DEVELOPING AWARENESS AND COMPETENCIES OF CDIO SKILLS THROUGH PBL APPROACH

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ABSTRACT

This study describes the educational experience of the students' perceptions to the teaching of CDIO skills through a problem based approach. It is a small-scale study in mathematics module of a group of second year Mechanical and Manufacturing students from the Singapore Polytechnic. It highlights the key changes that the author has implemented in her classroom practice and the findings to date. Findings from the research suggest that the self directed learning component in problem based learning has led students to acquire CDIO skills such as teamwork and problem solving skills. The implications of the findings from the survey have been used to formulate appropriate teaching strategies for the continued development of the module.

KEYWORDS

Problem based learning, CDIO skills, Mathematics.

INTRODUCTION

In recent years, certain courses from the four schools of Singapore Polytechnic (SP)- School of Mechanical and Manufacturing Engineering(MM), School of Chemical and Life Sciences(CLS), School of Electrical Engineering(EEE) and School of Built Environment(BE) implement the Conceive-Design-Implement-and-Operation(CDIO) initiative into their curricula in phases. Three CDIO skills; namely

- Personal Skills and Attitudes (initiative and willingness to take risks, perseverance and flexibility, creative thinking, critical thinking, curiosity and life long learning, time and resource management, etc)
- Teamwork (forming effective team, team operation, team growth and evolution, leadership, etc)
- Communication (written communication, electronic communication, graphical communication, oral presentation, etc)

have been selected for the first phase of integration into their curricula. Mr Low Wong Fook, principal of Singapore Polytechnic (SP), during his speech in Staff Rally 2007, urged staff to infuse some of the selected skills into the diploma modules. He said:

> *...To interpret CDIO a little more flexibly and more broadly so that we can all use CDIO to make learning more integrated, more meaningful and exciting for our students. ...Basically, a CDIO-based curriculum is one that is organized around fundamental, whatever the discipline, but interwoven with student projects which encourage active, experiential and group learning.* [1]

The teaching of Mathematics in SP typically involves transmissive practices of mere reproduction of knowledge to learners. Lecturers show students how to answer questions and solve problems related to mathematics. However, lecturers tend to omit the problem-

formulating stage where students need to handle facts and procedures to develop their own questions and investigate by themselves. In my opinion, students just memorise formulae and procedures but do not fully understand or be able to use it. Instead, students must be encouraged to go beyond the memorization of facts, and to move towards learning how to apply their knowledge in problem-solving [2]. Students educated for the world of 21st century must develop habits of thinking, researching, and problem solving to succeed in a rapid changing world [3].

How can we develop awareness and competencies of CDIO skills for SP students? My proposed approach is to adopt Problem-Based Learning (PBL) approach.

Problem-based learning (PBL) is a student-centered pedagogy that uses a problem trigger to drive the learning activities. It orients students from fact-collecting toward meaning-making [4,5]. The modern history of problem-based learning begins in 1969 at the medical school at McMaster University in Canada, and gained impetus in 1984 when the Report of the Project Panel on the General Professional Education of the Physician recommended less emphasis on lecture-based instruction and more on independent and problem-centered learning [6, p.156]. Its intellectual history is far older. Today PBL is used in a variety of institutions and disciplines [7,8]. For example, in Singapore it has been implemented in Temasek Polytechnic and Republic Polytechnic.

Many education reform movements have embraced PBL owing to its positive benefits [3] as

- PBL deals with problems that are as close to real life situations as possible
- PBL promotes students' active engagement in learning
- PBL promotes an interdisciplinary approach
- PBL requires students to make choice about how and what they will learn
- PBL promotes collaborative learning
- PBL helps raise the quality of education

I feel that the benefits of introducing PBL for students are many, not least in terms of their individual development as learners. Learning is not primarily a process of accumulation information and then stored for later use. It is more effective when learners are active in the learning process, assuming responsibility for their learning and participating in making the decision that affects it. PBL is a significant way forward to create an environment in which students are able to find the meaning of information for themselves.

The introduction of PBL approach involves shifting responsibility to students for their own learning and thus developing effective learning strategies. The emphasis should be on the development of students' minds - to develop the power of thinking, flexibility in thought process and ability in problem solving.

Reflecting on the evolving needs of engineering students to learn mathematics for applications in other disciplines, and to understand the connections between mathematics and engineering or everyday life, there is a call for all programmes of higher education to be geared towards developing the PBL method of instruction. I have been considering ways on how I could help to provide students with the opportunity to apply their knowledge and to gain the appropriate skills to perform the necessary tasks effectively in an actual working environment. Clearly, the PBL approach provides a structure for discovery that helps students internalize learning and leads to greater comprehension [3]. It also turns out to be the appropriate educational method to infuse some CDIO skills into students' learning of mathematics.

I was encouraged by Marincovich's [9] support of teachers new to PBL to start off something small and low-risk - to teach 'hybrid' forms of PBL rather than pure PBL. At this juncture, I

would like to highlight that the main aim of this small-scale research study was to offer a PBL approach in mathematics as a complementary strategy to enhance the effect of the traditional didactic lectures. It is a preliminary study yet, nevertheless, it can provide a very useful first taste of PBL for many students.

THE RESEARCH

The aim of this research sets in understanding how PBL develop awareness and competencies of CDIO skills in the context of the engineering students in this study.

In achieving this aim, the research is guided by the following research questions:

- What are the views of students about their PBL experience?
- To what extent does PBL experience promote students' learning in terms of team work and cognitive development?
- How can PBL allow integration of mathematical formulae and theories into real life scenarios?

METHODOLOGY

To implement the PBL format successfully, the students were given a brief overview of how PBL would be carried out. They were told to work in a small group on a real life scenario project. They were expected to participate actively. To incorporate collaborative learning, students were to group themselves in running order of the serial number from the class register with the intention to have heterogeneously mixed in terms of ability (This is to avoid the more academically able and motivated learners to form their own group). Each group consisted of 3-4 students. The group membership remained unchanged throughout the whole project. There was a leader from each group. He or she had to constantly provide feedback to the tutor of their progress for the entire PBL process. This was to help the tutor to have a closer monitoring of students' progress. Such team formulation is designed to enhance teamwork that is part of the CDIO skills.

After team formulation, students were given seven weeks to complete the project. The initial part of this project was carried out during the first three weeks of the tutorial sessions where 30 minutes were set aside for students to work on it. Students were encouraged to discuss the problem with team members and tutor was to assist in the facilitation as students needed scaffolds when they conducted systematic inquiry [10]. The problem was designed and structured in such a way that it consisted of many smaller parts. When students were unable to answer any of the parts, they were asked to investigate further and submit the results in the next tutorial session.

In the second phase, students learnt to map their own strategies to accomplish the work on hand. Students became self-directed learners working within the constraints of resources and time [11]. Most of the groups worked independently in carrying out their plans. Finally they needed to interpret the results obtained.

By doing it this way, students are exposed to a real life problem and they are challenged to solve problem with proper facilitation from the tutor. Thus, they need to have perseverance and flexibility in overcoming challenges, creative and critical thinking for coming up with ideas, self directed learning for acquiring new knowledge, and integration of prior knowledge to solve new problem. The CDIO components on personal skills and attitudes are thus exercised.

At the end of week 7 each group needed to submit a written report and each individual was required to write a report on his/her effort in terms of his/her contribution, reflection and areas for improvement concerning their PBL experience. Students were also required to complete peer evaluation forms to assess individual contributions within the group.

The written presentation, which includes e-communication and graphical communication, helps in improving their CDIO skill on communication. Reflective learning and holistic assessment by self and peer evaluation also meet CDIO skills.

The population of the researched subjects for this study was all the 67 students taking Engineering Mathematics IIA in Semester Two of academic year 2008/2009. They were from School of Mechanical and Manufacturing Engineering in Singapore Polytechnic.

FINDINGS

At the end of the semester, a survey is conducted to solicit students' feedback. The goal of the survey is to find is there any gap between the PBL theory and the practice in classroom. The instrument used in this study was a 12-items questionnaire that measured the views and perceptions of students towards the PBL method of instruction. The questionnaire consisted of 11 items on a 5-point Likert scale and an open-ended question. For each of the 11 items the students were asked to indicate from the scale of "1"(strongly disagree) to "5"(strongly agree).

Among the 12 questions, question 1 is about their perception about the problem trigger. Questions 2-6 are about teamwork. Questions 7-9 are about their cognitive development. Questions 10-11 are about knowledge integration and application. Question 12 is an open-ended question asked for general comments about the PBL project.

Based on the data collected from the 67 respondents, I categorized the findings into summary tables in percentages to enable easy interpretation. The tables below and their interpretations will attempt to answer the three research questions posed in my study.

Research Question 1: What are the views of students about their PBL experience?

Table 1
Item Related to Challenging Level

	Item	Strongly disagree	disagree	Neutral	Agree	Strongly agree
1	The PBL problem was challenging	9.0%	9.0%	25.3%	37.3%	19.4%

This PBL project started with an RL circuit mirror a real life problem. Initially the students had difficulties in generating questions and formulating their own problems. The students struggled with uncertainty as they tried to craft the questions. A substantial high number (57%) of the respondents found the problem challenging as shown in survey questionnaire Item 1 in table 1. Below were some of the comments made by the students:

- *We need teacher to push us and help us during the PBL. After the help from teacher, we are able to solve the PBL.*
- *We need tutor to help us kick start the project*

Research Question 2: To what extent does PBL experience promote students' learning in terms of team work and cognitive development?

Table 2
Items Related to Team Works

	Item	Strongly Disagree	Disagree	Neutral	Agree	Strongly agree
2	I have learnt how to work cooperatively with peers to plan, develop and work out the solutions	3.0%	1.5%	29.9%	32.8%	32.8%
3	I have learnt how to motivate group members, to keep the morale high no matter what happens.	3.0%	3.0%	38.8%	32.8%	22.4%
4	I am aware of my role and the contribution to the team	0%	5.8%	31.4%	31.4%	31.4%
5	Group interaction enhance my learning in Maths	3.0%	7.5%	28.3%	35.8%	25.4%
6	The assignment was mainly done by one or two members	22.4%	21.0%	38.7%	16.4%	1.5%

Table 2 reveals students thought quite strongly of the potential improvement upon team work skills even though they were not free to choose their own members. 65.6% of the students agreed that they learnt how to work cooperatively with peers to plan, develop and work out the solutions. More than half of the respondents believed that they learnt how to motivate group members and to keep the morale high no matter what happens in the learning process. 62.8% of the students were aware of their role and their contribution to the team in completing the project. 61.2% of the respondents felt the group interactions enhanced their learning. About 18% of the students admitted they relied on friends for assistance. From my experience, this 'free-rider' phenomenon always happens regardless whether it is in PBL scheme or in a conventional learning environment. In general, respondents thought that this PBL project helped to build teamwork skills and to enhance their learning. These were supported by some comments made by respondents on how they worked as a team to complete the project at the end of question 5.

- *manage time and help out with thinking for solutions*
- *Delegate tasks evenly for teammates*
- *Call for meeting to solve the problem*
- *consult tutor, research, refer to notes*
- *encourage each other, never say the word 'wrong' or 'impossible'*
- *listen before speak*
- *keep on trying and tell each other not to give up*
- *support, contribute ideas, split work equally,*
- *identify problem, brainstorm of solution*

Table 3
Items Related to Cognitive development

		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
7	I have improved my reasoning and problem-solving skills	0%	5.9%	35.8%	32.8%	25.4%
8	I increased/improved ability to think independently	1.5%	7.4%	42.8%	32.8%	16.4%
9	I have developed research skills (eg. some software to sketch graph)	4.2%	16.6%	33.3%	14.6%	31.3%

There was not very strong agreement of the potential of improvement upon cognitive development through PBL approach as shown in Items 7-9 of Table 3. Only 58% of respondents felt that PBL helped them improve reasoning and problem-solving skills. About

half of the students agreed that they had increased or improved their ability to think independently, while only 46% of them found searching for answers to the learning issues exciting.

Research Question 3: How can PBL allow integration of mathematical formulae and theories into real life scenarios?

Table 4
Items Related to Connection/Integration/Applications

		Strongly Disagree	Disagree	Neutral	Agree	Strongly agree
10	I better understand the connection between different mathematics topics and the real world problems	1.5%	9.0%	29.8%	32.8%	26.9%
11	I am aware that the assignment is an application problem related to the modules I have learnt in my course (*e.g. circuit theory…)*	1.5%	6.0%	19.4%	43.3%	29.8%

Generally, the students' responses skewed right agreeing that they

- *better understand the connection between different mathematics topics and the real world problems*
- *aware that the assignment is an application problem related to the modules I have learnt in my course (e.g. circuit theory…)*

DISCUSSION AND RECOMMENDATIONS

Table 1 gives good ground for discussion on the issue pertaining to students' lack of understanding about the fundamental concepts. It is a possible obstacle for them to tackle the PBL problem and may thus impede their later progress of the whole exercise if they cannot complete this stage. It is similar to the situation pointed by Wee and Kek [11] where learners are more challenged in the problem formulation stage. Even the better students commented on the high intellectual demand that they were not comfortable with. Students needed the constant reassurance from tutors on whether they were heading in the right direction. While it is difficult to write PBL activities to suit every student's level, tutor's support which is highly valued by students is believed to be a stepping stone for students who are particularly weaker conceptually.

The reason for the perceived difficulty could be:

- Students are used to traditional learning style as passive receiver of information, and feel it is a big change to be active learners
- Students are not taught how to model a real life problem

For these reasons, at this stage, I feel that this group of students would still not be ready for a course that is purely PBL format. Probably, a gradual and controlled introduction of the actual experience of working within the framework should be encouraged and built in, and more scaffolds and help on modelling part are necessary.

From the comments of the last question, it was shown that they formed expectations about the uses of PBL in their learning. Some of them reacted positively to it while others did not. Those positive comments can be seen from the following narrative comments collated from the Item 12 in the survey questionnaire.

- *I think that PBL assignment should include the design of the circuit designated in circuit-maker. More credit marks(10%) so that students will feel that it is important assignment.*
- *PBL question is complicated without the help of tutor. It is too indirect in many of the questions and my group had some difficulties solving the problem.*
- *The PBL is very effective way to make us realize that the module is for us to make use of the maths equation to solve the problems in some other modules like circuit theory , Electronics (to find currents….)*
- *Everything are fine to me.*
- *It was just the right thing I need.*
- *It is a bit tough to handle without proper understanding of both circuit theory & maths.*
- *Tough but helpful.*
- *PBL assignment is power.*
- *The PBL is suitable for us overall.*
- *Looking forward to seeing PBL like that.*

Some of the students reacted negatively to the whole project and were unhappy and felt discouraged and demoralized as illustrated by their comments below:

- *Was not very effective.*
- *The PBL is a waste of time.*
- *No more PBL, want maths game.*
- *PBL should have more interesting topics.*
- *No more PBL, if you still want it, must go through with us at first properly.*
- *Give easy question.*

Some students did not take PBL seriously as can be seen from the sub-standard works submitted by them. They tend to leave everything to the last minutes and thus they are unable to complete the assignment. Thus, they resorted to copying assignments from other groups. Whereas, some of them simply dashed off their assignment as just another meaningless academic exercise to be disposed off with as little effort as possible and with minimal personal involvement. In this case, I perceived the students lack the motivation and discipline in PBL learning. PBL require students to be active, self-directed learners. It is no wonder that the shift to PBL represents unwelcome change for some students.

It is clear from Table 2 that many students are able to identify the potential improvement upon teamwork skills arising from the PBL approach. This study indicated that the PBL approach helped students feel more confident in their ability to handle teamwork. Students felt that group interactions enhances their learning; they learnt from each other and worked together to solve the problem. However, the question remains as to whether this increased confidence will enable them to actually achieve the success they now believe is possible for them. On this issue, I have no hard data. Nevertheless, anecdotal evidence is available. I felt many students work effectively and collaboratively in teams to learn mathematical concepts and solve problems. Some even acquired leadership skills through leading their own team or through helping others with their research. These efforts were reflected in students' report as well as through the active participation in the discussion and group interactions.

From the survey in table 3, students did not think strongly of the improvement upon cognitive development through this PBL approach. While it is hard to conclude that this small-scale PBL project has much impact on building thinking and reasoning skills, I have found that some students were able to meet my expectation of the critical-thinking questions in the project.

The results from table 4 indicate respondents were aware of PBL project promotes an interdisciplinary approach. The very nature of this RL circuit project required students to be able to read, write, analyse, think, research, calculate and present the solutions. Not only that, students must be able to understand the connections among different mathematical topics and their applications in the subject of circuit theory in order to accomplish the task. It is hard to say that student understanding of mathematics has greatly improved since the introduction of PBL approach, however; from my observation, students could communicate and present mathematical ideas accurately using mathematical symbols, notations, words and graphs. Students seemed to appreciate more on the learning of mathematics as they could make connections between what they were learning in mathematics and other subjects. Hence, PBL approach is an effective way to show students the connections between and among the subjects, helps them make greater sense of their schooling as a unified whole, and helps them use their knowledge of one field to increase the understanding of another area [3].

The general responses from both closed and open-ended questions seemed to yield mixed feelings about PBL amongst students. In this project, students only experienced a very small scale of PBL instruction within a closely prescribed and directed curriculum where students do not have enough practice to reach the stage of "familiarity". For a successful implementation, there is probably a need for a further project with full un-restricted introduction of PBL within a module. In addition, the PBL program must be ill-structured in response to the outcomes of research so as to help students achieve the skills and confidence they will require. In short, they must also be self-motivated and interested in accelerating the study in spite of all the many "competing interest" he or she is facing.

The survey also shows the challenge students faced in the PBL process. For problem trigger, they generally have difficulty in handling real life problem. For teamwork, not everyone find it comfortable in discussion. For knowledge discovery, it may be a stretch for them to have self directed learning and be creative and critical in thinking.

In one way, these obstacles are normal as it is in the process they develop their full capacity of CDIO skills, not just absorb knowledge in classroom. In another way, it suggests a lot for improvement of the approach and teachers' role for facilitation. For example:

- For problem trigger, since students are seldom taught on modeling part and system thinking, more scaffolds and guidance are needed from teacher;
- For teamwork, scaffolding is also needed to shift the individual, competitive diagram to teamwork and cooperation
- For problem solving process, facilitation skills are needed for teachers to help students embark on self directed learning

The key is to take a balance between challenge (new pedagogy, new problem, new learning style, new assessment, etc) and support so that students are developed yet not over challenged. Thus, facilitators play a very crucial role in the PBL process.

With further improvement to the pedagogy, implementation and design of the research question and full support from the management, I think there is a possibility of achieving some of the benefits. The skills that PBL can develop include:

- Skills in working with others(collaboration);
- ability to continue to learn from learning;
- ability to identify problems and work creatively towards solutions.

CONCLUSION

Overall the project can be regarded as a form of a staging post on the road to the development of a full-scale PBL scheme. We have made progress, yet a lot more can be done with better results. In the long run, we hope:

- To use the experience gained to plan a more extensive programme for other courses, especially to part-time courses where the academic background of the student is more varied;
- To allow students to explore a wide variety of learning experience and to allow them to carry out their studies largely in their own time and their own pace;
- To cultivate a positive learning attitude so that students are able to take responsibility for their own learning; and
- To encourage lifelong learning.

The implications of the findings from the survey have been used to formulate appropriate teaching strategies for the continued development of the module. No doubt the project implemented was small but I strongly believe through this mode of study, students become more aware of how the knowledge they are acquiring can be put to use [12]. Finally, it is hoped that this account of one mathematics lecturer's experience will be of interest in a wider context.

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