Application of Problem Based Learning in Mechanics of Machines Course

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Abstract—The recent years have seen introduction of elements of active learning, and in particular problem-based (PBL) and project-based learning (PjBL) in engineering pedagogy. This research reports on an attempt to use PBL in a topic on kinematics analysis of planar linkages, in a 3-credit course on Mechanics of Machines, offered in Year 3 of a 5-year BEng Mechanical Engineering programme. The kinematic analysis was limited to a four-bar linkage and a slider-crank mechanism and each student received a different data set. Authors developed a new survey instrument to use during this research. Survey was administered and 50 answers, out of 61 students registered for the course, giving the response rate of 82%, were received.

Analysis of results revealed that most of the students were enjoying activity (72%), trying hard (94%), feeling positive (68%), considering time spent to be beneficial (90%) and believing in instructor having best interest of students (74%). The response was also positive to interest generation and motivation towards the subject of the project; 82% and 78% positive responses, respectively.

Keywords—Active learning, problem-based learning, students' survey

1 Introduction

Even though today's classroom teaching adopts various techniques, the predominant methods of engineering education still follow traditional classroom teaching; the focus being mainly delivering to students the prescribed material. In such environment, even with full consideration for learning, the students are not the main centre of attention in the process. However, the demand of the modern world calls for a different approach which would directly address attributes required by engineering graduates. The answer to that challenge is the use of active learning pedagogies, including problem-based (PBL) and project-based learning (PjBL). Project-based learning has been originally used in professional training in medicine [1] but has been also historically used in engineering. Traditionally, project-based learning has been used in engineering programmes to, so called, final year project [2, 3], or in the American educational system, capstone design project [4, 5]. Whereas, problem-based learning concept has been the strategy for teaching design in many engineering programmes [6]. The application of

PBL in engineering education has developed a lot although is still not overwhelming [7].

The university courses should make sure that the engineering graduates acquire both technical and professional skills. One of the most important of those skills are problem solving and lifelong learning. The problem-based and project-based learning methods, applied in several courses in the curriculum, should provide such opportunity [8, 9, 10].

Active learning in engineering education becomes more popular in the recent years. Although, it is normally associated with design teaching [10, 11] a number of educators report on application into other engineering courses. The reports in this respect come from different parts of the world; Australia, Americas and Europe [9, 11, 12, 13, 14, 15, 16, 17].

Elements of problem-based and project-based learning were also used in mechanics and related courses. Some attempts were more related to computer-based techniques and integrating of software tools as a form of virtual environment [18] or case-based instruction [19]. However, most of such efforts used project-based learning, with some using only one project through the semester to cover all topics previously taught by traditional lecturing [20, 21]. Project-based learning was reported to be successfully used in design courses as that approach allowed for more hands-on, active-induced learning, where semester-long projects generated more enthusiasm and the desire to learn among the students [22]. An engineering mechanics course based on a term project, that also involved building the designed product development, was reported by Haik [23]. However, in some cases, students felt that using the lecturing method would allow for covering more material [19]. Also, in majority of cases, projects were used as an illustration of the material delivered in traditional way, however the amount of homework was reduced to accommodate PjBL [20, 21, 24].

The current work reports on an attempt to use problem-based learning in a BEng Mechanical Engineering programme. The 3-credit course on Mechanics of Machines, offered in Year 3 of a 5-year engineering programme, has been taught in a blended method with an element of a problem-based learning; the PBL element was an individual project on kinematics of planar linkages. The aim of the research was to investigate students' reaction to the PBL as a key element of the course. The questions pursued were students' response and perception to such learning environment. To that effect, a survey, requesting students' views on the application of problem-based learning in the course, was administered after the project submission.

2 Problem Based Learning Concept

Project-based learning and problem-based learning are widely regarded as successful and innovative methods for engineering education, which are also believed to be effective in primary and secondary education [25]. Although, there is not enough research or empirical data to declare that such methods are better alternative for education even at a primary or secondary level [26], there is a general consensus that they provide students with an opportunity to assume responsibility for their learning and to take advantage of more active learning patterns [27]. Active learning may provide the students with deeper and more complex comprehension of the learning topics than the traditional classes [28].

Problem-based (or inquiry-based) learning and project-based learning, have developed together as part of active and experiential learning. Experiential and hands-on learning has been applied in education for a long time, especially in medical and engineering education [29]. Laboratory investigations and field trips or industrial training have all been expected elements of engineering programmes curricula. Projects are long-standing tradition especially in American education. Such learning methods were confirmed by research in neuroscience and psychology, corroborating that thinking, doing, knowledge, and the context for learning were interrelated. Learners respond better if they actively use what they know to explore, negotiate, interpret, and create. They tend to construct solutions, shifting the emphasis toward the process of learning [27, 30].

Problem-based and project-based learning are closely related sharing some common features. However, they are not identical; PBL approach is driven by the problem and focuses on research and inquiry, whereas the PjBL main focus is on the end product [11]. Some argue that problem-based learning is broader, and that that project work (or project-based learning) is by definition PBL [30].

3 Problem Based Learning Model

The primary reason for problem-based learning is a need to adapt to a changing world. The contention is that students should endeavour in a learning centred environment [31].

PBL is an educational approach that uses problems as a starting point of enquiry, providing students with the motivation for the acquisition and integration of new knowledge [12]. It attempts to create a setting focused on a student, who attempts and solves tasks. Such approach gives context to learning, activates previous knowledge, and encourages reflection. The purpose of PBL is to foster students' ability to active learning, to think analytically and to attempt and resolve problems through a process that focuses on practical applications and team work. PBL presents a valuable and effective choice to replace conventional instruction concentrating education on students' learning instead of staff teaching [32].

There are typically certain features of the problem-based learning [25, 32, 33].

- **Student centred**-Stimulates student interests, creates an environment of self-directed learning to perform self-learning, conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem.
- **Process centred**-Emphasizes the ability of students to create problem-solving strategies, transfer of information, integration of previous knowledge and capacity to obtain and generate information.
- **Teaching through skills**-Emphasizes students' learning through problem solving, solution dependent on the attainment and comprehension of facts and the ability to think analytically.

- **Taking responsibility for learning**-Students taking obligations to be self-directed and self-regulated in their learning, taking responsibility for their own learning.
- **Collaboration**–Providing students with an opportunity to either collaborate or at least exchange ideas about the problem, to consider alternative strategies in a group setting.
- **Self and peer assessment**–Reinforcing self-reflective nature of learning and reflection on the knowledge gained.

4 Mechanics of Machines in BEng Programme at the University of Botswana

Depending on the level of entry, the B.Eng. programmes at the University of Botswana (UB), extend over 10 semesters for GECS entry or 8 semesters, for A-level or Ordinary Diploma qualifications [34]. For the 10-semester duration, the minimum required number of credits totals to 150, at approximately 15 per semester, 28 of which will be gained from general education (complementary study) or elective courses.

The Mechanics of Machines is a core course in Year 3 of BEng programme in Mechanical Engineering. It follows a general Dynamics course in Year 2, which is being taken by all engineering students in the faculty. The course has a value of 3 credits and is covered in one 15-week semester in 2.5 hours of lecture, 1 hour of tutorial and 1 hour of lab.

The course covers several topics such as balancing (both rotating and reciprocating masses), turning moment diagrams and flywheels, epicyclic gears, gyroscopic motion, general equation of motion for the machine and vibrations. The analysis of planar linkages, which is one of the topics in the syllabus of the course, has always been a challenge for the students. The syllabus prescribes the use of the traditional velocity and acceleration diagrams for kinematic analysis. The elements of relative motion, including simple velocity diagrams, are covered in the Dynamics course in Year 2. Hence, the emphasis in the course should be on acceleration diagrams. However, from few years of experience in teaching the course even simple velocity diagrams must be repeated. The particular problem for the students is the difficulty in visualizing the motion of mechanisms. Another challenge is to imagine the whole and complete solution and to draw conclusions even for relatively simple mechanism. The lab part of the course is designed to complement the lectures and tutorials with specific emphasis on understanding of the subject matter. However, even complementing the theory with practical does not always bring the expected results.

The problem encountered by students in the analysis of planar linkages has manifested itself both by poor performance, as noted by their grades, but also by staff observation confirmed by informal discussions with students. A change in the pedagogical approach was an important step in addressing the issue. A form of student-centric learning, such as problem-based learning, was sought as an instructional strategy which would encourage students to be engaged in their own learning. Such approach was thought to improve understanding, retention and transfer of knowledge better than traditional classroom teaching.

Initially, only velocity and acceleration diagrams, which fall under the semi-graphical methods, had been used in the course. However, it is a very time-consuming method relaying on scale drawing related to one specific configuration, and valid only for that position of the mechanism. A complete solution would thus require many up-to scale drawings. Gradually other methods, such as analytical method, based on the closed loop equation, and the use of software, have been introduced into the course. The analytical technique has the great advantage of giving a general solution. However, the amount of analysis and differentiation frequently required for apparently simple mechanisms may make the analytical method unfriendly. The application of software overcomes the issues of tediousness of both scale drawing and long analytical derivations and gives easy access to visualization. The students can see the motion of the whole mechanism, specific elements or points of mechanisms of different structure and configuration. The software application has also been used as a tool to attract students to the topic and a course. However, the disadvantage of the software is normally related to the fact that students tend to treat it as a 'black box', which provides the solution, although it is not sure how that solution is achieved.

5 Application of PBL

Delivery of the kinematic analysis of linkages was normally done in traditional way, using lectures to introduce and explain the topic, followed by tutorials to practice and master problem solving. The topic was typically covered in 3 weeks and was assessed by a test (a week load in the course included 2.5 hours of lecture, 1 hour of tutorial and 1 hour of lab used for application of software). Such approach was changed to request students to basically learn the topic by performing kinematic analysis of a particular linkage. The aim was to give students' a chance to learn in a different setting, the one which would inspire and engage them in engineering problem. The concept pursued was that the transfer of knowledge as well as knowledge retention would be better in an active learning environment.

The students were asked to complete a project on kinematic analysis, however the main objective of the project was not the final result (as in the project-based learning) but consolidating previously acquired and learning new knowledge. The attempt was to motivate students by asking them to solve a practical problem, which they could solve only by combining prior knowledge from a Dynamics course and to acquire new knowledge, by self-study. The report, to be submitted at the end of the project, was to address students' professional skills.

The type of mechanism was limited to a four-bar linkage and a slider-crank mechanism, although each student was issued with different data (Fig.1). The students were to use and compare the following three methods:

- Velocity and acceleration diagram
- Analytical method based on the closed loop equation
- Software (FOURBAR and SLIDER) provided with the Norton textbook [35].

Students were not lectured on the methods and were given only a very brief introduction about the software. They were to use the problem as the starting point to learn the theory on the kinematic analysis, perform the analysis, as an application, and to report on the results. The tasks were to be done individually, as each student had been assigned a different data.

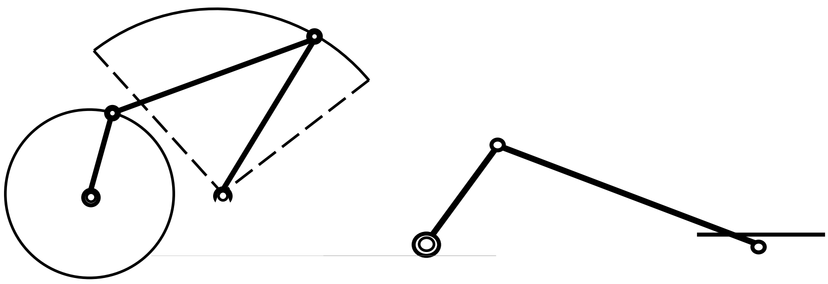


Fig. 1. Mechanisms considered in the project

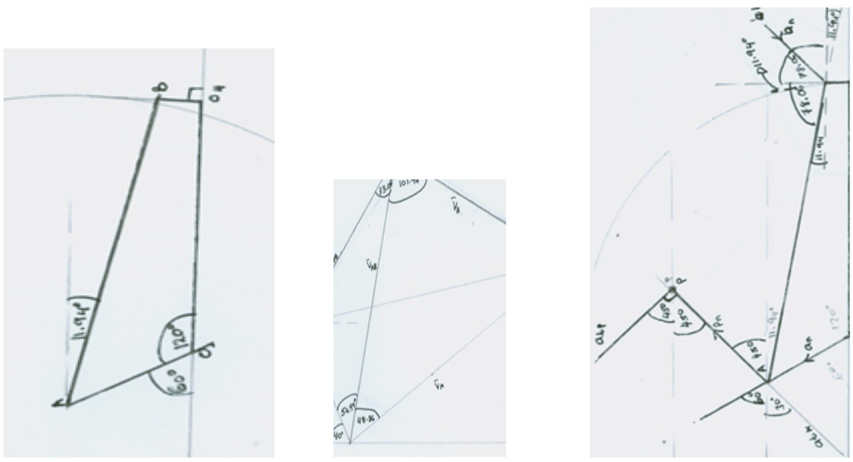
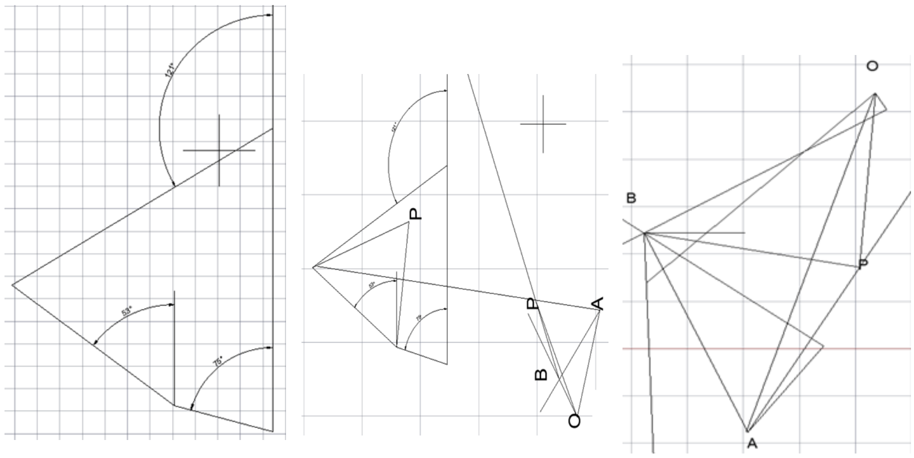


Fig. 2. Example of hand drawn kinematic analysis diagrams

Students were asked to perform full kinematic analysis, determining the position angles, velocity and acceleration of all joints and links, and additionally an arbitrary (although clearly specified) point on the coupler. The velocity and acceleration diagrams were to be drawn to scale, but only for one position of the crank. For the same position, the students were to determine kinematic values using an analytical method. However, they were required to derive equations for the velocities and accelerations, both linear and angular. The software was to be used for the full rotation of the crank, providing also visualisation of the motions.

Currently, there are several commercially marketed software that analyse the motion of mechanisms. Examples are Working Model, MSC and Roberts Animation. They are quicker than to construct a series of velocity and acceleration diagrams and they provide the same information on the kinematics of the analysed mechanism. They can also provide simulations to assist in visualising the motion of each part of the mechanism. After a few trials, a software accompanying Norton textbook (FOURBAR and SLIDER) was chosen as the most convenient for the use of the students. It is a flexible and easy to use program to analyse and animate simple planar mechanisms. Animation options enable velocity and acceleration vectors, instant centres and graphs of all selected parameters, and allows to print the results.



(a) Position (b) Velocity (c) Acceleration

Fig. 3. Example of CAD drawn kinematic analysis (diagrams)

Additionally, students were asked to calculate and comment on the velocity ratio, export the results obtained using the software into Excel and plot the results. The most important part of the report was to compare and comment on the results obtained using three methods. Finally, the professional report, to be submitted via Blackboard (virtual learning environment used at UB), was to be prepared as one electronic document (to include all figures, graphs etc.). Some students used CAD software to produce the position, velocity and acceleration diagrams, although it was not required, and the majority made hand drawings. Examples of those are shown in Figs. 2 and 3.

6 Survey Design

Voluntary, anonymise survey was administered electronically to students registered in the Mechanics of Machines course. All of the students were registered for undergraduate programme in mechanical engineering. Majority of students took the course for the first time, although there were 6 students who were retaking the course (failing previously). As the survey was anonymous it is not known whether any or all of those students responded to the survey. All students must have passed a Dynamics course, which was the pre-requisite for the Mechanics of Machines course.

The aim of the survey was to inquire about students' experience with the application of the PBL in the course. The focus was on the pedagogical aspect of the approach and not on the results or marks achieved for the project or in the course. The questionnaire, created mainly using Likert items, consisted of 16 questions asking students' opinion on the following themes.

6.1 Attitude towards learning by PBL:

- Interest generation,
- Students' responses to instruction
- Qualities gained

6.2 Ability and skills improvement:

- Critical thinking skills
- Self-directed skills
- IT skills as a tool for learning
- Communication skills

6.3 General experience with PBL.

One open-ended question seeking general opinion about the pedagogy was placed at the end of the questionnaire.

7 Results and Discussion

There were 50 answers, out of 61 students registered for the course, giving the response rate of 82%. The students responded to the survey after submitting the report on the project, however before receiving marks for their work.

Students had no previous knowledge or experience with problem-based learning (Table 1). They were also mostly not sure whether they actually participated in such activity, clearly indicating no previous conscious experience with such learning strategy.

Despite a novelty of the exercise, students enjoyed the activity (72%) and tried their hardest to perform well in the project (94%) – Table 1. It was expected that all students will be involved in communicating and exchanging ideas and concepts regarding the project with their classmates, however, extensive interaction was declared by only 68% of the students. Great majority of the students felt that the time spent on the project was beneficial (90%) and that the introduction of the project was in their best interest (74%), and mostly felt positive about the project (68%) – Table 1.

Table 1. Survey Questions and Answers

Question	Response Percentage		
	No	*Not Sure*	*Yes*
I know what Problem Based Learning is.	39%	30%	31%
I have participated in activities related to Problem Based Learning.	30%	50%	20%
I enjoyed the activity	4%	24%	72%
I tried my hardest to do a good job	2%	4%	94%
I talked extensively with classmates about the activity	10%	22%	68%
I felt positively towards project	4%	28%	68%
I felt the time used for the activity was beneficial	2%	8%	90%
I felt the instructor had my best interests in mind	0%	26%	74%
The use of PBL increased my interest in the subject	2%	16%	82%
I am more motivated to learn more about the subject	4%	18%	78%
The project was stimulating and important to my training as an engineer	0%	4%	96%
I can apply what I have learnt to new tasks and situations	2%	24%	74%
I felt that what I have learnt was personally relevant	4%	18%	78%
Is your PBL experience better than traditional education?	8%	40%	52%
I would recommend this form of teaching	2%	18%	80%

The students were presented with individual data for a particular linkage and were responsible for facing the problem and solving it. It appears that inspiration of being self-directed learner brought increased interest (82%) and bigger motivation to learn more about the subject (78%) – Table 1. That generation of interest for the subject was precisely the main intention of the exercise in the first place however, it was somewhat unexpected that almost three quarter (72%) of the respondents declared that they learnt details of the course better than in the traditional class. Though, that is actually one of the main arguments for the use of PBL.

Students had a high opinion on the assisting in their learning provided by the use of PBL (Fig. 4). Almost two third of the students (66%), indicated that they learned more than in a traditional class because they had to gather information on their own. However, there were also voices (20%) stating that they would have learnt more in the traditional teaching environment. Some indicated that since the students were confused about PBL they did not learn as much as it was possible (14%).

Collecting information and studying on their own was an inevitable element of the project. Most students (70%) expressed the opinion that barely one fifth (less than 20%) of the material required for the project was covered during formal teaching (Fig. 5). However, that assessment may have been obscured by the time the students devoted to the project, which may not necessarily require new knowledge. The course instructor opinion was that at least half of the elements of the project, both in terms of knowledge as well as skills, were covered in previous courses.

Students had skewed opinion on the overall position of the project in the course (Fig. 6). More than half of the students (54%), believed the more than 60% of the course time was devoted to the project. Unfortunately, they may have been reporting on their own time devoted to the project, in comparison to other topics. As such, kinematics of planar mechanism is only one of the topics under the heading of general plane motion of a rigid body and can be considered to constitute ca 10% of the whole course.

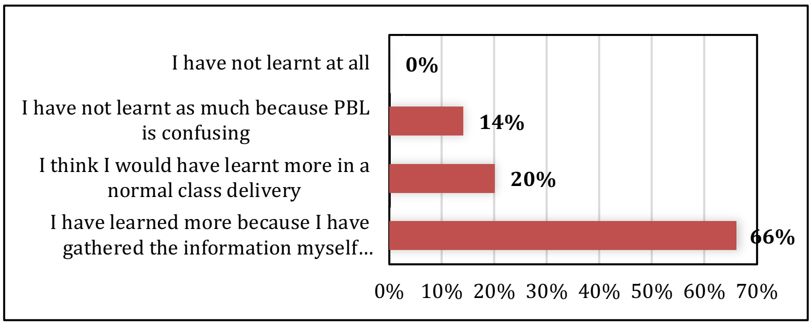


Fig. 4. Students' opinion on their learning using PBL.

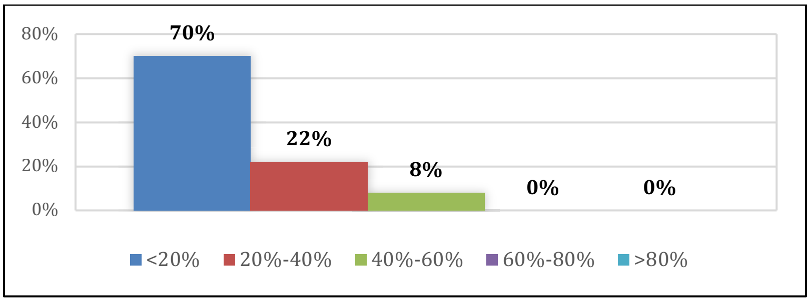


Fig. 5. Students perception of the amount of project material covered during formal classes

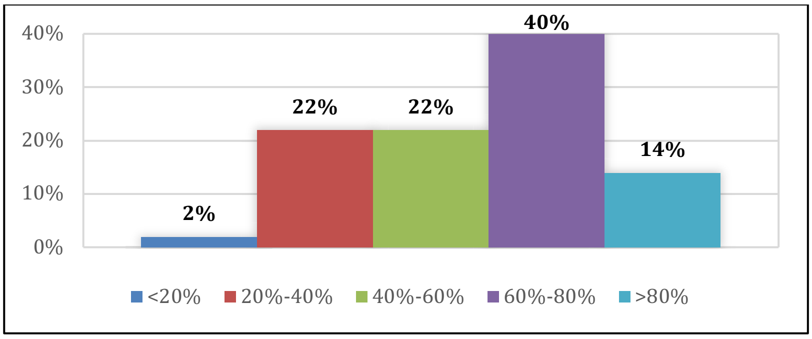


Fig. 6. Students perception of the overall course time devoted to the project

Students considered the whole exercise as a stimulating and important element of their engineering training (Table 1). They also judged that what they learnt in the project was personally relevant, and an experience which they could use in the future.

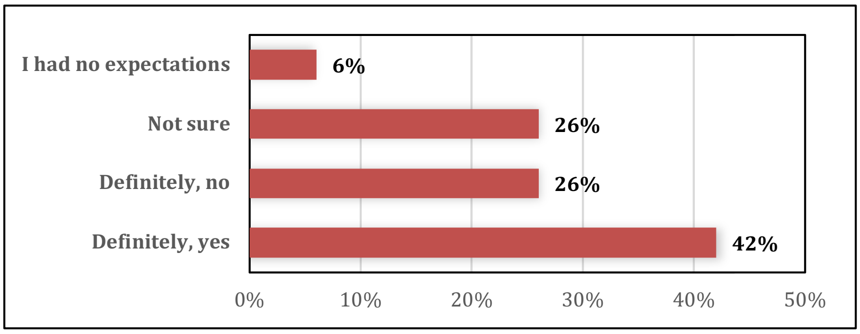


Fig. 7. Students' expectations on PBL.

One of the questions in the survey was asking directly whether PBL exercise achieved students' expectations (Fig. 7). Although 42% of students answered positively, there were 26% who gave categorically negative answer and 26% who were not sure. Expectations, which are not fulfilled or those which are not clear, may be related to the general lack of knowledge and experience of students in respect to project-based learning. An extended introduction to the project, including information regarding PBL may be a solution to that problem.

The open-ended question resulted with some typical comments like '*The project was very challenging*' or strange comments of the type '*Too much time given to it*', although there were also somewhat shrewder comments. Some of those were quite positive such as:

- 'It was great exposure and experience when problem solving.'
- 'The project is good and more practical exercise which leads student to thinking analytically and logical, when coming to solving engineering problems.'
- 'It gave the opportunity to find information completely on my own and were necessary discuss with friends.'
- 'It is a very crucial component which help in moulding and building practical, hands-on and analytical engineers. '
- 'With gathering information on my own for the project this helped to understand much better some concepts I did not understand in class.'

Those statements proved that students indeed valued the experience mainly due to the necessity to search and acquire information on their own. That realizes the main benefit of problem-based learning. That benefit, was also confirmed even in, what looked like, negative comments, such as:

- 'I would recommend rather traditional teaching as well. It was very hard to have to start teaching myself everything from scratch without any knowledge of what I was doing. It probably would have been a little more helpful to have covered a question or two in class, with at least some idea of what was supposed to be done.'

- 'It was a good experience, but it added a lot of work load to an already demanding course as we had to search for information and learn a lot on our own.'
- 'The project was time consuming and it was difficult for us to find the relevant information needed for the project. We had to spend a lot of time educating ourselves which was quite a challenge.'

Students' complains regarding searching for information and learning on their own should be also looked at from the perspective, that despite instructor's availability, easy access and readiness to help, out of 61 students only 2 took the opportunity to ask any questions related to the project. The easy possibility for out of class help by the instructor was confirmed by the Students Evaluation of Courses and teaching, performed at the end for the course, as the item '*available to assist students outside class hours*' was assessed at 4.17 out of 5.

Despite that students were not entirely certain about whether their PBL experience was better than traditional approach (52% positive with 48% negative or 'not sure' answers) the overwhelming majority (80%) would recommend this learning method (Table 1).

8 Conclusion

Problem Based Learning changes the educational emphasis from teaching to learning. The main goal of the learning is for students to acquire knowledge through attending to the problem; the ultimate focus is not the answer to the problem, but the process of attending to it. The process encompasses steps taking in thinking about the problem, discovery of topics to be explored and studied, developing of the plans etc. How the above description relates to the kinematics project introduced in the Mechanics of Machines course?

The project carried out was certainly student-centred. Also, the main purpose of the project was the process of learning and not the outcome. However, project was an individual work of each student, although they were advised and encouraged to discuss issues related to the project with classmates. Those discussions were declared by 68% of students and that was a somehow disappointing result, as such activity was strongly recommended.

Students responded well to the project in terms of their attitude, most enjoying activity (72%), trying hard (94%), feeling positive (68%), considering time spent to be beneficial (90%) and believing instructor having best interest of students in mind (74%). The response was also positive to interest generation and motivation towards the subject of the project; 82% and 78% positive responses, respectively.

Problem-Based Learning should be an attractive and efficient approach to acquire new knowledge. Students should use their own abilities and skills to present a feasible solution to a problem. The process of doing research on the problem, collecting data and information, and applying those, should provide them with deeper understanding and retention of knowledge. They should be more inspired and motivated to do that as they would attending to their own questions in the process of solving a problem.

The respondents to the survey were very positive about the learning new knowledge aspect of PBL. The majority declared learning more by gathering information themselves (66%) and that they learnt more details in comparison to the traditional lecture (72%). However, some of the students were either confused about PBL (14%) or who thought they would have learnt more in the traditionally delivered lectures (20%). The remedial action for the confusion about the approach should be to devote more time at the project initiation for the explanation of not only the technical problem but also the educational approach.

This experimental research shows that the project-based learning can be used as an effective method to acquire and comprehend new knowledge that requires the students to engage completely and utilize their own abilities and skills to do research, collect data and use information to present a feasible solution to a problem. It should help students in comprehension and retention new information. That follows the concept of active learning in which it is easier to remember own experiences, own research and in general, attending to own questions, not the ones imposed in a class.

The major limitation in the project introduced in the course was its individual base. It is a serious weakness as it did not provide students with the team-working skills, also restricting the communication and exchange of ideas with peers or resolving potential conflicts. The next step in the application of the PBL will be introduction of group projects, although with careful consideration with respect to the marking. Assessment in general, both, self and peer assessment, is another issue which must be addressed. In order to really assess 'process' rather than the final result, it may be necessary to introduce few assessments elements when the students are progressing with their projects.

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