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Civil Engineering Students' Problem-Solving Skills on Calculus-Based Problems

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Abstract

The main goal of learning mathematics is to solve problems. In engineering, problem solving and mathematics are always together. The study investigated the civil engineering graduating students' mathematics problem-solving skills, specifically their level of solving skills, common errors, and strategies in solving mathematics problems. Thirty-six graduating civil engineering students taking the correlation course in a private school in Baguio City were the study's respondents. Results showed that the students have below satisfactory level of problem-solving skills. Although the level is low, students, in general, are able to understand the problem and represent it in a mathematical equation. Furthermore, most of the students' errors in solving the problems are attributed to the use of incomplete formulas, errors on signs, errors in differentiating equations, and other typographical errors. Common students' solving strategies involved remodeling, using a diagram, and using and deriving a formula. The study recommends programs to help students recall and practice mathematics concepts, especially calculus problems, such as retention programs, review classes, and other similar activities. If possible, students are encouraged to usea geometric representation or diagram when solving mathematical problems.

Introduction

Problem-solving is the main reason for learning mathematics. The importance of problem-solving in learning mathematics should be emphasized as it reflects how many concepts or principles the learneracquired. While it is true that learning theorems, postulates, axioms, and other theories are an important part of learning mathematics, still the main goal of learning the subject is to be able to solve problems (Halmos, 1980; Arslan & Altun, 2007; Calub, 1998). Researchers worldwide emphasized the importance of incorporating problem-solving into the mathematics curriculum. According to Clark (2008), as cited by Oryan (2015), since 1992, the Singapore Ministry of Education has put mathematics problem solving central to mathematics learning, making Singapore a top nation in Mathematics and Science.

In engineering, problem solving and mathematics always go together. Adams et al. (2010) and Houghton (2004) described problem-solving as "what engineers do". Pan et al. (2014) also described engineering students after graduation as problem solvers. Mohd-Yusof et al. (2014) identified problem-solving skills as one of the top priority attributes of an engineering graduate. He further stated that it is problematic if a student graduates with an engineering degree and can not solve simple problems.Thus, an engineering student should prioritize developing good problem-solving skills.

Developing future engineers as problem solvers will not be overnight; they learn problem-solving with time. As Calub (1998) stated that the skill to solve problems does not come naturally, and it must be practiced in simple situations if it is to be used in difficult ones. Before students can effectively solve real-world problems, they must first build engineering knowledge and develop skills to be used in applying knowledge, such as problem-solving and self-assessment (Felder et al., 2000). Thus, engineers must learn first how to approach and solve problems. The best place to start this development is at the classroom level. In the classroom, students simulate problems similar to actual work problems.

Creativity and critical thinking are two essential characteristics of a good problem solver. Ryan (1993) confers that higher-level mathematics requires higher-order thinking skills that will further develop students' critical thinking, creativity, and capabilities for independent study. Calculus is one of the higher-level mathematics that requires higher-order thinking skills, and that needs prior knowledge of other mathematics such as algebra and geometry. This subject is also considered the gateway to engineering, as it provides foundations fora higher level of science, mathematics, and engineering courses (Gainen & Willemsen, 1995).

Difficulties in the Calculus subject are evident during review for the civil engineering board exam as experienced and observed by the researcher. De Mello et al. (2002) described that due to difficulties in this subject, many stop studying engineering and make students believe that engineering is a difficult course and that you need to be good at mathematics. Baisley (2019) further emphasized that calculus is commonly the stopping point for most engineering students to switch majors or leave an institution altogether.

Difficulties in solving mathematics problems are not only evident in the field of engineering. It is widely reported that the Philippines has a poor performance in mathematics, as shown in the study of Trend in International Mathematics and Sciences (TIMSS, 2019). Trance (2013) also cited the report of the National Education Testing and Research Center of the Philippines that Filipino students have not reached mastery in Mathematics. Furthermore, Chegay (2018) reported that even with the introduction of the K-12 curriculum in basic education, the National Achievement Test (NAT) still shows poor performance of students in mathematics. In a study conducted by Pusayen (2016), her findings showed that grade 10 students lacked the skills in solving problems. Students have poor performance in solving geometric-related rates problems (Martin, 2000). Research shows that most of these problem-solving difficulties can be attributed to a deficiency in mathematics skills, mathematical problem solving, and lack of conceptual understanding (Nite et al., 2016; Gleason et al., 2010; Fowler et al., 2003).

Knowing the level of solving skills of the learners, the difficulties, and strategies used in solving mathematical problems can make educators more effective and efficient in teaching. For instance, if the teacher knows how good the students are at solving a particular problem, they can craft better problems that maximize students' full potential and deliver topics based on their level. On the contrary, if graduating civil engineering (CE) students have a low level of solving mathematical problems, the institution may provide an intervention program to improve their skills before letting them take the licensure exam. Since the nature of the degree program encourages a good level of problem-solving skills, knowledge of the level of problem-solving skills of graduating students may help curriculum developers craft a better Engineering curriculum. Educators can also re-evaluate their strategies in teaching their students.

This research aimed to determine the level of problem-solving skills, common errors, and strategies of graduating civil engineering students based on calculus-related problems.

Methodology

The study used a quantitative descriptive research design. The level of problem-solving skills in calculus problems, specifically on application problems related to civil engineering was obtained from a three-item test question. The researcher prepared 20 questions based on different books, articles, and previous research. These 20 questions were presented to 12 engineering faculty teaching in the college. The faculty were asked to rate which among the questions can satisfy the following criteria: 1) the test is a representative problem in calculus application problems; 2) the questions can evaluate the problem-solving skills of students; 3) the number of questions can be answered in an hour; 4) the best solution is through calculus; 5) requires knowledge on topics related to civil engineering; and 6) A board exam type question.

The initial evaluation stage was to verify if the question could satisfy criteria number 2. Each evaluator marks the question/s that are possible and can satisfy the criteria. Then the evaluator also selects the questions that can satisfy criteria numbers 1, 4, 5, and 6. Further, the evaluator organized the number of questions that he or she thinks can satisfy criteria number 3. After the evaluation, the researcher compiled three questions incorporating their feedback and recommendations. The selected questions were based on a calculus book (Ayres, 1987; Adams, 1983), an engineering board exam reviewer (Gillesania, 2012), and previous research. These questions were used as a basis for quantifying the level of problem-solving skills of students:

Water fills a tank in a shape of a right circular cone with a top radius of 3m and a depth of 4m. How much work be done (against gravity) to pump all the water out of the tank over the edge of the tank.

A 3-meter diameter long steel pipe has its upper end leaning against a vertical wall and the lower end on level ground. The lower end moves away at a constant rate of 2cm/sec. How fast is the upper end moving down in cm/sec when the lower end is 2m from the wall?

The cost of running a heavy truck at a constant velocity of v km/hr is estimated to be 4+ $v^2/200$ dollars per hour. To maximize the total cost of a journey of a hundred kilometers, what should be an approximated average velocity of the truck?

The study was conducted at a private university in Baguio City, and the study's respondents were 36 civil engineering students. The students were purposely selected based on the criteria that these students must be graduating and able to take the licensure examination in less than a year and a similar program (trimester program).

In the administration of problems, the students were informed that the data and other information to be collected would be used for research purposes only. Furthermore, the purpose and importance of the study were thoroughly explained before the student started to answer. The respondents were instructed to provide complete solutions for each problem. For the confidentiality of the data gathered, the researcher personally administered and checked the test. After checking the outputs, each solution was grouped based on the strategy used in solving the problem. Grouping was based on Krulik and Rudnick's (1996) eight strategies of problem-solving. Each type of solution was coded as solution 1, solution 2, solution 3, up to solution 8. The common errors committed during the solution were also carefully checked and tallied.

A rubric based on Rabacal (2013) was prepared to check solutions and answers; however, it was modified to fit the current research. The modification of the rubric can be seen on the column criteria, where an additional description was included (Table 1).

A t-test for one sample test was used to test the hypothesis that the students' Levels of Problem-Solving (LPS) are better than very satisfactory. Ranking was used to determine the common errors encountered by students in solving these problems and the most commonly used strategies in solving the problem.

The level of problem-solving skills was based on the percentage grade (PG) of the students on the given test. The PG was calculated by transmuting the values of the tentative score (TS) (Eq.1) using Appendix 1, and if the value is in between ranges,

Table 1

Rubrics in Checking Solutions

Solution Steps	Points	Criteria
Understanding the Problem (interpretation)	4	Completely understand the problem. The problem is well represented mathematically.
	3	Misinterpret part of a problem; although the misinterpretation is not critical, a correct answer can still be produced.
	2	Misinterpret the problem/misrepresent a major part of the problem. The misinterpretation will lead to an erroneous answer, although some interpretations are close to the problem.
	1	Completely misinterpret the problem
	0	No attempt
Solution of the problem (computation)	4	Correct solution. No errors in doing computations/calculations and no errors in the use of mathematical rules, formulas, etc.
	3	Substantially correct solution. Minor errors in computations/calculations and using mathematical rules, formulas, etc. Error is not detrimental to the answer.
	2	Partially correct solution but with a major fault. Mathematical rules, formulas, etc. were used inappropriately. The solution can lead to an erroneous answer.
Answering the problem (conclusion)	1	Inappropriate computations/calculation
	0	No solution
	2	Correct final answer
	1	Wrong answer
	0	No final answer

interpolation was used. The researcher constructed the PG descriptors based on the descriptors used by different institutions offering engineering courses in the country. Appendix 1 was taken from the software used by the College of Engineering in computing grades, and Table 2 shows the description of each grade into an equivalent level of problem-solving skills.

$$\text{[illegible]} = \frac{\text{[illegible]}}{\text{[illegible]}} \; \text{[illegible]} \; 100 \qquad \text{(Eq.1)}$$

Results and Discussion

Students' Level of Problem Solving

The mean score of students' level of problem solving (LPS) is 79.47, which is described as below satisfactory. This LPS shows that the majority of students can demonstrate sufficient solving skills in solving calculus-based problems; however, most of them cannot complete a correct problem solution. Further calculation revealed that the mean level of problem-solving skills is significantly different from the assumed and expected level of solving skills which is very satisfactory as indicated by the p-value, which is less than 0.01. The result is highly significant, as confirmed by the t-value of -4.82 (Appendix 2). This LPS is below the expected level of solving skills for a graduating engineering student. This

Table 2

Percentage Grade and Level of Problem-Solving (LPS)

PG	LPS	DESCRIPTION
96-100	Excellent	The student demonstrates mastery in solving calculus-based problems and can solve these problems with no errors.
93-95	Superior	The student demonstrates mastery in solving calculus-based problems. Almost all solutions and answers are correct; very few are incorrect.
90-92	Very Good	The student demonstrates mastery over solving calculus-based problems. Most answers and solutions are correct, with few incorrect answers.
87-89	Good	The student demonstrates adequate solving skills in solving calculus-based problems. The student can solve problems and show correct solutions with less than half incorrect answers.
84-86	Very Satisfactory	The student demonstrates adequate solving skills in solving calculus-based problems. The student can solve problems and show correct solutions. There are more incorrect answers than correct answers.
81-83	Satisfactory	The student demonstrates adequate solving skills in solving calculus-based problems. Combinations of wrong and correct answers and the majority of solutions are erroneous.
78-80	Below Satisfactory	The student demonstrates sufficient solving skills in solving calculus-based problems—few correct answers and solutions.
75-77	Fair	The student demonstrates sufficient solving skills in solving calculus-based problems—few to no correct answers and solutions.
74 and below	Poor	The student demonstrates very low solving skills in solving calculus-based problems. Solutions and answers are incorrect.

result corroborates the findings of Rabacal (2013) on mathematics majors,who concluded that the majority of mathematics majors are apprentice problem solvers, which is below the expected level of solving. Also, Barbado (2013) concluded that the mathematical proficiency of students along a different strand was predominantly below average.

Furthermore, 72.22% of students have lower LPS than the hypothesized mean, which is very satisfactory. This result indicates that the majority of students have errors in their answers or solutions. This result is similar to Trance (2013), as he highlighted that engineering students did not perform well in solving problems. However, Elger et al. (2003) have opposite findings where they concluded that present engineering science classes are producing students who are acceptable problem solvers.

The low LPS result may be affected by intervening variables such as preparation comprehension and topic retention. Preparation can influence students' performance. As Grigg (2012) pointed out, academic preparation influences how students solve problems. Accordingly, even an excellent problem solver will have difficulty solving a problem without preparation. Patena and Dinglasan (2013) also stated that students' study techniques affect students' performance in solving problems. Trance (2013) concluded in his research that one factor that affects engineering students in solving a problem in the Philippines is the comprehension of the problem. Furthermore, topics that were discussed years ago can be forgotten if not constantly recalled.The concepts related to these types of problems were introduced to them almost two years before the study; thus, a problem with topic retention can be a contributor to low performance.

Common Errors in Problem Solving

Further evaluation of the student solutions revealed that students have difficulty applying mathematical concepts. Almost 50% have problems applying mathematical concepts, rules, formulas, or theorems (Table 3). This result is evident in the mean score, which is 1.94. These problems include the use of incomplete or wrong formulas, errors on signs, problems in differentiating equations, using the wrong mathematical concepts, hastiness, and other typographical errors. These factors have a direct consequence on the solutions and final answer.

A solution (Figure 1) shows that the student forgot some basic mathematical concepts that could help solve the problem. In this case, Student A forgot the principles of algebra; the student substituted the equation of the cost as time (t) in the equation s=vt. Student B (Figure 2), on the same problem, started the solution with the wrong concept since the student started the solution by integrating the equation. However, it can be noted that the integration of the equation is still erroneous.

Student errors or problems in mathematical concepts such as algebra, differentiation, geometry, and others can be attributed to the fact that these students took their mathematics courses more than two years ago. In addition, some students forgot some basic mathematical formulas like the formula of a cone as shown in the solution of

Figure 1

Student A

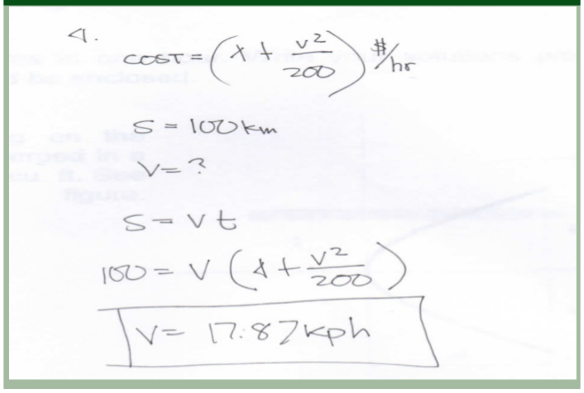


Figure 2

Student B

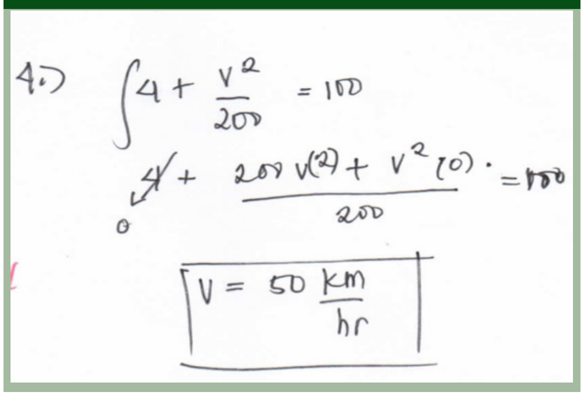


Table 3

Solution Scores

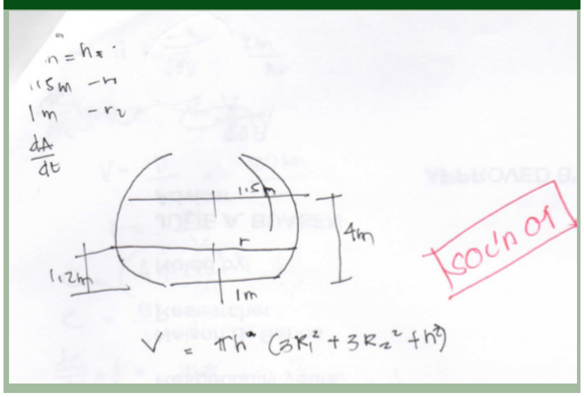
Solution Steps	Mean Scores	Descriptions	Percentage of students who were able to:
Understanding the Problem	3.07	Misinterpret part of a problem; the misinterpretation is not critical; the answer can still be produced.	76.35%
Solution of the problem	1.94	Partially correct solution but with a major fault; Mathematical rules, formulas, theorems, etc., were used inappropriately;the solution can lead to an erroneous answer	48.38%
Answering the problem	0.98	Did not produce an exact answer; answers were close to the correct answer.	49.07%

student C (Figure 3). The formula he is trying to write is a formula similar to a volume of a spherical segment, however, it is still incomplete. It can also be the case that the student forgot the difference between a sphere and a cone. Also, student D's solution started with a wrong value of B (Figure 4), although the solution is not complete this will still lead to an erroneous answer. This result supports the findings of Calub (1998) that previous knowledge of other mathematics such as geometry and algebra is related to student performance in solving mathematical problems.

Typographical errors are also common when solving mathematical problems. As shown in the solutions of student E, the solution shows an answer of -1.789, but when the student encircled the final answer, he missed an item, leading to a wrong answer (Figure 5). This error, especially when it happened at the beginning of the solution, cannot be discounted. Observation shows that these errors occur primarily due to the hastiness of students in finishing the problem.

Figure 3

Student C



Students' Strategies in Solving the Problems

Most students were able to formulate and transform the problem into a mathematical statement or equation. They were able to use calculus on the problems correctly. The majority of students' solution to the problem involves a diagram or model of the problem, then the use of a derived formula (direct substitution). Others derived the formula through differentiation by representing the problem in a basic mathematical equation. Also, many students reworded or simplified the problem before starting their solution.

Sixty-six (66) percent of students solve the problem using an illustration or drawing a diagram of the problem. In the solutions, it can be noted that almost 100% of students having a Very Good to Excellent tend to solve problems with the aid of an illustration or diagram of the problem. In contrast, only 59% of the students with Poor LPS started their solution using a diagram of the problem. This comparison can be seen in the solution between two students in Figures 6 and 7. Student G calculated the radius of the cone at 1.2m deep without a proper figure and resulted in a wrong value, as compared to student F. These types of solutions are also evident in other papers. This finding implies that creating a diagram when solving similar

Figure 4

Student D

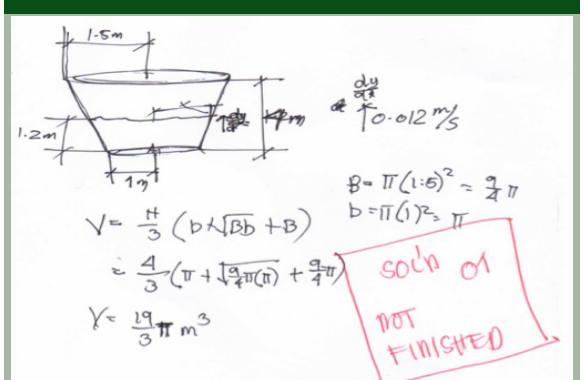
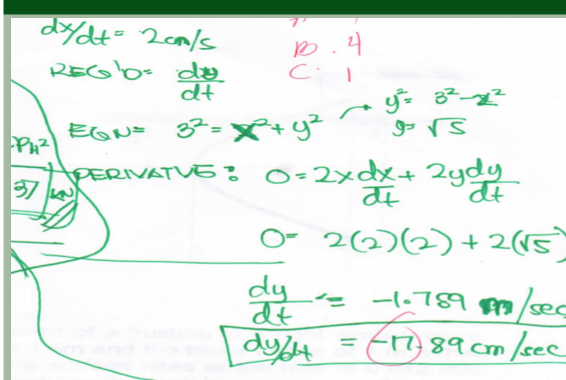


Figure 5

Student E



mathematics problems helps answer the problem correctly. This finding corroborates the conclusion of Maries and Singh (2016) that diagrammatic representations of problems are a superior strategy when solving problems. Likewise, almost 50% of students rewrite or remodel the problem to a form they better understand, then continue to complete the solution. Remodeling, rewording, or simplifying the problem includes transforming the problem into a drawing and labeling by isolating and arranging important points given in the problem or changing phrases into simple words. Remodeling or rewording the problem is also a popular strategy used by mathematics teachers in teaching word problems (Pusayen, 2016).

Figure 6

Student F

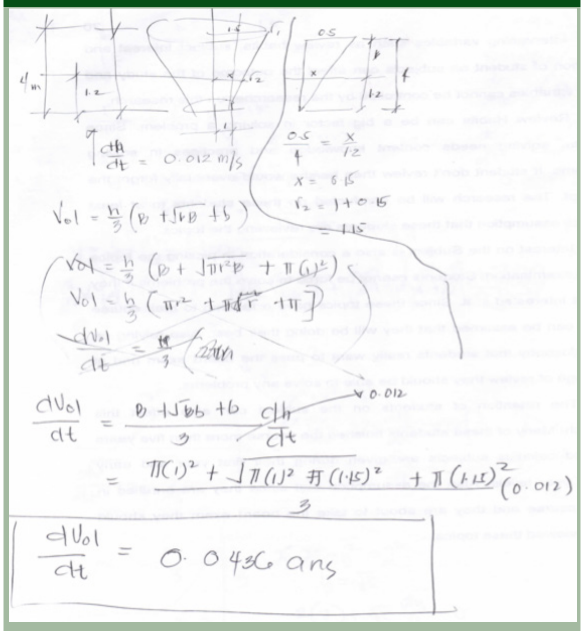
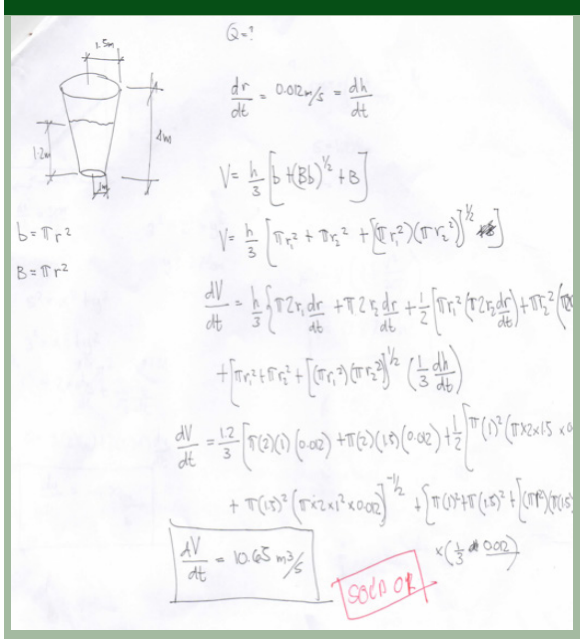


Figure 7

Student G



Conclusions

The student's level of problem-solving skills based on calculus problems is below satisfactory, and this LPS is low for a graduating engineering student. Although this LPS is low, the students can still demonstrate sufficient solving skills on these types of problems. Difficulties in solving calculus-based problems include the application of mathematical concepts such as algebra, geometry, and calculus. Typographic errors,even though considered minor,can lead to erroneous answers or solutions. Students solving strategies mostly involved remodeling, using a diagram, and using and deriving a formula. Furthermore, remodeling and using a diagram show a better impact on the solutions when solving these types of problems.

Recommendations

With the low LPS, the program provider is encouraged to revisit the curriculum, especially in the area of mathematics. Educators may look into interventions for the improvement of this skill, interventions such as review classes and other similar activities, especially before students take the licensure examination. It is also recommended that when solving these types of problems,the student is encouraged to represent the problem using appropriate illustrations or diagrams. Furthermore, to increase the chances of solving calculus-based problems correctly, it is suggested that students master the basic concepts of other fields of mathematics such as geometry and algebra and solve problems carefully to minimize typographical errors. Lastly, future research related to solving skills may be conducted by incorporating the other program areas, such as design. Also, a future study may be conducted considering other institutions.

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Appendices

Appendix 1

College of Engineering and Architecture (CEA) Transmutation Table

PG	TS		PG	TS	
70	0.00	12.00	85	76.67	78.34
71	12.00	24.00	86	78.34	80.00
72	24.00	36.00	87	80.00	81.67
73	36.00	48.00	88	81.67	83.33
74	48.00	60.00	89	83.33	85.00
75	60.00	61.67	90	85.00	86.67
76	61.67	63.34	91	86.67	88.33
77	63.34	65.01	92	88.33	90.00
78	65.01	66.67	93	90.00	91.68
79	66.67	68.34	94	91.68	93.34
80	68.34	70.00	95	93.34	95.01
81	70.00	71.67	96	95.01	96.68
82	71.67	73.34	97	96.68	98.34
83	73.34	75.00	98	98.34	100

Appendix 2

Level of Problem-Solving Skills of Students on Calculus Problem Results (CPR)

LPS	CPR	
	F	%
Excellent (96-100)	1	2.78
Superior (93-95)	0	0.00
Very Good (90-92)	2	5.56
Good (87- 89)	3	8.33
Very satisfactory (84-86)	4	11.11
Satisfactory (81-83)	6	16.67
Below satisfactory (78-80)	2	5.56
Fair (75-77)	5	13.89
Poor (74- below)	13	36.11
Mean	79.47	
t – value	-4.82**	
p – value	0.00	

*** - highly significant*