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Problem-Based Learning and the Development of Key Skills in Foundation Mathematics

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Abstract: Problem-based learning (PBL) is a student-centered teaching and learning (T&L) approach capable of stimulating students' mathematics and related skills. The T&L of Mathematics has always been routine and lacked the capability to develop certain skills in learners. As a result, students learning Mathematics are unreceptive and unable to reason mathematically. No available data has yet reported on the impact of PBL in enhancing students' mathematical, problem solving, communication and teamwork skills, in any HE institution in the Arabian Gulf region. This study, therefore investigates and evaluates the impact of PBL in the effective T&L of Mathematics on Foundation students' skills at the Bahrain Polytechnic. The PBL instructional strategy adopted by the Polytechnic in 2013 has been systematically implemented across the curriculum in the various faculties. Its impact, although visible however, has not yet been empirically evaluated. Both qualitative and quantitative data on Foundation Mathematics students was obtained for the study; which included tutors' feedback from focused group meetings, data from questionnaire administered to students and a comparative data on traditional teaching strategy versus PBL-based instruction. Data was subjected to Descriptive statistical analysis and Wilcoxon's test, to ascertain the development of students' mathematical abilities and skills after implementing PBL teaching strategies in the Foundation Mathematics courses. Findings indicated that PBL impacted positively on students' mathematics related skills. Students demonstrated enhanced effective problem-solving skills, better mathematical communication skills, independent learning and stronger teamwork.

Keywords: Foundation Mathematics, Teaching Strategy, Problem-Based Learning, Key Skills

1. INTRODUCTION

The study of Mathematics helps to generate creativity by creating an enabling environment as well as learning flexibilities (Brunkalla, 2009). Mathematics plays a significant role in representing, communicating and predicting events (Padmavathy & Mareesh, 2013). Learning Mathematics therefore requires the learners to actively participate in constructing knowledge, and their grasp of the subject can lead to a more creative environment and improve the quality of teaching. The knowledge gained from learning Mathematics will guide learners to think about how to make changes for the betterment of society (Ali et al. 2011). Mathematics is applicable in many fields in the real world (Baki, et al. 2009); however, the learning of Mathematics tends to emphasize more on the procedural methods/approach rather than allowing the students to think mathematically. This therefore makes it difficult for the learners to connect mathematical concepts with the real world (Ginsburg & Amit, 2008; Macmath, Wallace, & Chi, 2009). In schools and colleges, students find courses in Mathematics difficult to grasp due to the lack of interesting teaching strategies and methodologies, average/poor quality of Mathematics teachers and limited Mathematics laboratories (Ali et al. 2010).

Furthermore, the traditional method of teaching and learning Mathematics (teacher-centered) has lead students to become passive; as, teachers act as information providers who place more emphasis on drilling the questions and rote learning than meaningful learning (Hatisaru & Küçükturan, 2009; Noor et al. 2011; Othman et al. 2010). However, the T&L of Mathematics should instead lay emphasis on student-centered approaches that require learners to construct their own knowledge and develop their ability to think mathematically in school. The student-centered approach is rooted in constructivism which support several learning approaches including problem-based learning (PBL) (Gürsul & Keser, 2009;

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Macmath et al., 2009). Students are required to construct their own strategies about associated mathematical ideas towards solving a problem. (Fatade, Mogari, & Arigbabu, 2014).

Since the inception of problem-based learning of mathematics, learners appear to have gained additional skills (such as problem-solving skills) which enables them to solve the problems/tasks assigned to them (Roh, 2003) by working in collaboration with other colleagues (Letchumanan, 2008). Even in these settings of working in groups, learners still need facilitators (teachers) to play significant roles in the learning of Mathematics.

Mathematics as an evolving science and an active subject that requires exploration. The role of teachers is to give students the opportunity to discover mathematics in an exploratory manner (Cazzola, 2008). Problem-based learning is the instructional approach that requires students to apply theory into practice, which will lead to the construction of knowledge and skills through an ill-structured problem (Savery, 2006). In a mathematics teaching environment, PBL focuses on problem-solving and conceptual understanding (Fatade, Mogari, & Arigbabu, 2013), unlike the conventional setting which emphasizes computational skills and the solving of problems without understanding the concepts. Since the PBL approach to T&L has been adopted as a practice in the school setting, a comprehensive investigation on the impact of learning mathematics on the development of skills, through problem-based learning in schools, is necessary.

2. METHODOLOGY

At the Polytechnic, three Mathematics courses are offered by the Mathematics Department in the School of Foundation. These include Mathematics 1, Mathematics 2 General (M2G) and Mathematics 2 Technical (M2T). Students who do not gain direct entry into their degree programmes of choice are mandated to take these Foundation Mathematics courses. Mathematics 1 is taken by students who demonstrated in the University's entry test that they lacked basic Mathematics skills. Students taking Mathematics 2 General are those who demonstrated that they have acquired some basic Mathematics skills to some extent and that by learning a few more additional skills in Mathematics, they may be able to pursue their chosen major Degree programmes of study, which include Logistics, Web Media, Web Design, Business, Accounting and similar degree programmes. Similarly, students who take the M2T course are those who equally demonstrated that they have acquired some basic Mathematics skills to some extent and that by learning a few more skills in Mathematics, they will be adequately prepared to pursue their chosen major Degree programmes of study, which include Information Technology and Engineering programmes.

Two sets of data, qualitative and quantitative, were collected. The qualitative data comprises of tutors' responses and feedback obtained from focused group discussions. These discussions were organized half-way during the period when students were engaged in their projects. During these discussions, we interviewed groups of 3 tutors who were teachers of Mathematics 2 General and Maths 2 Technical classes. The second set of data (also qualitative data) was obtained through survey by administering a questionnaire to students after they had completed their six-week PBL-based research project in Foundation Mathematics and submitted their reports.

One of the major segments of the Mathematics 2 General and Technical courses is to assign PBL-based Statistical/Mathematical projects to student groups of three and four (maximum). Examples of some of the topics assigned to the students include Engineering and ICT projects like:

a) Investigating the relationship between air conditioning unit sizes (in tons) to room volume size (in m^3) in Bahraini households.
b) Investigate the increase in electricity consumption in Bahraini households during summer compared to winter.
c) With so-many factors that determine the quality of an ISP, investigate which aspect is considered the most important in determining the effectiveness of an ISP

The projects last for 6 weeks after which students write a 17+ page report. The role of the tutor/lecturer during the project is to facilitate students' work since it is purely a PBL-based approach. The outline of final report submitted by the students is like the outline of a Thesis or Dissertation. It comprises: Introduction (Background /Literature Review), Materials and Methods, Data Presentation, Data Analysis, Results, Conclusions, Recommendations, and References (in APA style). On the last page of the report, students reflect (written) on the project they have done.

After students have undertaken the project/study and submitted their final reports, we conducted a survey by constructing and administering a questionnaire to the students in order to solicit their responses (quantitative data) for analysis on the impact of the PBL instruction strategy on their learning experience (development of key skills). The questionnaire was developed using Google Forms (an App in Google) that enables the construction of different varieties of questions including multiple choice, linear scale, check boxes and short answer questions. The timing of the survey was made to coincided with the period during which the PBL experience was still fresh in

learners' minds. The data obtained from the questionnaire that was administered was subjected to descriptive statistical analysis and Wilcoxon's tests to ascertain the development of students' mathematical abilities and skills after implementing the PBL teaching strategies in the Foundation Mathematics courses. The data analysis method used in this study is similar to that used in previously reported studies (Nur et al, 2010).

Quantitative data was also obtained by comparing data obtained from two groups of students' performances in assessments using statistical analysis. One group was instructed using the Traditional approach (tutor-based) and the other by using the PBL-based T&L strategy. Both groups of students, however, were instructed in the same Mathematics topics, after which they were assessed

3. RESULTS AND DISCUSSION

The findings from this study indicate clearly that PBL teaching strategy helps to develop key skills in learners. This is corroborated by other studies which reported that the introduction of PBL into a foundation programme can develop self-directed learning skills in students (Malan, Ndlovu & Engelbrecht, 2014), and has significant positive effects on students' meta-cognition (Rohani & Bayat, 2010) leading to the development of skills associated with self-monitoring (Williams, 2001; Loggerenberg-Hattingh, 2003).

Both the qualitative and the quantitative data that were obtained in this study and analysed. The qualitative data comprises tutors' feedback on the PBL process (through focused discussion groups) and students' responses to a questionnaire after engaging in a PBL-based process for 6 weeks. In the questionnaire, learners were asked to express their opinions based on their experiences while working on their PBL-based projects with their colleagues (in teams). The questionnaire was therefore structured along the lines of a Likert scale and was categorised into 3 sections by the authors. The questions in section 1 addressed the 5 main elements of the PBL process which included critical thinking, problem solving, collaboration, and other different modes of communication; while the questions in section 2 considered students' overall experience rating for the PBL process; while the section 3 questions were designed to solicit students' responses/reactions on the overall PBL teaching strategy.

A. Tutors' Feedback-Focused group:

Some of the key feedback/comments from the tutors during the focused group meetings indicated that the PBL T&L strategy encouraged students to become independent and effective learners. The T&L strategy also enabled students to be effectively engaged in the process of learning and reflecting. In addition, tutors found PBL T&L in Mathematics more effective than the traditional methods of teaching in agreement with reported findings (Roh, 2008; Malan, Ndlovu & Engelbrecht, 2014; Dunlap, 1997; Johnston & Tinning, 2001; Mierson, 1998), . While the strategy helped students in raising their levels of confidence in Mathematics and making the learning environment more competitive, in conformity with data published by Nur et al (2010), furthermore, it also enabled students to acquire more time to practice and to excel in the subject.

B. Students' Feedback-Questionnaire:

Section 1 of the questionnaire administered to the students consisted of 5 main elements that are related to the PBL process. The table (Table 1) below gives a summary of learners' response ratings to the elements in this section.

TABLE 1. SUMMARY OF LEARNERS' (STUDENTS') RESPONSE RATINGS TO THE ELEMENTS

Elements	Activity	Learners' responses
1	Initial meeting and tutorial	84% of students gave a positive affirmation
2	Independent study within PBL	85% of students gave a positive affirmation
3	Second meeting / tutorial	82% of students gave a positive affirmation
4	Roles within PBL	74% of learners gave a positive affirmation
5	Feedback within PBL	86% of students gave a positive affirmation

In section 2, learners gave their overall rating about the PBL process and 85% of students gave positive affirmation about it. The third section (section 3) which presented a summary of the general comments and feedback obtained from learners in reaction to their engagement in the entire PBL process and its impact on their learning. Learners indicated (in their own words) in response to the questions in this section that:

- PBL is a great way to learn, and that I do not need to always rely on the teacher
- The nature of the PBL process was such that I did not feel like I was studying Mathematics because the mathematical concepts were broken down to make it more comprehensible
- PBL projects are very good for the students to improve their computer skills among many other employability skills
- This is a new way of learning that I have encountered and what makes it special is that it is not boring and makes learning fun.

C. Challenges faced by tutors in the PBL process

Notwithstanding the perceived success of the implementation of PBL in T&L, however, the process involved some challenges, which included:

- Difficulty in designing PBL tasks that are relevant to the Mathematics topics;
- Challenge of ensuring consistency across the cohorts
- How to make the PBL process more engaging
- How to extend the implementation of the PBL process into other topics in Mathematics
- How to facilitate larger class sizes during the PBL process.

D. Quantitative Data Analysis:

This part of the study compares data obtained from two groups of students' performances. One group was instructed using the traditional approach (tutor-based) and the other by using the PBL-based T&L strategy. Both groups of students, however, were instructed in the same limited Mathematics topics, during and after which they were assessed. It is worth mentioning that each of these groups/class consisted of 15 students. For the purposes of categorisation, in each of the experimental classes, a set of 5 students were categorized as Strong-high level performing students; Average-middle level performers; and Weak-low level performers. The categorisation was based on both pre-performance test results and students' performance.

One of the advantages associated with the implementation of PBL-based instruction strategy here at the Polytechnic is the fact that there are smaller class sizes. Fortunately, the policies in place here at the Polytechnic enables a class size not to exceed 20.

Different assessment methods (such as written assessments and assignments) were used during the lessons in order to evaluate learners' acquisition of skills in three identified areas that include: (i) solving simple, direct and straight-forward mathematical problems

TABLE 2. SUMMARY OF RAW DATA

	Straight-forward		Application		Retainment		Overall Mark	
	PBL-based	Tutor-based	PBL-based	Tutor-based	PBL-based	Tutor-based	PBL-based	Tutor-based
Strong	98	100	89	85	80	80	98	100
	84	90	94	91	89	94	94	98
	77	99	95	75	86	83	86	94
	93	87	88	82	90	88	91	87
	100	85	90	80	92	89	89	93
Average	60	84	90	76	89	64	84	84
	60	84	90	76	89	64	84	84
	60	84	90	76	89	64	84	84
	60	84	90	76	89	64	84	84
	60	84	90	76	89	64	84	84
Weak	54	71	63	59	75	45	75	67
	63	79	68	66	73	43	73	58
	70	71	80	70	85	52	69	55
	66	83	81	58	74	35	75	78
	59	69	75	68	73	31	68	49
Variance	222.9	85.0	85.0	98.9	51.0	434.5	86.3	251.8

(Straight-forward), (ii) solving real-life application mathematical problems (Application); and (iii) retainment of knowledge (mathematical concepts), classified as Retainment.

Data from students' assessments results together with their overall grades (Table 2 above) were obtained and analysed using Wilcoxon's W test, to make comparisons between the two groups' (PBL-based teaching and non-PBL-based teaching methods) performances and to ascertain whether there are any significant differences.

E. Descriptive Statistics

Straight-forward problems category:

With reference to Table 3, it can be concluded that the test average marks of students who were subjected to the tutor-based teaching strategy was higher by approximately 5 marks in comparison with the students exposed to the PBL-based teaching strategy. Furthermore, the performance of the group of students who were instructed by the PBL-based approach deviated significantly from the mean, suggesting that students' performance between high, mid and low levels is inconsistent for straight-forward types of problems.

That is, students categorized as low ability levels performed poorly even when they were instructed through PBL T&L approaches.

TABLE 3. W TEST FOR 'STRAIGHT-FORWARD RESULTS'

	PBL-based	*Tutor-based*
Mean	77.2	84.6
Variance	222.8857	84.97143
Observations	15	15
W calculat	14.5	
W critical	15	

Real-life applications category:

In this category (Table 4, below), students who were tutored with the PBL-based T&L strategy outperformed those who were instructed using the tutor-based approach, by approximately 9 marks on average. This outcome was expected as the PBL approach places more emphasis on learning by doing and on exposure toproblems. With regards to results variance, both approaches seemed to obtain close stability results; suggesting that the different levels of students show consistency in their performances.

TABLE 4. W TEST FOR 'REAL-LIFE PROBLEMS RESULTS'

	PBL-based	*Tutor-based*
Mean	83.2	74.8
Variance	85.02857	98.88571
Observations	15	15
W calculated	8	
W critical	19	

Knowledge Retainment category:

Table 5 below illustrates that the test average mark for PBL-based instructed students was higher by approximately 15 marks in comparison with the tutor-based taught students. Furthermore, the PBL-based instructed students' performance was less deviated from the mean, suggesting that students' performance between high, mid and low ability levels was highly consistent for these types of problems. That is, students who are categorised as low abilities were capable of performing just as well as the other ability categories when instructed through PBL in this category. This gives an indication that the PBL approach provides a wider spectrum of collegial supportive environment, which enhances students' knowledge retainment and, therefore, students' life-long learning.

TABLE 5. W TEST FOR 'KNOWLEDGE RETAINMENT RESULTS'

	PBL-based	*Tutor-based*
Mean	81.6	66.33333
Variance	50.97142	434.5238
Observations	15	15
W calculated	10	
W critical	15	

Students' overall mark (Table 6):

Students tutored through PBL outperformed those who were instructed through the tutor-based approach by approximately 5 marks on average. With regards to the results variance, the tutor- taught students' performance was highly deviated from the mean, suggesting that students' overall performance between high, mid and low levels was inconsistent. That is, students categorized as low performers, overall performed poorly when they were taught through the tutor-based approach.

TABLE 6.W TEST FOR 'OVERALL MARK RESULTS'

	PBL-based	*Tutor-based*
Mean	82.86667	77.06667
Variance	86.26667	251.781
Observations	15	15
W calculated	18.5	
W critical	15	

4. CONCLUSION

The findings in this study indicated that the PBL T&L strategy adopted in Foundation Mathematics, significantly impacted learners at the Polytechnic. Students' feedback and comments obtained are testament to the fact that the T&L strategy is reshaping students' thinking (meta-cognition) and approach to learning, thereby enabling learners to acquire the targeted skills as well as to attain their academic goals.

Wilcoxon's W test was used in the quantitative data analysis as it is a non-parametric test applied at 5% level of confidence to compare between two groups' performances. The following conclusions can be drawn based on the analysed data by Wilcoxon's test results:

In the Straight-forward problems category, the W value was highly significant, suggesting that students' performance in solving straightforward problems is different between the teaching approaches. By looking at the mean, it can be concluded that students taught through the tutor-based T&L approach outperformed those who were instructed using the PBL-based strategy.

In the case of the Real-life applications category, the W value was also significant, suggesting that students' performances in solving real-life problems was different between the two T&L approaches. By looking at the mean, it can be concluded that students instructed using PBL outperformed those who were tutor taught.

With the knowledge retainment category, the W value was highly significant, suggesting that students' performance in retaining knowledge was different between the teaching approaches. By looking at the mean, it can be concluded that students who were taught through PBL highly outperformed those who were tutor instructed.

On the overall mark, the W value was insignificant. This suggests that the students' overall performance was not impacted irrespective of how they were instructed, whether through PBL or by their tutor in their Foundation program. This finding is highly positive, as it addresses the controversial claim that implementing the PBL approach at the Foundation level may disadvantage students coming in from a strictly tutor-based background in high school and may create a hard transition experience for them, as inferred (Malan, Ndlovu & Engelbrecht, 2014).

It is increasingly obvious from the data we have reported in this study that (since the inception of problem-based learning of mathematics) learners have gained additional skills in problem-solving, leadership, team work and many others which enables them to solve the problems/tasks assigned to them as confirmed by Roh, (2003) and Letchumanan (2008).

LIMITATIONS AND RECOMMENDATIONS

The results of this study are limited by time constraints and logistical challenges which did not allow authors to extend and expand the study to cover a larger student sample size. Lager experimental sample sizes may be considered in future studies to measure overall academic performances of learners. Further studies may be required to obtain quantitative data on the PBL teaching/Traditional teaching strategies that cover a wider scope (topics) in Foundation Mathematics and assessment data (including Geometry) whose concepts are very often challenging for students to grasp, in order to determine whether indeed PBL T&L strategies help to develop skills in learners.

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