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Effectiveness of Problem-Based Learning Approach to the Students' Problem Solving Performance

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Abstract - The Philippines' ranking in Trends in International Mathematics and Science Survey (TIMSS) is indicative of how mathematics is taught in the classrooms. This descriptive research determined the performance of 12 BSMT and 17 BSMarE freshmen students in solving general mathematics problems. They were preselected cadets who enrolled in a Maritime School in the Philippines first semester school year 2009-2010. Two sets of test instruments of similar context and style were used as pretest and posttest. The selected problems included routine or nonroutine and multistep problem and within the context and level of the students. Result shows a significant improvement in the performance of both BSMT and BSMarE students and as a whole at 0.05 alpha. Further, students developed various heuristics which includes Guess and Test, Working Backwards, Act it Out, Use of Diagram, Use of Algebra, Direct Counting, and Systematic List. Significant performance of students in the posttest is an indicator of the effectiveness of the problem-based learning (PBL) approach. Exposing them to various routine and non-routine problems enable students to apply mathematical concepts and understanding into real life problem situations. This makes mathematics more relevant which enhanced students' interest and level of performance in mathematics.

Keywords - TIMSS, math performance, heuristics, mathematics instruction, nonroutine problem, real life problem

INTRODUCTION

Singapore, being one of the top performers in the Third International Math and Science Survey (TIMSS) in 2003 claimed that mathematical problem solving (MPS) is at the centre of the framework of the mathematics curriculum in Singapore **(**Ministry of Education, 2000**).** On the same survey, the Philippines ranked 35th of the 40 countries that participated. The poor performance in mathematics is brought about by the kind of mathematics instruction currently followed in most of our mathematics curriculum (Tan, 2008). According to Limjap (2001), mathematics instruction in the Philippines is taught starting from teaching standard algorithms to develop arithmetic skills, followed by board work and seat work to develop mastery level. This is because many mathematics teachers in a typical classroom setting chooses to focus on the learning of fundamental mathematical concepts with limited time spent in exposing students to various nonroutine problems. Unfortunately, most of our mathematics curriculum in the Philippines is made with the development of these skills as its ultimate goal.

According to Schoenfeld (1992), mathematics instruction should provide students of the general concept of mathematics, its scope, power, uses and history. It should develop students' conceptual understanding and procedural understanding of mathematical concepts and processes rather than mere acquisition of mechanical skills. It should also provide students the opportunity to explore a broad range of problem situations and to apply various problem-solving heuristics in dealing with such problems. Moreover, it should develop students' analytical skills and ability to reason in extended chains of argument. Moreover, it should help students learn to present their analyses in clear and coherent arguments using the language of mathematics acceptable in the mathematics community.

With these goals in mind, school mathematics should engage students in problem solving and reasoning learning activities. [Mathematics] instruction should not be limited to plain mastery of algorithms or development of certain mathematical skills but should involve them into investigations that promote reflective thinking among students (Limjap, 2002).

Furthermore, Schoenfeld (2007) stresses that if teachers want to help their students become good problem solvers, then instruction in mathematics should be approached as a problem solving domain. This means that problem solving in mathematics classroom should not be taught as a separate topic but as an approach in the teaching and learning process.

John B. Lacson Colleges Foundation-Bacolod (JBLCF-B) is destined to pass Level III accreditation by the Philippine Association of Colleges and Universities Commission on Accreditation (PACUCOA). One of the criteria to be met is for the school to exhibit a reasonably high standard of instruction; that is, exposure of students to scientific problem-solving method is evident in classroom instruction (PACUCOA, 2005). To comply with the said requirement, the researcher experiment on the integration of problem-based learning (PBL) approached in a selected mathematics class for a possible improvement in students' mathematics performance.

In JBLCF-B, teachers make use of instructor's guide (IG) in teaching a course. Analysis of the IG for Math 11A/Math 1 plus revealed that mathematics is taught as a closed system characterized by "chalk-talk" instruction and board works. Problem solving is merely one of the topics being discussed towards the end of the course.

This study attempts to explore various common heuristics in dealing with the general mathematics problems, to determine the possible improvements in the students' performance in mathematics. The experiment employs problem-based learning (PBL) approach in a constructivist-inspired environment.

FRAMEWORK

A constructivist-inspired instruction employing problem-based learning (PBL) approach is a student-centered, experiential, context-specific and process-centered learning. This approach is inductive in nature and builds on prior learning of students (Brunner, 2007). It aims to develop critical and creative thinking skills of students, and to promote an active, interactive and cooperative type of learning (De Gallow, 2000). Students are allowed to logically think any possible solution through any possible representation and medium. The subject focus changes from facts and algorithms to process approached. This approach gives the teacher the opportunity to process the learning deeply rather than to identify and enumerate the contents, thus learning is leading towards higher order thinking.

Schoenfeld (1992) suggest that school mathematics should engage students in problem solving and reasoning learning activities. It should not be limited to plain mastery of algorithms or development of certain mathematical skills but should involve them into investigations that promote reflective thinking among students (Limjap, 2002). Teachers shall motivate their students to go beyond the study of rules, it makes mathematics more abstract. According to Michalewicz and Fogel (2004), there is a great deal to be gained from solving problems; and a great deal to be lost if students solved them poorly.

Generally, problems are categorized as routine and nonroutine problems. The types of word problems usually solved in a typical mathematics class are called routine problems. On the other hand, Green (2003) presented nonroutine problems as those whose solutions are not immediately obvious and the method of solving is not readily known.

Polya (1973) presented problem-solving process as a series of five stages. These stages are neither independent nor consecutive (Krulik and Rudnick, 1996). A person engaged in the problem-solving process moves back and forth, sometimes unconsciously with a goal for each stage. Contrary to the linear model for solving problem, Polya's problem-solving stages are dynamic and cyclic in nature that promotes his goal of teaching students to think (Wilson et al., 1993). The five stages include Read and Think, Explore and Plan, Select a Strategy, Find an Answer, and Reflect and Extend (Green, 2003; Krulik and Rudnick, 1996). In the Read and Think stage, problem is analyzed and critical thinking begins. Facts are examined and evaluated, physical setting is visualized, described and understood. Furthermore, problem is translated into students' language, relationships between problem parts are identified and the question asked is identified. In the Explore and Plan stage, given information are analyzed for completeness while irrelevant information are identified and eliminated. Data are organized in tabular or graphical form (drawings, models, graphs and the like), and a plan for finding the answer is developed. The Select a Strategy stage is considered by many as the most difficult part of the problem-solving process. Since there are many established heuristics (strategies and techniques), a good problem solver should be able to select appropriately one or a combination of available heuristics. The Find an Answer stage makes use of students' algorithmic skills. The use of calculator and other technology is made applicable at this stage. In Reflect and Extend stage, answers are checked for accuracy to determine if the question has been answered correctly. Creative thinking is maximized in this stage wherein variations to the original conditions can be applied to create new yet related problem situations (Krulik and Rudnick, 1996).

Krulik and Rudnick (1996) describe heuristics as more than just strategies and algorithms but are "road map" that directs an individual's path towards a solution and resolution of a problem situation. Unlike algorithms, heuristics are more general approach and cannot guarantee success. However, if students are taught these heuristics, they are in a good position to resolve problems successfully (Krulik and Rudnick, 1996). The common heuristics available include guess and check, make a systematic list, act it out, simplify the problem, look for pattern, working backwards, use of diagram or model, direct counting, use of an equation or algebra, and many more.

To synthesize the conceptual framework, a schematic diagram of the conceptual framework of the study is presented.

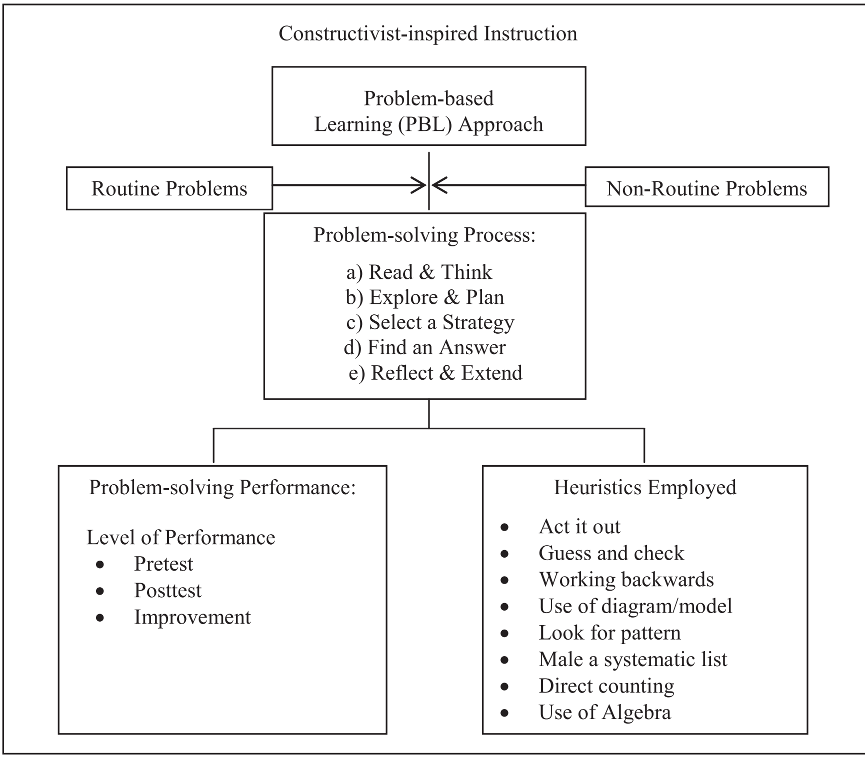


Figure 1. Schematic Diagram of the Study

Figure 1 above shows the schematic diagram of the conceptual framework of the study. Students were given the opportunity to engage in solving routine and nonroutine problems involving general mathematics problems within a constructivist-inspired instruction using PBL approach. The students' problem-solving process was evaluated in terms of problem-solving performance reflective of their level of conceptual and procedural understanding and the problem-solving heuristics employed.

OBJECTIVES OF THE STUDY

This study aimed to evaluate the students' level of problem-solving performance and heuristics employed by the freshmen BSMT and BSMarE Odfjell projects students during Math 1A/Math 1 Plus instruction using PBL approach.

Significance of the Study

This study may be significant to the following:

Curriculum Developers. The result of this study may be used as their basis for developing a curriculum that develops higher order thinking skills among the learners.

Teachers. This study may serve as a motivating factor and an awakening for teachers to explore further beyond traditional instruction, that is, to use different pedagogical approaches in teaching mathematics that are suited to the type of learners. It may encourage teachers to exert more efforts in teaching students the real mathematics.

Parents of the students. This study may serve as evidence to prove that educators are doing something to improve the learning capability of their children. Thus, their full support for the enhancement of their children is also expected.

Students. This study may serve as a benchmark in developing metacognitive skills among students and as an inspiration to perform well in mathematics as well as in other related discipline particularly in solving various problems.

Scope and Limitation

The purpose of this study was to evaluate the problem-solving process of the students in a constructivist-inspired instruction in Math 1A/Math Plus using Problem-based Learning (PBL) approach.

The participants of the study were the 12 freshman BS Marine Transportation and 17 BS Marine Engineering students of John B. Lacson Colleges Foundation–Bacolod under the NSA/Odfjell project enrolled during the first semester, school year 2009-2010.

The researcher-made evaluation instruments were the 5 routine and nonroutine problems for the pretest and similar 5 routine and nonroutine problems for the posttest.

MATERIALS AND METHODS

A descriptive research method using the quantitative-qualitative approach was employed. It aimed to evaluate the performance of the students in the problem-solving process and the heuristics they employed in solving general mathematics problems using Problem-based Learning (PBL) approach. Baseline information was gathered using the pretest. The participants were exposed to various mathematics problems during the course of study. A posttest was administered to measure the improvement made thereafter.

The participants of this study were the 12 freshman BS Marine Transportation (BSMT 1) and 17 BS Marine Engineering (BSMarE 1) students who were enrolled in Math 1A/Math 1 plus during the first semester of the school year 2009-2010. The group is under the NSA/ Odfjell cadetship project and underwent prior selection process from the company. The participants were considered small enough to consider the entire population. They were not informed about the study in order to avoid any biases or subjectivity as well as to maintain the normality on the performance of the class.

Two sets of test instruments of similar context and style as pretest and posttest were used. The pretest consisted of two (2) routine and three (3) nonroutine problems involving general topic in mathematics. The posttest consisted of two (2) routine problems by virtue of being repetitive from the pretest and three (3) nonroutine problems by virtue of its complexity.

The selected problems included in the test instruments should qualify as routine or nonroutine and multistep problem and within the context and level of the students in the maritime program as perceived by the researcher. These routine and non-routine problems were taken from The New Sourcebook for Teaching Reasoning and Problem Solving in Junior and Senior High School by Krulik and Rudnick (1996) and from the personal collection of problems developed by the researcher.

Students who answer each item has a minimum score of 1 point and a maximum score of 5 points. A perfect score of 25 points is awarded to students who answered all the problems excellently as describe in the rubrics for determining the performance in solving a general mathematics problem. A score of zero is given only if there was no attempt had been made to answer the problem. The 5-point scale is interpreted and described as follows:

Mean Score	Interpretation	Description
5	Excellent	• Uses common sense and knowledge in mathematics to identify relationship variables leading to a correct answer. Excellent representation of the problem situation.
4	Very Good	• Uses known formula to relate various elements of the problem situation leading to a correct answer. Very minimal item is missing.
3	Good	• Identifies basic information correctly. Represents the problem situation correctly. Some representation of the problem situation is missing leading to a wrong answer.
2	Fair	• Identifies given information correctly. Uses erroneous relationship among variables leading to a wrong answer.
1	Poor	• Minimal attempt has been made to answer the problem.

The mean score that determines the level of performance in solving general mathematics problem is distributed and interpreted as follows:

Mean Score	Interpretation	Description
21 – 25	Very High	• Wider range of knowledge and understanding of the mathematical concept and algorithmic skills
16 – 20	High	• Wide range of knowledge and understanding of the mathematical concept and algorithmic skills
11 – 15	Average	• Average knowledge and understanding of the mathematical concept and algorithmic skills
6 – 10	Low	• Limited knowledge and understanding of the mathematical concept and algorithmic skills

0 – 5	Very Low	• Very limited knowledge and understanding of the mathematical concept and poor algorithmic skills

Validity of the Research Instruments

The test instruments used were subjected to a content validation by three mathematics professors who are experts in the field of mathematics. The criteria developed by Good and Scates (1995) were used. The experts rated the test instruments with a mean rate of 4.03 interpreted as very good.

Data Gathering Procedure

The following procedures were followed when gathering data for this research study.

1. Researcher-made rubrics were developed based from various literature readings. The rubrics were submitted to the experts for critiquing.
2. The pretest and posttest consisting of routine and nonroutine problems were finalized. The instruments were subjected to content validity and readability test by three (3) subject experts from various schools.
3. A pretest consisting of two routine and three nonroutine problems was administered on day 1 of the regular class schedule.
4. Regular classes follows adopting the topics presented in the IG of Math 1A/ Math 1 plus. Additional topics on problem-solving processes, techniques, and heuristics were discussed. Students were exposed to various problems in general mathematics.
5. Students were normally grouped into two or three members in solving word problems on their seats. Quizzes and assignments were given as part of the formative process and for the purpose of giving grades.
6. The posttest was administered as part 2 of the regular final examination to ensure that the participants will perform their best in answering the problems.
7. Individual answers were scored and analyzed. All information were organized and synthesized and presented quantitatively to

answer the specific problems presented.

8. The problem solving heuristics manifested by the students was determined using a rubric for determining students' problem-solving heuristics.

Data Analysis

To establish objectivity in the analysis of the respondents' answers in the ten routine and nonroutine problems, the following rubrics and the corresponding statistical tools were used:

1. To determine the students' level of performance in solving general mathematics problem during pretest and posttest, mean was used. Mean is the most stable of the measures of central tendency. It is appropriately used when the data are categorized as ratio and if higher statistical treatment is further desired.
2. To determine the significant improvement on the performance of students in solving general mathematics problem in the posttest, paired sample t-test was used.
3. To determine the problem-solving heuristics students employed in solving routine and nonroutine general mathematics problems, a rubric for determining problem-solving heuristics adopted from Singapore's Primary Mathematics Syllabus available at http://sc-math.com/math/heuristics.php and frequency count was used.

RESULTS AND DISCUSSION

The level of students' performance in solving general mathematics problems during the pre-test when grouped according to BSMT, BSMarE and as a Whole are shown in table 1.

Table 1. Level of students' performance in solving general mathematics problems during the pre-test and posttest.

Respondents	N	Pre-Test		Posttest	
		Mean	Interpretation	Mean	Interpretation

BSMT	12	8.0	Low	21.8	Very High
BSMarE	17	10.1	Average	20.2	High
As a Whole	**29**	**9.2**	**Low**	**20.9**	**Very High**

Table 1 shows that the BSMT level of performance in the pretest is **low** as indicated by their mean score of **8.0**. Analysis of their pretest showed that 8 or 66.7% of the BSMT students had obtained a score of zero in at least 1 item because they left the item unanswered. Table1 also showed the BSMarE students level of performance in the pretest is **Average** as indicated by their mean score of **10.1**. Analysis of their pretest showed that 12 or 70.6% of the BSMarE students leave at least 1 item unanswered while 9 or 52.9% students have a level of performance of Average to Good.

Further, Table 1 shows the level of students' performance in the posttest with a mean score of **21.8** for the BSMT interpreted as **Very High**. Contrary to the pre-test, analysis of their posttest showed that 9 or 75.0% of the BSMT has a level of very high while none of them leaved any item unanswered. One cadet or 8.3% got the lowest score of 9 interpreted as Low while two others or 16.6% got a score of 16–20 interpreted as High and five of them or 41.5% got the highest level of performance as indicated by a perfect score of 25 points. Of the total BSMT group, 11 or 91.7% of them exhibited high to very high level of performance as indicated by their scores of 19 and above. Table 1 also showed the BSMarE students' level of performance in the posttest with a mean score of **20.2** interpreted as **High**. Analysis of their posttest showed that 8 or 47.1% of the BSMarE students had a very high level of performance and none of them left any item unanswered. The lowest score in the group was 15 interpreted as average and three of them or 17.6% got the highest level of performance as indicated by a perfect score of 25 points. Of the total BSMarE group, 16 or 94.1% of them got a high to a very high level of performance as indicated by their scores of 16 and above.

As a whole, the level of performance in the pretest is **Low** while the posttest performance is **Very High** as indicated by their pretest and posttest mean scores of **9.2** and **20.9** respectively.

The significant improvement on the level of performance of the students in solving general mathematics problems in the posttest as revealed by the result of paired-sample t-test is shown in table 2 below.

Table 2. Significant improvement on the level of performance in solving general mathematics problem on their posttest.

Program	Mean Improvement	df	t	p-value	Interpretation
BSMT	13.8	11	7.614	0.000	Significant @ 0.05 α level
BSMarE	10.2	16	12.493	0.000	Significant @ 0.05 α level
As a Whole	11.9	28	12.499	0.000	Significant @ 0.05 α level

Table 2 revealed that the performance of the students in solving word problems improved significantly in the posttest. This is due primarily on the intervention that is the use of problem-based learning approach in dealing with mathematics instruction during the duration of the course in Math 1A/Math 1 plus.

Statistically, table 2 showed that the mean improvement of the BSMT group is 13.8 greater than that of the BSMarE group which is 10.2. As a whole, the mean improvement of the participants' score in the posttest is 11.9. Paired sample t-test reveals that the improvement of participants' performance in solving general mathematics problems as indicated by their posttest scores are significant regardless of as groups or as a whole. This implies that exposing students to various word problems of real life situation significantly improve their performance in solving mathematics problem. Analysis on their posttest performance showed that none of the cadets neither BSMT nor BSMarE left any of the 5 problems unanswered. This is in contrary to their pretest performance. That simply shows how enthusiastic they are in taking time to analyze each of the problem situation in order to arrive at a correct answer. That attempt to solve a problem simply implies that during the 5-month period, the participants developed some level of belief in them that in some way or the other, they knew that they had the capacity to solve a problem.

Furthermore, independent sample t-test between the improvement of BSMT and BSMarE groups revealed a t-value 2.03 and a significant value of 0.052 interpreted as not significant at 0.05 alpha level. This means that the higher mean improvement of the BSMT students is not a strong evidence to claim that the BSMT students performed better in the posttest than the BSMarE students. This implies that there are BSMarE students who are as good as much as there are BSMT students. Inversely, there are BSMT students who are not so good in as much that there are BSMarE students who are quit slow. It just happened that in this particular group, there are more bright cadets in the BSMT than in the BSMarE, making their mean score higher as compared to that of the BSMarE group.

Table 3 below shows the list of heuristics employed by students in solving general mathematics problems during the posttest.

Table 3. Heuristics employed during the posttest.

B S M T		**B S Mar E**	
Heuristics	Frequency	Heuristics	Frequency
Use of Algebra	6	Use of Algebra	16
Guess & Check	8	Guess & Check	14
Use of Diagram	6	Use of Diagram	10
Systematic List	1	Systematic List	3
Act it Out	0	Act it Out	1
Direct Counting	6	Direct Counting	9
Working Backward	4	Working Backward	2
Assumption	1	Assumption	2

Table 3 showed that the Use of Algebra is the most frequently used heuristics. Nevertheless, they also made use of Guess and Check, Use of Diagram, and Direct Counting as the next frequent. Further, the BSMarE group used eight (8) kinds of heuristics while the BSMT group used seven (7) types of heuristics.

Figure 2 shows how cadet D7 made use of systematic list as a heuristic to come up with a scientific guess in solving the problem. He listed the possible combinations of 11, 15, and 12 to be able to conclude using the diagram that the sizes of the gates are 4 & 7, 7 & 8, and 8 & 4. The solution is logical and does not violate any mathematical concept, thus considered correct.

This problem can be solved using Algebra. Cadet E12 used the concept of systems of linear equations in solving the problem situation as shown in figure 3. He uses three equations in 3 unknowns A, B, C representing the lengths of the gates. Substitution method was further used to solve for the values of A = 7, B = 4, and C = 8. The answer satisfies the condition stated in the problem, thus the solution is logically correct. This simply shows that their knowledge of heuristics allows them to generate more than one way of solving a particular problem.

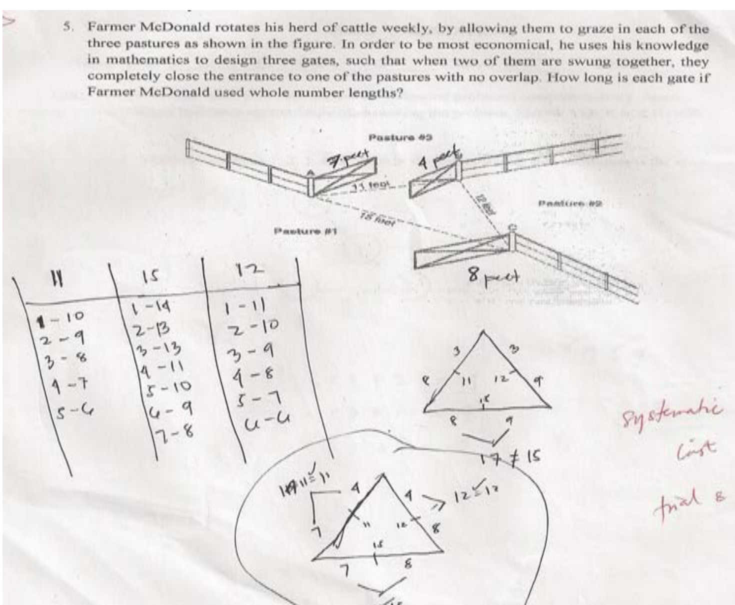


Figure 2. D7 solution of problem 5 using systematic list and guess & check.

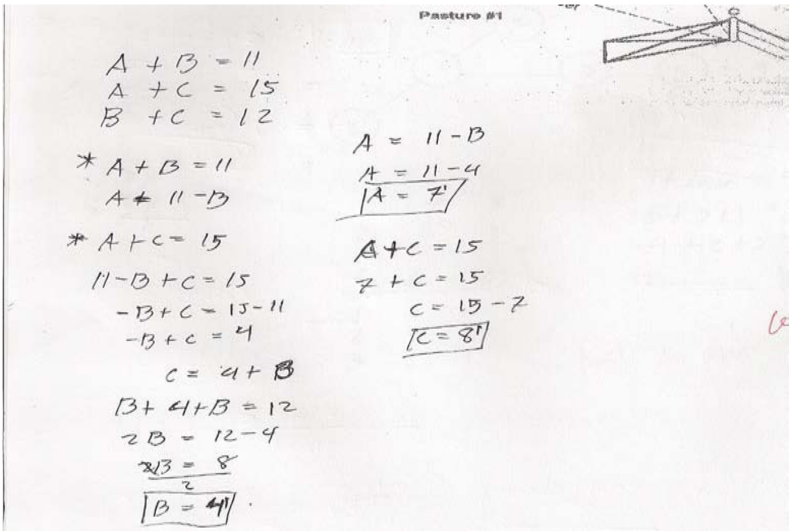
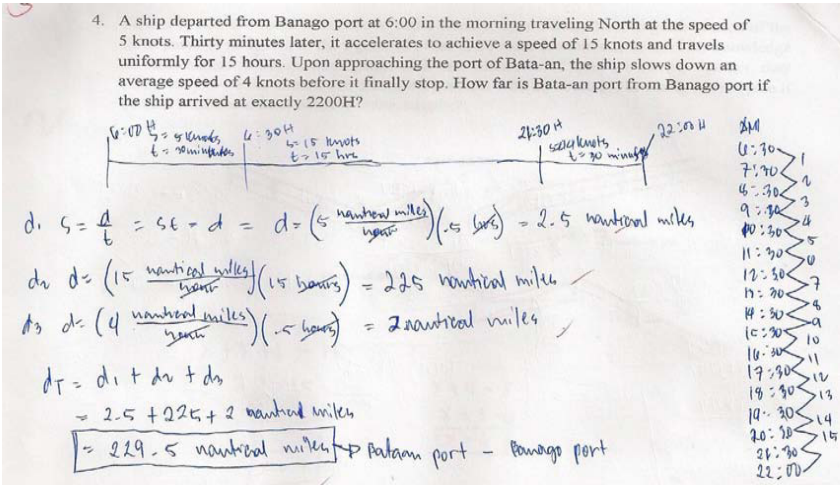


Figure 3. E12 solution of Problem 5 using Algebra.

Figure 4 illustrates the use of the diagram and direct counting as heuristics to answer problem 4. Cadet D4 used diagram to visualize a ship traveling as presented. In his diagram, he was able to emphasize that there are variations in speed at specified intervals. He used direct counting to determine the time element in the last lap. With some mathematical relationship among distance, speed, and time, cadet D4 was able to determine the distance traveled by the ship as being asked in the problem. The problem solution was short; this is because the diagram in itself is a solution as a product of his understanding of the problem situation. If indeed he made an erroneous diagram, chances are he ended with a wrong answer.


4. A ship departed from Banago port at 6:00 in the morning traveling North at the speed of 5 knots. Thirty minutes later, it accelerates to achieve a speed of 15 knots and travels uniformly for 15 hours. Upon approaching the port of Bata-an, the ship slows down an average speed of 4 knots before it finally stop. How far is Bata-an port from Banago port if the ship arrived at exactly 2200H?

d_1 $S = \frac{d}{t} = St = d$ $d = \left(5 \frac{\text{nautical miles}}{\text{hour}}\right)(.5 \text{ hrs}) = 2.5$ nautical miles

d_2 $d = \left(15 \frac{\text{nautical miles}}{\text{hour}}\right)(15 \text{ hours}) = 225$ nautical miles

d_3 $d = \left(4 \frac{\text{nautical miles}}{\text{hour}}\right)(.5 \text{ hours}) = 2$ nautical miles

$d_T = d_1 + d_2 + d_3$

$= 2.5 + 225 + 2$ nautical miles

$\boxed{= 229.5 \text{ nautical miles}}$ → Bataan port – Banago port

Figure 4. D4 solution of problem 4 using diagram and direct count as heuristics.

Figure 5 illustrates how cadet E14 uses guess and check commonly known as trial and error to answer problem 1 in the posttest. Guess and check is a useful heuristic to some problems that learners should be familiar of; or else using this heuristic will lead learners into an extraneous solution, a waste of time.

In his work, he made three trials, making the third one satisfies the given condition and concluded to be correct. This item actually is an indeterminate situation consisting of 3 equations with 6 unknowns. The learner should be creative enough to be able to determine the required numerical combinations. Trial & error is the most appropriate heuristic to be used. This item aims to develop the student's creative thinking skills.

CONCLUSIONS

The level of performance of the students in solving general mathematics problems regardless whether grouped by program or as a whole improved significantly in the posttest. This is an indicator of the effectiveness of the PBL approach in developing students'

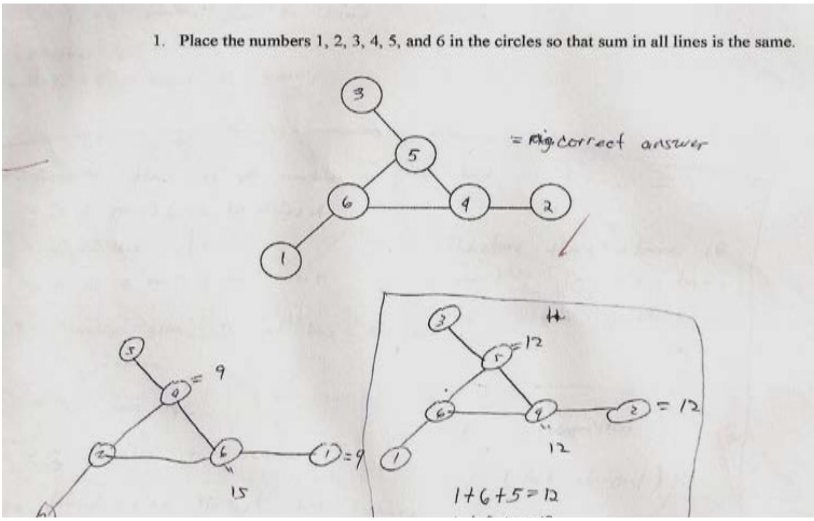


Figure 5. Cadet E14 solution of problem 1 using trial and error as heuristics.

skills in solving problems which is considered as the essence of mathematics instruction. Exposing students to various routine and non-routine problems enable students to apply mathematical concepts and understanding into real life situation making mathematics more relevant; thus enhanced their interest that makes them more eager to solve problems. During the past 5 months, they experienced difficulty in solving problems at the same time they also experienced the joy of triumph whenever they solve problems with competence and excellence.

Heuristics are new things for this group of students. They found it effective and practical in solving general mathematics problems. Students enjoy exploring and using heuristics to solve nonroutine problems. Familiarizing themselves with various heuristics makes them in a better position to answer problems (Krulik and Rudnick, 1996). They realized that there are many ways of attacking a particular problem such that when one approach fails there are a lot more others to try. Creative thinking was developed during the process. This is a manifestation of a development of higher order thinking skills (HOTS) that quality education aimed for to be developed among students.

RECOMMENDATION

The following recommendations were drawn based from the above-mentioned conclusion:

1. Contents in Math 1A/Math 1 plus should be revised to include exposure of students to various routine and non-routine problems in real life situation to make them appear more relevant and interesting.
2. Teaching students to solve problems is a difficult task. Thus, teachers should exert more effort to spend more time in teaching word problems among students. They should consider immersing themselves in experiencing the pain and joy in solving non-routine problems.
3. Teachers should be open-minded enough to allow students to explore various methods and use various heuristics in solving problems in mathematics.
4. A training program on Constructivist Philosophy and the use of problem-based learning approach (PBL) be designed and implemented among teachers to be initiated first by the mathematics and science teachers.

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