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Suitability of Project-Based Learning (PBL) in Mechanical Design Education

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Abstract: This paper discusses the suitability of Project-Based learning (PBL) in mechanical design education. We first introduce project-based learning and highlight its main differences with problem-based learning. We discuss the advantages, disadvantages and highlight main obstacles in application of this approach. The suitability of PBL in mechanical design education is then discussed by first investigating goals and typical curriculum in such education and various aspects of implementing PBL. Reference to experience in applying the technique in the Department of Mechanical Engineering at the University of British Columbia is highlighted. Brief assessment and review of existing assessment of the approach are discussed.

Key-Words: Project-Based Learning, Mechanical Design Education, Design Curriculum.

1. PBL Definition and Aims:

In this paper we use PBL to indicate Project Based Learning. The discussion is largely applicable to both project and problem based learning but we will generally focus on the use of project based learning in teaching mechanical design. Many aspects and outcomes of PBL (Project based learning) are similar to those found in the more commonly known problem based learning approach. The discussion in this paper will rely and exploit such common grounds. Although many authors use PBL as interchangeable between the two approaches, there are slight differences between them. First, one may note that project based tasks are closer to the reality and practice of professional engineers than problem based tasks. A key difference between the two approaches is that project based is more directed to the application of knowledge whereas problem based is more directed to the acquisition of knowledge [1-3]. Also in project based learning, management of time and resources by students is, generally, more emphasized.

The concept of PBL is normally used to enhance multidisciplinary skills using planned problem scenarios or projects. The focus of PBL is to set the curricular content around projects rather than subjects or disciplines. Problem based learning was first introduced in the late 1960s at McMaster University in the medical school. Since then it has

spread around the world, but mainly in medical education.

Although problem or project based learning is still far from being widespread in engineering education, it has been implemented to a limited extent in some schools. In most of its applications, PBL is practiced in a few courses in the early years of the program [1]. Attempts to generalize PBL for the whole program have been rather limited. Examples of such attempts are the second year Electrical and Mechanical Engineering programs at the University of British Columbia. In the Mechanical Engineering version, the program has been applied to all students and for all subjects in the second year.

In PBL, the classroom is student rather than teacher-centered. Although in the first classes, the instructor must provide some direct teaching, it is through guidance and support of student activities that information is delivered to the students [2]. This point also constitutes an extra difference between problem based learning and PBL since in the latter the amount of lecturing would be usually more extensive. Examples of distinct teaching modes in PBL are the group tutor who works with a specific PBL group and the case study champion who creates a specific case study exercise. The tutors shouldn't generally impose their knowledge and standards on the group, but instead help the students explore the problem on their own.

The principal aims of implementing PBL are: to integrate knowledge and skills from a range of multidisciplinary modules; to acquire knowledge through self-study; to enhance working in groups and manage group projects; to develop problem solving skills of students; to encourage self-motivation, curiosity and thinking; and finally, to make learning enjoyable [3]. Also PBL helps in enhancing the technical curiosity of students which has been diminished by the very little contact students have with machinery and devices that they use in practice.

2. Overview and Examination of PBL:

2.1 The Need for Change:

The need for PBL and other changes in engineering education stems from industrial and market requirements. Today, industry is in need of graduates that not only possess a solid foundation of engineering knowledge, but also have good communication skills, the ability to work in a team, the ability to solve problems both critically and creatively, and a desire to learn for life. Today, engineers are required to have a broader perspective of social, environmental and economic issues. Other areas of deficiencies in engineering education include: time management skills; producing proper documentation; and hands on skill in shop work. The ultimate objective is to provide industry with designers who are equipped with the essential characteristics and skills required in real-life situations.

These deficiencies are especially apparent in design. Some faculty members used to feel that students could only engage in design until they had gone through several years of education. This feeling has generally been replaced with the realization that students must practice design over time, and that a single experience at the end of a four-year program is simply not sufficient. Engineering design requires not just the analytical competence to analyze and size components, but, also, the know-how to formulate a problem in a way that is in tune with the resources at one's disposal. It requires, therefore, knowledge of fabrication techniques, costs, aesthetics, decision making under uncertainty, marketing study and negotiation skills. It is this nature of design that makes it generally suitable for PBL application.

2.2 Critical View on PBL:

It is generally agreed that PBL leads to better skills in the areas of independent learning, communication, and critical thinking. Students are more confident of their own abilities, better able to work in a team, keener to learn and have a greater understanding of the practical aspects of engineering. Although PBL imposes increase in work load, staff have found its implementation a relatively rewarding experience. Due to much closer contact with students, PBL gives instructors greater opportunity to respond to at risk students.

On the other hand, PBL generally requires team teaching and integration of faculty from various disciplines which may pose some practical obstacles. PBL requires moderate to high (approximately 30-40%) increase in teaching resources. Because of the group projects, proper means for individual students' evaluation would be always a problem. One of the significant issues encountered with PBL is the 1 or 2 students in a group that may provide little or no contribution. To address the problem a peer review is usually required. Students should provide evidence of activities in the form of minutes of meetings and personal journal [1]. If PBL is to be implemented in the whole program of one year, failing students may be required to repeat the whole year. This would add to the already critical problem of scheduling and resources in PBL. To avoid this, the program may be delivered in smaller consecutive units and students have to pass these units in consecutive order. This approach was adopted in our implementation in the mechanical engineering department in UBC. It should be noted that such approach would, however, pose more constraints on the resources and scheduling of the program.

2.3 Assessment of Students in PBL:

In a PBL environment, generally each group of students is typically expected to submit one or a more of the following at the end of each project: a design report, a working device that may enter a competition, a poster, an oral presentation, or a web page. Groups are assessed on the ability to analyze the problem, create innovative possible solutions, evaluate concepts, demonstrate and utilize prior theoretical knowledge, show evidence of newly acquired knowledge throughout the project and, finally, use practical skills in completing the project.

Usually the assessment also involves some individual evaluation such as a short test of concepts related to the activity and/or a personal journal review. As discussed above, there is an element of unfairness in such assessment methods because the work load and the activities performed by various members of a group would be, generally, not equal. Unfortunately methods to avoid this problem would put more restraints on resources and management of the program. Some faculty members downplay this problem on the basis that this is the practice in industry anyway. The counter argument here is the fact that in industry there exists many other methods of assessment and the different time scale in industry.

2.4 Assessment of PBL:

Unfortunately, there is very little published quantitative assessment for PBL programs in the literature. The evaluations that have been undertaken have been almost entirely along the lines of student interviews or responses to open-ended questions. This qualitative research has generally found students in favor of the program although they generally believe that it adds more work on the part of the students. The limited assessment for PBL in the literature indicate that the approach significantly improves important skills such as solving open-ended, real-world problems; finding, evaluating, communication skills, team work and using appropriate learning resources. On the other hand, available assessments indicate that there was no gain in students' performance on standard tests and exams. Also, no apparent decline in student's performance was reported.

In the area of PBL assessment, it is obvious that more research is needed. Proper assessment measures and avenues for obtaining assessments are required. Also, assessment of PBL graduates in the work place is crucial to reach proper conclusion for this approach. As the practice in industry, it may be constructive to consider various methods of assessment such as final product, presentations, portfolios, peer reviews, self-assessments, and competitions.

3. Suitability of PBL in Engineering Design Education:

3.1 Engineering Design Curriculum:

In order to assess the suitability of implementing PBL in engineering design education it is necessary to take a closer look at topics and aims of engineering design curriculums. As discussed above, engineering design is the process of applying and integrating various scientific techniques and engineering science principles for the purpose of creating a device, a process or a system to perform a given function. There is a certain element of creativity, decision making and inventiveness in the design process. By nature, the design process is both interdisciplinary and iterative. The word design comes from the Latin word *designare* which means to work out.

The Canadian Engineering Accreditation Board uses the following definition for engineering design: "Engineering design integrates mathematics, basic sciences, engineering sciences and complementary studies in developing elements, systems and processes to meet specific needs. It is a creative, iterative and often-open ended process subject to constraints that may be governed by standards or legislations to varying degrees depending on the discipline. These degrees may relate to economic, health, safety, environmental, social or other pertinent factors" [4].

Design may be categorized in three general categories. Original design to create an original solution for a system to perform a new task or function where both the function and the solution principle are new; adaptive design to adapt a given system to accommodate a new task or function where the original solution principle remains the same; and variant design to vary the size, material, or arrangement of a given system while keeping the function and the solution principle unchanged. A study made in the mid seventies by the German Association of Mechanical Engineering Companies (VDMA) showed that 55% of products are based on adaptive designs, 25% on original designs and 20% on variant designs.

Fig. 1 shows a schematic diagram of various design phases with some details of various aspects in each phase.

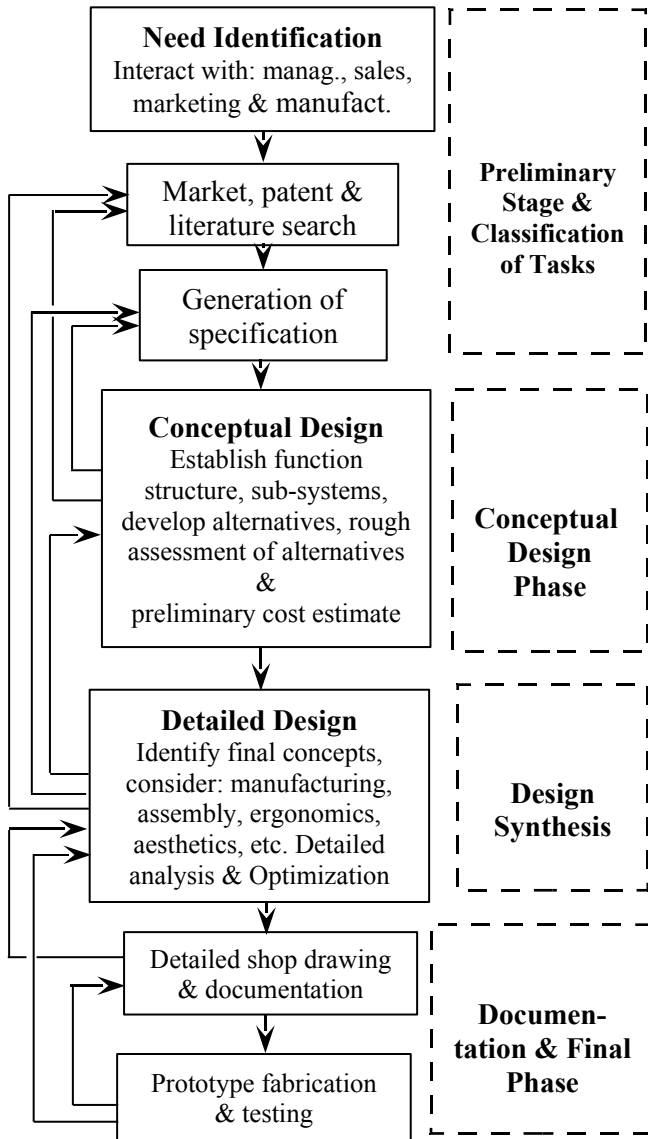


Figure 1 Schematic of the design process

To study mechanical engineering design curriculum in detail, a survey of the curriculum of twelve North American schools is carried out. The objectives were to identify various topics taught and learning objectives. It should be noted that it is sometimes difficult to identify such topics in a curriculum and distinguish it from engineering science topics. Care has been exercised to use a unified reference frame and to comply with course specification in the particular school. This is done by first obtaining a union of all design topics and objectives from all schools in the survey. Each school is then surveyed to identify how much of the union topics being offered. The results of the survey

are shown in Fig. 2. In this figure, topics taught by less than three schools are omitted from the discussion. It is important to note that some of these topics are quite extensive and may require one or more course under the design umbrella. As an example is the design of machine elements which may include design and/or selection of shafts, gears and gear trains, linkages and mechanisms, bearings, brakes and clutches, bolts and bolted connections, welded joints and power screws.

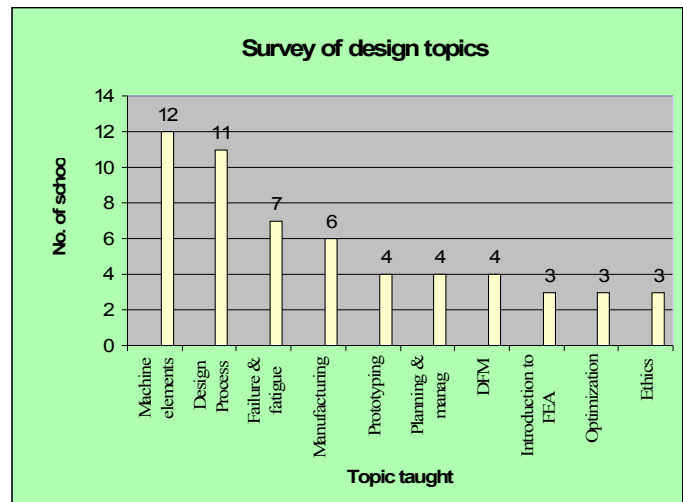


Figure 2 Survey of design topics

3.2 PBL Assessment for Various Levels of Design Education:

As indicated above, a typical design curriculum is composed of an extensive and wide range of topics. In order to deliver such topics discussed in a PBL environment, one has to design multiple projects and still provide extensive lecturing to students. This would simply render the PBL as regular course with intensive project type work. On the other hand, our experience in the Mechanical Engineering department at UBC shows that many of the topics in the design curriculum may be quite effectively handled through a true PBL program. In our new reconstruction of the curriculum, we found that it is quite effective to deliver topics related to conceptual design phase into a PBL unit. This included the design process, planning and management, ethics, prototyping and some basics of design for manufacturing. Our experience shows that a single project (usually ending with fabrication, testing and competition) may be easily designed to

cover all or most of these topics. Students enjoy doing the project and have an effective mean to apply the above concepts. Some of our specified projects have been quite successful and popular and their competition has been televised on local as well as national TV-channels. It should be noted that the instructor still has to provide good number of lectures. This was done, however, in a condensed and focused way at the beginning of the module. Copying the same experience in the embodiment design phase is, however, not as successful and effective.

It is instructive to discuss and examine some of the rational and discussions that led to the above conclusions. One of the main problems in applying PBL in the embodiment and detailed design phase is the nature of the subjects covered in this phase. Many topics have hierarchical knowledge structure and must be covered in certain order and it is not easy to cover all (or the majority) of the topics in one practical project. The hierarchical knowledge structure is pertinent to most of the engineering subjects and is probably one of the fundamental obstacles for implementation of PBL through an entire engineering program, as opposed to within individual courses in the program. This is in contrast to medical knowledge where Perrenet et al. [3] describes the pertinent knowledge as having a “rather encyclopaedic structure, so the order in which various concepts are encountered is not prescribed and further learning will hardly be affected by missing a topic”.

Another important factor is the nature of design and the engineering knowledge and its practice compared for example to medicine where problem-based learning has been widely adopted and successful. Practical engineering problems are inevitably different, more complex and needs longer time to solve from those handled in schools. Problems facing engineers always vary and have new elements, uncertainties and many unknowns. Engineers are always required to solve problems outside of their experience and the knowledge they acquired. In addition, design and engineering problems normally have many solutions. In contrast, the medical field problems differ in that, there will only be one correct diagnosis, it will usually be made relatively quickly and treatments after diagnosis may vary, but will generally be selected from a range of well-defined options. Because of these facts, Perrenet et al. [3] report that “findings

from research on misconceptions suggest that PBL may not always lead to constructing the ‘right’ knowledge and hence it may or may not be useful for engineering education with regard to the acquisition of knowledge that can be retrieved and used in a professional setting”.

One of the important objectives in restructuring an engineering curriculum is the integration of various topics in a uniform stream. Undergraduate engineering students normally tend to deal with each course in isolation as a separate compartment from other courses with no or little connection or interaction. PBL would generally eliminate this problem. A step forward in the teaching methodology that is close to the PBL environment is to aggregate closely related topics and courses into one super unit that would be normally co-taught and would have a project linked to it. In the PBL implementation in the Mechanical Engineering Department at UBC, this approach has been utilized in some of the curriculum units. The extent of the projects and lecturing in a specific unit may qualify the unit as a true PBL application.

3.3 PBL Evaluation in Design Education:

Assessment and evaluation of PBL in design education is important at every level, from project selection, through project and course grading, to curriculum monitoring and accreditation. Most of the engineering associations or accreditation boards do not provide specific or quantitative measures for evaluating a specific program or methodology. For example, the professional engineering association in the United Kingdom defines a list of accreditation topics (e.g., knowledge, design, and analysis) with no specific level of achievements. In the United States, the Accreditation Board for Engineering and Technology (ABET) lists outcomes for student training with no quantitative measures. For example, one of the ABET outcomes that is related to PBL; “an ability to function in teams” doesn’t provide a level of expected proficiency.

In the above regard, Crawley [5] presents an extensive effort for setting goals and competencies for an engineering syllabus. Crawley’s work was done in stages with interaction and input from stakeholders such as employers, ABET and alumni. The result was an extensive list of more than 270 competency attributes with expressions representing

the expected level of achievement in a qualitative sense. This list appears to be, however, very extensive and may be impractical for the purpose of assessment. The list was reduced by Malmqvist et al. [6] but still didn't gain popularity and universality of application. It is important to note that this is an critical point that needs proper attention from researchers. As in the above discussion for general PBL assessment, proper measures and avenues for obtaining assessments are required. Also, assessment of graduates in the work place is crucial to reach proper conclusion for this approach. Various methods of assessments may be adopted from industry measures and procedures. It may be constructive, for example, to consider methods of assessment such as quality and performance of the final product, presentations, portfolios, peer reviews, self-assessments, and competitions.

4. Conclusions:

The paper presented an overview of Project Based Learning (PBL) in engineering education as opposed to the common application in the medical environment. It is shown that many obstacles exist in applying true PBL environment in the engineering field. Special attention was given to the application of PBL in mechanical design education. It is shown that certain aspects of engineering design are quite suitable and would actually benefit from a true PBL implementation. Other aspects or areas such as the embodiment design phase are not, however, suitable for the same implementation. Discussion of the reasons for the above conclusions and a brief overview of PBL assessment in the mechanical design field are given.

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