Does Problem Based Learning (PBL) improve your understanding of material covered in your design lectures?**

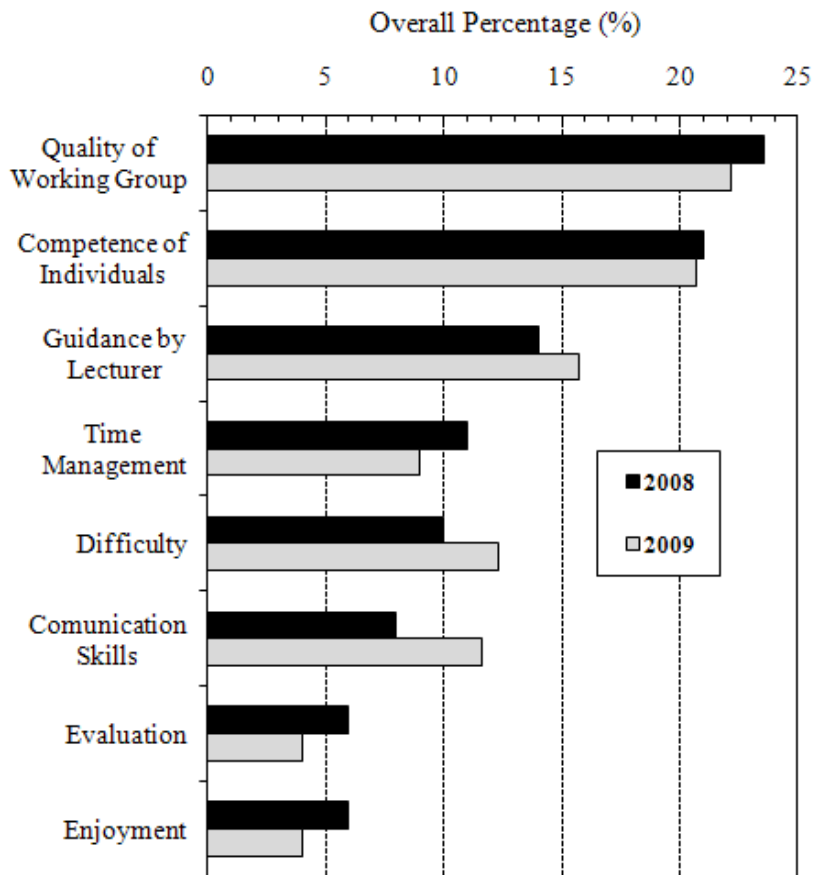


Figure 2 Response to survey question 2 - How would you rate the importance of the following elements of PBL?

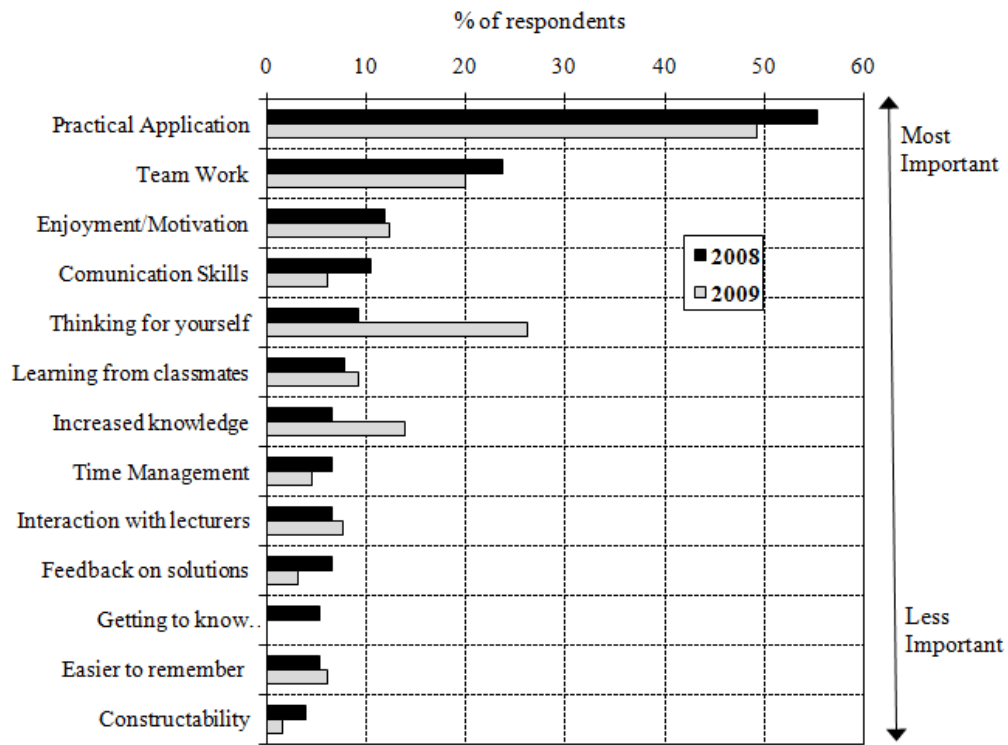


Figure 3 **Response to survey question 3 – Please rank the positive elements of PBL?**

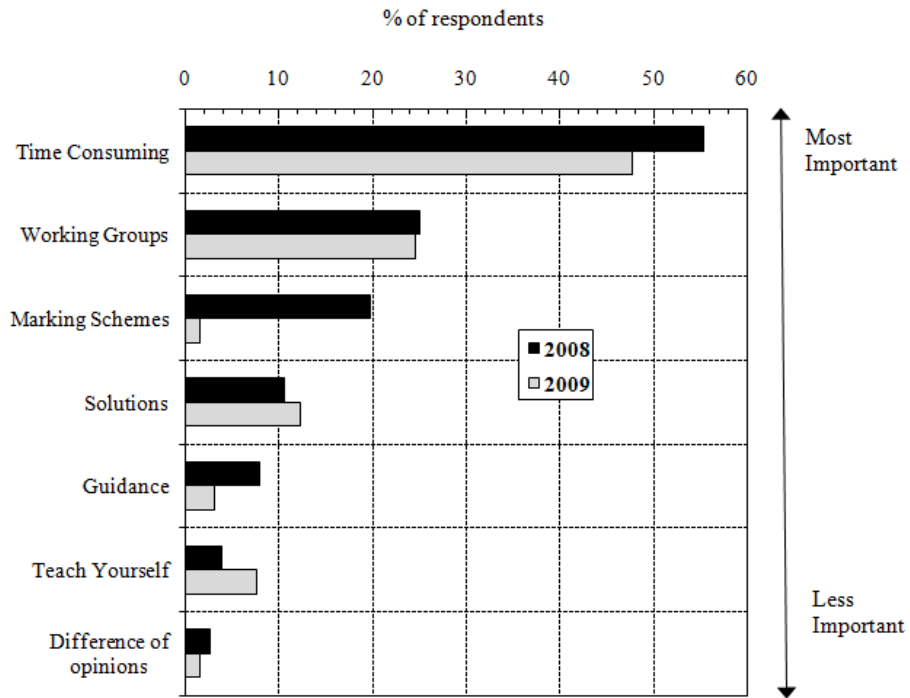


Figure 4 Response to survey question 1 – Please rank the negative elements of PBL?