Int. J. Engng Ed. Vol. 19, No. 5, pp. 725–729, 2003
Printed in Great Britain.
0949-149X/91 $3.00+0.00

Challenging the Administration to Implement Problem-Based Learning in the Undergraduate Engineering Curriculum*

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Stakeholders in engineering education should change the learning paradigm from a teacher-centred to a student-centred approach. Experience gained in teaching automatic control, mechanical engineering orientation, machine language, engineering orientation and technical drawing has given the author confidence that changing the approach, enhances the quality of learning as well as rewards the instructor with greater professional fulfilment. Unfortunately changes made so far 'here and there' in the educational programs are not enough to secure full conformity with present requirements of the real engineering practice. Suggestions are made to improve the curricula as a whole in industrial engineering, mechanical engineering and control system engineering with the hope that we will be soon witness more administrators encouraging changes in teaching approach.

INTRODUCTION

THERE IS NO DOUBT that many engineering educational institutions—such as Technical University of Denmark, Chalmers University of Technology and Aalborg University just to name a few—are already implementing problem-based learning (PBL) successfully. Nevertheless it must be admitted that the majority of the institutions still do not accept the importance of the need for change in the mode that engineering knowledge is to be delivered. This paper challenges administrations to make changes in order to avoid the risk of facing an increase in the number of engineering students dropping their program.

Suggestions are made as how undergraduate curriculum could be changed to meet the professional skills to be demanded in the future. To back up this challenge here we present five evidences. A modest beginning of 10% in the late 60s, followed a gradual increase in the weight of project-based assignments up to 50% today. We now feel confident that these evidences are enough to prove the effectiveness of the PBL approach. As a method that allows students to learn by hands-on experience in engineering design, PBL has without doubt a significant contribution in preparing students for the real world.

BACKGROUND

According to Kelly, human beings in their search of prediction and control of the surrounding events have a natural drive to act like *scientists*. The aspirations of the scientists are essentially the aspirations of all men. Each individual classifies their world by developing 'personal constructs' on what is common and what is different in those things that surround us. As a consequence, instructors should be models and help students to develop the skills that are necessary while doing research. The research activities—vital for raising funds and building public image—should help in making students more flexible in adopting new constructs [1].

Clarifying his 'vision for the future', Yerlici proposes that higher education should:

- improve the ability to question and seek for answers;
- sharpen the vision of details;
- refine the mind for greater sophistication at interpreting data and encourage independent thinking.

Although specialisation and research can help students develop this ability, excessive costs are incurred when research is used as a tool for teaching. While providing the basic knowledge good teachers should stimulate the minds of their students in the direction of critical thinking and creativity [2].

The UNESCO report published in the year 1996 and prepared by a commission headed by Jacques Delors titled 'Learning: the Treasure Within', suggests the 'four pillars' that must be strengthened for the reformation of education in the next century. According to this report learning must enhance the quantity/quality of knowledge, the ability of doing, the development of the self and the skill to share with others and '. . . *this process must begin with self-understanding through an inner voyage whose milestones are knowledge, meditation and the practice of self-criticism*'.

* Accepted 1 October 2002.

Employers have a very important role to play in the enhancement of the quality of engineering education. Their active participation as members of the academic boards should be encouraged. This practice enables the development of sound policies as the result of collaboration between all the educational parties. 'Engaged dialogue' can make curriculum changes an enduring possibility. By establishing a formal and informal network between the parties, peers and superiors, new ideas can be put forward and rapidly implemented.

EVIDENCES

The first application of PBL was introduced by the author in the year 1969 under the name of *individual project*, with a 10% share in final grade. Among the many successful students in this novel implementation, one student distinguished in particular. As a student of the technical drawing course, he worked on a new car design project. His father—being involved in the automotive industry himself—provided an adequate setting for him to continue on working with the subject. He became the general manager of Ford in Turkey—recently producing exclusive models for foreign clients—and now is working in the international headquarters. The following evidences attempt to illustrate how educational changes can be made from within a traditional system.

First evidence

In 1997 the author increased the project assignment weighting to 30% in an automatic control course offered by the Electronic Program in the School of Advanced Vocational Studies at the university where he is currently affiliated. The outline of the course that sophomore students were to take during their third semester included: an introduction to control theory; the analysis of electrical, hydraulic and pneumatic systems; and the study of transfer functions and controlling techniques. Students attending this course have completed during their freshmen year the requirements for mathematics, technical drawing, programming techniques, electrical circuits, logic circuits, machine language and operating systems.

At the beginning of the course, as a starting point to their research, students were allowed to choose freely the topics using the excellent examples provided by Dorf in the *Modern Control Systems* textbook published in 1989. Eventually the instructor intervened by giving specific assignments to each student to avoid duplications. The instructor provided extra information about mechanical systems—fasteners, bearings, handling components—from leaflets collected from manufacturing companies. The study of mobile robots, which include perception by sensors, cognition by intelligence and behaviour by actuators, was strongly encouraged because it provided a very complete coverage of the automatic control field [3].

Second evidence

Latter in the same university, the author was asked to take on the responsibility of launching an introductory course in mechanical engineering. He was already familiar with the background of the students. This information was gained during personal contacts in the technical drawing course offered the previous semester. The idea of using the recently published *An Introduction to Engineering* textbook by Onwubiko showed little prospect of encouraging students to be involved in the mechanical engineering design as required in the course description. It was expected that this course—integrated in the recently designed undergraduate program aiming—would meet the demands of the industry.

Assigning each student a different mechanical device, proved to be a very challenging idea. At the beginning students expected to find clear-cut solutions to their assignments in the literature suggested, but soon realised that they had to follow the suggestions made by the instructor in order to accomplish positive results. Again, here the example of a mobile robot was presented to show students the procedure to be followed in an engineering design. The results of the work were eventually published in the proceedings of a national mechanical engineering symposium. To encourage students to present outstanding work, grades higher than 100 points was possible [4].

Third evidence

A wonderful opportunity occurred while teaching 'machine language' to freshmen students in the same Junior College that was reported in the first evidence. Since the foundation of a first research centre in the university during early 60s, the author was able to witness the development in medical engineering research that eventually culminated with the creation of a biomedical engineering institute. As information technology is changing dramatically the way we live, medical care is taking a new turn as we approach the new millennium.

At this crucial time, the author assigned his 48 freshmen students specific topics that where generated by the cross-tabulation of sensory, nervous, tissue (hard), respiratory, cardiovascular, gastrointestinal and tissue (soft) topics with measurement, diagnosis, design, manufacturing, treatment, simulation and monitoring topics. A summary of the course outline is described in Table 1. Students had to present progress reports every week on their work. After having selected the variables, deciding the equations, fixing the memory addresses and registers to be used they had actually to write and trace the program [5].

Fourth evidence

In an engineering orientation course offered by the author in a private university in Istanbul, each week every student was requested to present one stage of a project in compliance to the engineering project preparation steps given at the beginning of term. Students had to describe the basic components, the manufacturing process, the time schedule for production, the analysis of deformation, the cost calculation, layout of the manufacturing plant, the mesh description for manufacturing routing, the breakeven calculation and the impact on the environment (Table 1). Written reports were graded before the oral presentations and short examinations assured that concepts were properly covered [6].

Just before every lesson each student was expected to post the personal work on the walls of classroom for the oral presentation. This provided both to students and to the instructor an easy and fast way to compare each work. Openness and easiness of evaluation made possible instant feedback and grading which is so important in learning. We must recognise that to cope with the present changing conditions, stakeholders in the global economic development should provide more help by encouraging the use of educational technology and reconciling research with education.

Fifth evidence

The author has been teaching engineering graphics for more than two decades and developed in this time several strategies to enhance the motivation of the students to do better work. The course curriculum included the topics of multi-view projection, sectioning, dimensioning, explosion, assembly and animation. Each topic was first covered using the classical pencil and paper technique. Since computer-based design software is very popular today, special effort was made to give the students hands-on experience in the use of this modern tool. Some students did not have the necessary computer skills to use the available software and some of them had not yet had the engineering orientation course offered the previous semester [7].

Students were expected to prepare each week a project to be handed in before the lecture period. A similar work was graded during class that helped to verify the authenticity of the project presented. This was further developed with the computer design package program in use. Unfortunatelly students are in general reluctant to take notes so additional material had to be provided as the course developed. It was clear that since the students were used to solving only science problems, they had difficulties in realising that there is no 'one' aswer to engineering problems. Encouraging students to change some of the parameters of the assigment while adding different new components was indeed a challenge.

SUGGESTIONS

As the author gained confidence in the power of the new approach to teaching engineering courses, it became evident that important changes had to be made in the undergraduate curriculum if the positive effect of PBL was to be maintained. The explanations given in this section attempt to summarise the efforts made to suggest changes in the curriculum parallel to the implementations made in the course educational approach. When they were questioning the need of taking the courses they were assigned, it became clear that students had no idea about the curriculum and the aim of the undergraduate program. Here are some suggestions to improve the current situation.

First suggestion

The first attempt to develop an integrated undergraduate curriculum where PBL would have a key role was made in 1996. Personal contact with many senior students that had taken the freshmen courses from the author revealed that many students wasted valuable time in the initial phase of their graduation project. Considering that industrial engineering education has to be more open to changes as demanded by the employers, we suggest the setting up of 'knowledge lanes'. The project development lane would assure that the information acquired each year in the other lanes is applied in relevant projects. Students would develop the required skills of project development in small steps, ending with the project in the last year.

Since PBL requires that students work sometimes without the direct supervision of their instructors, mutual trust must be developed to ensure that indeed the work is original and not simply 'borrowed'. Students are expected to work extra hours outside the classrooms doing research in the libraries and consulting different documents that the instructors may provide. There are possibilities for 'unfair practice'. Creating an atmosphere that enhances the enthusiasm of the students to work for intrinsic motivation can prevent misconduct [16].

Second suggestion

Another attempt was made to develop an integrated undergraduate program, this time for mechanical engineering. Three areas of mechanical engineering practice—namely energy, transportation and handling—are considered as the output of the program. The basic engineering sciences and the basic engineering applications are the inputs to the educational system. From these basic inputs the core courses are developed as a whole. The flow of the design process is given in the identification, description, embodiment, control and implementation stages. These stages should go in parallel with the development of the specifications, diagrams, drafts, systems and prototypes of the project.

The program described above tries to show that the courses alone are not enough to give an understanding of the content of an engineering program. Students should be encouraged to reflect on the relations that exist with the courses and the aim of the main areas of application. Even a relation can be established between the areas of application, as in the case of energy being part of a transportation system. The courses should be closely integrated with the design system approach so important in engineering practice. As new knowledge is acquired in the core courses, the relevant information must be applied in a project leading to the final year project [9].

Third suggestion

During a joint work with a colleague in the field of electronics, an education program for control system design was developed. Starting with the basic courses in mathematics and physics, core courses such as logic circuits, assemblers and simulation, the program continues with system components and product development. A project originates with the problem definition and ends with the program validation. This fact demonstrates that computer programming forms an integral part of the design process. It is important to understand also the operation of the mechanical equipment as part of the whole design.

We proposed a novel model that showed promising results. Students learn through projects with a top-down approach; not only does this motivate students but also is expected to help in equipping them with skills for life-long learning. The 'just in time teaching' pedagogical strategy appears to be suitable for helping the delivery of the curriculum proposed. As emphasised by the mechatronics discipline, the integration of different engineering areas is a necessity in a modern control system design approach. In this new approach the complexity of the final product dictates a holistic view to design [10].

CONCLUSIONS

The evidences given in this paper show clearly the advantages of PBL both for the students and the instructors. Instructors can take the opportunity of the project to pursue their own research. As long as administration is willing to acknowledge the importance of collaborative work with the students, we see no conflict between the efforts given to teaching and those required for research. Unfortunately many instructors argue that much time is lost in the implementation of the PBL approach and many critical topics relevant to the engineering practice face the risk of not being covered. Using Table 1 it is our duty to convince the administration that since the learning method is as important as the content, PBL should be seen as a valuable educational tool within the traditional system [11].

Using the successful case at Texas A&M as an evidence, Wald during the UICEE conference at Wismar in the year 2000, gave some clues on the way to approach change in educational institutions. During the oral presentation, a chart showing how actual change lags behind the initial efforts made by the institution was presented. Unfreezing people's attitudes by identifying individual and organisational barriers, developing people's awareness of the situation and interest to participate, making people more involved in decision making and accountable for their behaviour and ensuring people's long-term commitment to change were recommended [12].

On a more practical stand, Pudlowski suggests that a model for curriculum design should assure that 'the product outputs meet the prescribed educational objectives and appropriately adjust in accordance to the requirements of the changing technology, practices and processes'. He argues that the methods should allow for the development of a new education structure or the restructure and modernisation of existing curricula should be possible without any undesirable effects and disturbances [13].

We wish to conclude by making an appeal to the community of education administrators to encourage the use of PBL by highlighting 'best practices' through special publications. These publications should highlight the profile of the students involved, the projects developed, the students' responses and performance evaluation. Such a practice will hopefully encourage collaboration between institutions. As has always been demanded by the strong and experienced voice of Hernaut—wearing his hat of manager of a well-known industrial enterprise—it is now the right time to convince administrations that this is the right way to go forward [14].

Acknowledgement—The author wishes to acknowledge the inspiration given by Nikos Mourtos of the Mechanical Engineering Department of San Jose State University, San Jose, California, USA.

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