Dr. Zareena Gani, Higher Colleges of Technology

Dr. Zareena Gani started her career in Engineering with a degree in Mechanical engineering from MK University, India. She has over 20 years of experience in both academia and industry. She has worked as a Design and Manufacturing engineer in Singapore before joining National University of Singapore from which she obtained her M.Eng degree. She also has worked in Singapore Institute of Manufacturing Technology (A*STAR) as a Research Fellow before moving to Canada. She gained exposure with the Canadian tool making industry while she worked in Profine Molds and her keen interest in research brought her back to school. She obtained her Ph.D. from McMasters University in Canada as an NSERC scholar. After graduation, she moved to United Arab Emirates in 2011 and joined Higher Colleges of Technology. Dr. Zareena has published her research findings in reputed international journals and conferences.
Abstract:

At Higher Colleges of Technology, UAE, the objective has been to prepare students to be work-ready and professionally equipped for immediate employment. Computer Integrated Manufacturing (CIM) course is taught for the Bachelor of Science (Mechanical Engineering) students as an elective during their graduation year. To develop in-depth knowledge and student understanding of the CIM course and to help them prepare for the work force; course delivery methodology and the assessment strategies were modified to adapt PBL. Project Based Learning (PBL) - a successful teaching strategy in higher education has been gaining popularity in the engineering education community. The details of the projects, requirements, assessment strategy and the benefits of adapting PBL approach are presented in this paper.

Keywords: Project based learning, Computer Integrated Manufacturing, Engineering Education, Mechanical Engineering.

1. Introduction

The United Arab Emirates continues to pursue a strategy of diversifying its economy from non-oil sectors to high technology and high growth sectors and the demand for qualified mechanical engineering graduates are in rise [1]. However, today industries demand more than technical experts, competent professionals. Also one of the measures necessary for achieving employability is developing transversal skills and competencies, such as communication and languages, the ability to handle information, to solve problems, to work in teams and to lead social processes. The accreditation bodies’ recent trends in engineering education have led to increased integration of design and other important engineering practice skills i.e., teamwork, project management, communications, ethics, economics of engineering, etc. into the engineering curriculum [2].

The traditional ‘chalk and talk’ pedagogy is more unlikely to satisfy the requirements of the accreditation criteria and what industries need from engineering graduates. PBL seems certainly the best way to satisfy industry needs without sacrificing the knowledge of engineering fundamentals and welcomed by students, industry and accreditors alike [3] [4].

Computer Integrated Manufacturing – CIM is being taught as an elective course during the graduation year in undergraduate Mechanical Engineering program. The course syllabus covers a wide range of topics including integration of Computer Aided Design (CAD) / Computer Aided Manufacturing (CAM), Manufacturing Planning, Process Planning, Production Planning, Capacity Planning, Materials Requirement Planning, Manufacturing Resource Planning, Manufacturing Control, Automation in manufacturing, Programmable Logic Controller (PLC), Industrial Robots, Flexible Manufacturing System (FMS) and Enterprise Resource Planning (ERP). Traditional lecture based methodology could only help the students learn the theory without understanding the practical implications of these concepts. Lecture-workshop based approach might not give the students the opportunity to gain the wholesome real world experience of managing projects while applying technical details. Since CAD, Materials
Selection & Testing and Manufacturing Technology courses are the prerequisite for CIM, students have fairly good practical knowledge on the basics of materials and machining which they learnt through “Learning by doing” approach [1], Project based learning PBL seemed to be the most appropriate methodology to adapt for this course since the focus is on the application as well as the integration of previously acquired knowledge.

2. Literature Review

As an integral part of a global society, engineers today are expected to master a combination of disparate capabilities, not only technical competencies concerning problem solving and the production and innovation of technology, but also interdisciplinary skills of cooperation, communication, project management and life-long learning abilities in diverse social, cultural and globalized settings. Thus, in addition to traditional engineering skills, present and future engineers are required to be able to analyze, develop, create and form part of cognitive and social interrelations among human beings, with the aim of facilitating the development of technology and analyzing its positive and negative impacts on society. These new engineering competencies challenge the existing and traditional lecture-based approaches to teaching and learning and PBL seems to provide a possible answer to these challenges [5]. In PBL, students participate in a learning environment that allows them to acquire knowledge, skills and personal and interpersonal abilities. Students may gain skills like engineering design, problem solving, information retrieval, engineering thinking, laboratory skills, building products and identifying the relationship between the elements of the constructed product. The personal and interpersonal abilities acquired by the students are mainly the ability to work in an engineering team and to engage in self-study both as individuals and as members of a team [6].

What is Project-Based Learning (PBL)? In PBL, students work in groups to solve challenging problems that are authentic, curriculum-based, and often interdisciplinary. Learners decide how to approach a problem and what activities to pursue. They gather information from a variety of sources and synthesize, analyze and derive knowledge from it. Their learning is inherently valuable because it is connected to something real and involves adult skills such as collaboration and reflection. At the end, students demonstrate knowledge and are judged by how much they have learnt and how well they communicate it. Throughout this process, the teacher’s role is to guide and advise rather than to direct and manage student work [7]. In project based learning, the projects will have varying complexity but all will relate in some way to the fundamental theories and techniques of an engineer’s discipline specialization. Successful completion of projects in practice requires the integration of all areas of an engineer’s undergraduate training. Project work is more directed to the application of knowledge, management of time and resources by the students as well as task and role differentiation is very important in project-based learning [8].

The aspects that enterprises has pointed out as the main deficiencies in university education are insufficient preparation for research and creation, excessive theoretical instruction with a reduced practical component, knowledge that is too general with deficient specialization and updated knowledge. One of the great challenges of the university system is to demonstrate capacity for adaptation to the changes in today’s society and its new demands in which the concept of profession focuses on what are called professional competencies.
Numerous studies around the world have proposed PBL as achieving effective competence-based education that integrates knowledge, skills and values. The models integrating PBL have scientific evidence in generating learning processes where students are not passive recipients of knowledge. PBL is grounded in the belief that humans construct new knowledge over a base of what we already know and of what we have experienced, which we make available through active participation and interaction with others. [9]. It was claimed that the PBL as the most adequate educational methodology for the development of competences, linking teaching with professional sphere. PBL technique is based on cooperation, active participation and interaction, offering multiple possibilities for developing technical, contextual and behavioral competences. It was also concluded that any learning-centered process requires that both teachers and students assume a more active role, greater shared commitment, and greater responsibility for their own leaning. The scientific basis of PBL was maintained to generate learning process in which students are not passive recipients of knowledge but are immersed in a pre-professional experience in defining projects with real content that required students to integrate the knowledge they have already gained from other courses with new knowledge attained in developing the project. Students also developed personal competences such as working in teams, investigation and innovation, creativity for the generation of new knowledge, productive thought and motivation to learn and solve problems.

The dominant pedagogy for engineering education still remains “chalk and talk”, despite the large body of education and research that demonstrates its ineffectiveness. In recent years, the engineering profession and the bodies responsible for accrediting engineering programs have called for change. The modern engineering profession deals constantly with uncertainty, with incomplete data and competing or rather conflicting demands from clients, governments, environmental groups and the general public. It requires skills in human relations as well as technical competence. Whilst trying to incorporate more “human” skills into their knowledge base and professional practice, today’s engineers must also cope with continual technological and organizational change in the workplace. They also must cope with the commercial realities of industrial practice in modern world, as well as the legal consequences of every professional decision they make [3].

Julie E Mills et al. have listed the current practice and critical issues in engineering education. Engineering graduates are required to have strong communication and teamwork skills; a broader perspective of the issues that concern their profession such as social, environmental and economic issues, good knowledge of fundamental engineering science and computer literacy and should know how to apply that in practice. There are several studies that have informed reviews of engineering education and have had a major influence on the revision of national accreditation criteria for engineering programs in USA, UK and Australia, in which the approach has shifted from “what is being taught” to “what is being learned”. There are requirements for increased management education, design education and industry relevance of programs.

The critical issues that need to be addressed in Engineering Education are summarized as

1. Programs are content driven i.e. Engineering curricula are too focused on engineering science and technical courses without providing sufficient integration of these topics or relating them to industrial practice.
2. Current programs not providing sufficient design experience to students.
3. Graduates lacking communication skills and teamwork experience, thus more opportunities need to be incorporated for students to develop these skills.
4. Students need to be made aware of modern engineering practice such as social, environmental, economic and legal issues.
5. Existing faculty lack practical experience hence are not able to adequately relate theory to practice or provide design experiences. Present promotion systems reward research activities and not practical experience or teaching expertise.
6. Teaching and learning strategies in engineering programs need to become more student-centered [3].

Some of these critical issues are addressed and analyzed in this paper.

3. CIM – CLOs & Accreditation
The Course Learning Outcomes covered in the Computer Integrated Manufacturing course are, (I) Understand the importance of computer aided manufacturing and design principles with the interfacing of CAD / CAM, (II) Appreciate the way computer based systems support the operation of a manufacturing business, (III) Display "hands on" experience with tools and systems used in industry. Special attention is given to computer-aided design and computer-aided manufacturing, (IV) Display "hands on" experience with tools and systems used in industry. Emphasizing computer-aided process planning, Manufacturing Resource Planning, programmable logic controllers, industrial robots and supporting technologies and (V) Apply fundamental concepts using industrial software.

The Program Learning Outcomes (PLOs) included the following technical skills: (1) An ability to select and apply the knowledge, techniques, skills, and modern tools of mechanical engineering to broadly-defined engineering technology activities. (2) An ability to design systems, components, or processes for broadly-defined mechanical engineering technology problems appropriate to program educational objectives. (3) An ability to identify, analyze, and solve broadly-defined mechanical engineering technology problems. (4) An ability to apply written, oral, and graphical communication in both technical and non-technical environments; and an ability to identify and use appropriate technical literature. (5) Ability to apply specific program principles to the analysis, design, development and implementation of advanced mechanical systems or processes.

Also, the skills set requirements included, (1) The ability to apply project management techniques to analyze, design and implement advance mechanical systems. (2) A commitment to quality, timeliness, and continuous improvement. (3) An ability to function effectively as a member or leader on a technical team. (4) A knowledge of the impact of engineering technology solutions in a societal and global context. (5) An ability to select and apply a knowledge of mathematics, science, engineering, and technology to mechanical engineering technology problems that require the application of principles and applied procedures or methodologies. Traditional lecture based approach would be inadequate to meet all the above listed CLO and PLO requirements. Various pedagogies such as: Learning by Doing, Problem Based Learning, Lecture-workshop approach, Project Based Learning, etc. were analyzed and compared before
choosing Project Based Learning as the appropriate technique to meet most of the listed requirements within the stipulated time frame of one term.

4. **Project Based Learning (PBL) approach**

The projects carried out in this course were split into two phases (1) CAD / CAM integration with tools and systems used in manufacturing industries including industrial software (2) Industrial Robots, Flexible Manufacturing System and Programmable Logic Controllers (PLC) for a total of 45% of the course grade. These projects were usually combined with lectures introducing the new technical concepts such as integration of CAD/CAM, Process Planning, Material Requirement Planning, Manufacturing Resource Planning and Production Planning. The projects focused on the application of these concepts along with the integration of previously acquired knowledge from the prerequisite course which was Manufacturing Technology and other courses such as Computer Aided Designing, CAD Modelling and Project Management. The assessment strategies of the course had been modified to evaluate the projects on various aspects including innovation, problem solving skills, meeting technical aspects, project management, team work and presentation skills.

Projects were carried out in small groups of 3-5 students per group and undertaken throughout the length of the course with the focus being learning rather than teaching. The project requirements for Phase-I are (1) Design a product with minimum 4 components using AutoCAD or Solidworks software. (2) The components need to be machined at the college workshop using both CNC mill and CNC lathe. (3) The size restrictions for CNC lathe is Dia. 25 x 50 mm and for CNC mill it is 100 x 70 x 17 mm. (4) The machines could only be used during the time-slot allotted for the group and should be completed within the given time-frame. (5) The list of tools available in the machines were provided. (6) The final assembly has to be submitted by the set deadline. The weightage for Phase-I was set to 35% of the total course grade.

The students worked as a team to finalize the product they would design and fabricate with all the restrictions listed in the project requirements and get approval from the faculty. Then, they prepared the CAD model of the assembly and the part drawings using the provided software. The students then prepared a Route Sheet for each component elaborating the machining sequence they would follow, machine to use, tools, set-up time and machining time. They also learnt to use the Boxford - CAM software to generate the part program (CNC codes) for each component and run the machining simulation to verify the machining time. The students then scheduled their machines within the slots allotted for the individual group to complete the fabrication, inspection and assembly on time.

The students were required to submit all the part drawings, 3D model, Route Sheet, CNC codes with simulation, a short video of the machining process and images of the machined components. A project report summarizing the project activities along with the list of skills learned, followed by a presentation was mandated.

Rubrics with clear marking scheme for each required component i.e. CAD, CAM, final product, etc. were given to the students at the outset to let them know what exactly was expected and the goals to be met. The rubrics were set to check the quality of work critically and the students were held accountable for accuracy, clarity and honesty.
Following figures shows samples of student’s project work. Figure 1 shows the final assembly of the students’ work, sample solid modelling as submitted by students is given in Figure 2; 2D and 3D assembly views of another student project is shown in Figure 3 and Figure 4 shows the screen shot of Boxford CNC tool path simulation as generated by students.

Figure 1: Sample product assembly (Students’ work)
Figure 2: Solid Model of components (students’ work)

Figure 3: Assembly drawing with 2D view (students’ sample)

Figure 4: Boxford – cutting action simulation (students’ sample)
In Phase-II, the project requirements included (1) Programming the Robotic arm to mimic Industrial Robots, (2) Program the PLC to run the FMS system. The weightage for this project was 10% of the total course grade. The students worked with the same group, used PLC programming and Robotic arm programming to run the Flexible Manufacturing System model that is available in the workshop, to suit their own production process. All the programs, simulations along with a short video of the PLC / Robotic Arm / FMS system were to be submitted along with a detailed review on Enterprise Resource Planning (ERP) software system used in industries within the time frame set for the project. Again a short report followed by presentation were included in the rubrics of this project.

Figure 5 shows the robotic arm in action and Figure 6 shows the entire set-up of the PLC / FMS / Robotic arm with the remote control used for lead-through programming of the robotic arm.

Figure 5: Robotic arm programming

Figure 6: Robotic arm with PLC and FMS model & Robotic arm remote control
5. Analyses and discussion

PBL approach has been adopted since 2017-Spring term for the CIM course. All projects had the same phases of preparation, problem solving, conclusions and presentation. Earlier the students worked individually on generating CNC codes for specific CAD part drawings given to them and machined the component which was more of a traditional lecture and workshop based methodology (2017-Fall) Table 1.

Prior the PBL approach, since students were given the CAD model to generate the CNC tool path, it was not challenging enough and the students only gained just one skill of generating tool path for the given CAD model. In PBL approach, students as a team, worked together and brainstormed to pick a product while considering the limitations imposed in terms of availability of the type of machines, cutting tools, workpiece material, size of the available raw material and time constraints. This was meant to mimic the real-life machine shop scenario. Then, they were designing the product and the components either in AutoCAD or Solidworks and generate the solid model in stl format (Figure 2 and Figure 3). They imported the stl files in Boxford and also learnt to generate tool path using Boxford software, mitigate errors such as tool collision and simulate the tool path (Figure 4) and find the actual machining time. The students then transferred the tool path – CNC codes to the appropriate machine (mill / lathe), set-up the workpiece and the required tools in the tool magazine and machine all the components with the CNC machines. Later, they inspected the components and assembled it to a final product as shown in Figure 1. After completing the assembly, they elaborated these tasks in a report and presented to a committee for grading. The students exhibited enthusiasm and were willing to learn and acquire new skills throughout the process unlike the non-PBL approach.

The assessment strategy earlier was set only to evaluate the CNC tool path and final assembly. In PBL the assessment strategy was modified to included students’ creativity, complexity of the design, details included in the solid model, generation of tool path, dimensional accuracy of each component, aesthetic look of the final assembly, team work, presentation skill, project management skill and report writing skill. The weightage of each of these elements were listed in the rubrics and given to the students at the start of the course.

A non-formal feedback form was sent to the students at the end of the term to complete it anonymously. Almost all students were positive about their experience and mentioned that they learnt more technical details and acquired interpersonal skills through the PBL and it also helped them comprehend what they learnt in the lecture based lessons and the rest of the course. With the non-PBL approach the students were not required to work as a team or on a project. Students’ knowledge retention and reflection were assessed in the final written exam that covered all the CLOs. Significant improvement in student attainment was evident with the PBL compared to the earlier lecture – workshop based approach. Students who particularly developed PBL skills also performed well on other assessments.

There were a minimum of 50 students enrolled in the CIM course each term. Following table illustrates the weightage of each CLO, weightage of selected response (SR) and constructed response (CR) questions, and the student attainment in the final exam.
Table 1: Average CLO attainment comparison with and without PBL.

<table>
<thead>
<tr>
<th>CLO</th>
<th>Weightage (%)*</th>
<th>Weightage for SR questions</th>
<th>Weightage for CR questions</th>
<th>Average score (2018-Fall)</th>
<th>Average Score (2017-Spring)</th>
<th>Average Score (2017-Fall)</th>
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<tbody>
<tr>
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<td>6</td>
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As stated in the CLOs description above in section 3, questions in CLOs 3 and 4 focused on hands-on experience and higher weightages have been given for these 2 CLOs which is 30% each. Questions were set based on the CLO requirements and the weightage as described in the course syllabus.

It is evident from Table 1 that significant improvement in the average CLO attainment had been achieved with Project Based Learning, i.e., 2017-Spring onwards; compared to lecture-workshop approach till 2017-Fall. The knowledge retention reflected in the final exam as well as in the other assessments such as tests and quizzes have also shown improvement with the PBL. It was also identified that the students emerged with stronger team skills, communication skills and the ability to carry out a total project and generally more adaptable and thus more directly employable on graduation [10] [11] [12].

The learning experience of the students were captured in the project reports that summarized all their project activities and skills gained along with the evaluation survey completed at the end of the term with students’ feedback. Students were positive about their learning experience and satisfied with the new skills they gained through this approach and by using the previously acquired knowledge. They were particularly enthusiastic about them being able to work as a team, the roles they played throughout the project, and the communication and presentation skills they improved. Students who later got employed, emailed their feedback voluntarily, stating how the knowledge and skills they gained in this course was helping them in their workplace as they were more confident about the industrial practices.

6. Conclusions

The objective of Computer Integrated Manufacturing course is to enable the students learn the integration of CAD/CAM along with other automation techniques using PLC, robotic arm and FMS. In addition to mastering the technical competency including innovation and problem solving skills, the students in engineering programs in general are required to develop interdisciplinary skills of communication, project management, cooperation and leadership to get the students readily employable on graduation. It is a challenge to meet all these emerging competencies requirement along with hands-on technical skills with the traditional lecture-based
approach. Project based learning approach has become increasingly accepted as a useful concept in education since it supports the relation between theory and practice. Thus, Project Based Learning methodology has been identified as the most appropriate approach to combat the above listed challenges to teach CIM course, where the students are required to work on projects and are expected to manage complex problems related to real world.

The assessment results shows positive impact on student learning. PBL also let the educator cover all the CLOs while promoting in-depth practical exploration of the core concepts, better knowledge retention of learning skills and the ability to apply these skills in the projects. It was also found that since PBL engages reluctant students, it can accommodate the needs of a diverse population, creating a learning environment that is more equitable for students with different skill levels. Students who participated in project-based learning are generally motivated and demonstrated better team work and communication skills. They have a better understanding of the application of their knowledge in practice and the complexities of other issues involved in professional practice. Some of the positive aspects as noted by students of PBL in CIM were the use of real world application and the development of technical and problem-solving skills which in turn helped the students gain confidence with their acquired skills. In addition to these positive outcomes, the accreditation requirements were all met with this PBL approach for the CIM course.

Engineering educators without industrial exposure might find it challenging to adapt PBL methodology since adequate industrial / practical experience and up-to date knowledge of industrial practice are required to facilitate learning through PBL approach. Such real-world experience could be attained by collaborating with industries to get an insight of the current practices and requirements. Experts from industrial partners could also train the faculties during the program’s professional development sessions in order to combat the issue.

7. References


