STRUCTURED PROBLEM SOLVING, MATH ABILITY AND PHYSICS PERFORMANCE OF ENGINEERING STUDENTS

Ester L. Forlales
1College of Engineering and Technology, Romblon State University, Philippines
tingforlales@yahoo.com

ABSTRACT
This study focused on the effect of structured problem solving approach and math ability (MA) in Physics performance of engineering students. It determined 1) Students’ Physics performance in pre-test and post-test; 2) Effect of students’ mathematical ability in Physics performance in pre-test and post-test; and 3) Interaction effect of teaching method and mathematical ability in students’ Physics performance in pre-test and post-test. Using quasi-experimental design with non-equivalent control group, four intact Physics classes were randomly assigned as experimental and control. Experimental group were 56 Agricultural Engineering and Civil Engineering students, and control group were 61 Electrical Engineering and Mechanical Engineering students. Both groups were given math proficiency test, pre-test and post-test in Physics. Results showed that structured problem solving approach significantly improved students’ Physics performance. Mathematical ability of students had significant effect on understanding physics such that high MA students performed better in problem solving than those with low MA. There was no interaction effect of teaching methods and mathematical ability on Physics performance. It really matters if structured problem solving is considered a fundamental approach in teaching Physics for better learning outcomes. Math ability should be given utmost consideration in Physics instruction.

Keywords: instructional approach, math ability, physics performance, structured problem solving

I. INTRODUCTION
Outcomes-based implementation of engineering and technology programs is one of the main thrusts of learning institutions in the local and global community. More strategic instructional processes were being introduced by education experts, but still there exists a big room for improvement especially in Physics and Mathematics among engineering students. According to [1], the state of science education in the Philippines lags behind other countries in the world. In the Second International Science Study and Third International Mathematics and Science Study, the Philippines ranked almost at the bottom of the list of 17 nations which took part in such large-scale evaluation of educational achievement. Part of the matter is the need for wide range of teaching strategy to address problem solving difficulties. In recent studies, [2], showed that students often contend with many difficulties during solving physics tasks at high school. To mitigate the problem, it is important to determine the cause of these difficulties. On the same concern [3], pointed out that academic problems of college students come in various forms such as difficulty in math subject, lack of motivation and study habits, strict teachers and failed major examinations. Identifying these problems along with their negative attitude towards the engineering program would provide better understanding of students’ situation and behavior in classrooms. Physics in particular was described by [4] as a discipline which requires learners to employ a variety of methods of understanding and to translate from one to the other- words, graphs, equations diagrams and maps. It requires the ability to use algebra and geometry and to go from the specific to general and back. This makes learning Physics particularly difficult for many students not only at present but even in the past. Reference [5] commented that one of the most serious impediments to teaching problem solving is the covert quality of the mental processes which are to be modified. By providing a standard format in presenting the problem solution, students are given a mechanism for describing their thinking that enables a teacher to get inside student’s head where the action really is.

Physics curriculum had similar aims with mathematics curriculum since both emphasize skills in decision making and problem solving. All mathematics skills has strong positive influence and strongly predictive value on
physics students’ performance in senior secondary schools [6]. As stressed by [7], Physics students who have
deficient skills in algebra achieved poorly on problem solving tasks in physics due to little knowledge of
mathematical skills needed, or students do not know how to apply the math skills they have to solve the problems
situation in physics. Although a wide conceptual difference exists between Physics and Mathematics, it is no
longer history that mathematical knowledge is needed to tackle numerical physics problems, leaving much to be
done in order to change students attitude in mathematics and science.

Problem solving, according to Altun, cited in [8], is “to know what to do when you don’t know what to do”. As
defined [8 p.1], problem solving is a cognitive process that requires the memory to select the appropriate
activities, employ them, and work systematically. As a process, Beichner, cited in [8 p.1], claimed that problem
solving was brought up by George Polya for the first time in his book “How to Solve It” published in 1945. In
same account, [9], claimed that Polya was the pioneer in the field of structured problem solving, who outlined a
four-step strategy in working with problem solution. The steps are description, planning, implementation, and
checking. In the first step, students list the given and desired information and draw a diagram of the situation. The
second step tells students to select the basic relation pertinent to solving the problem. The third step asks students
to execute the plan by doing the necessary calculations. The last step tells the student to check if the final answer
makes sense. Physics faculty of Romblon State University, Philippines contend that Polya’s strategy could be
effective in math and science classes and may possibly improve performance in science education in the country.

II. OBJECTIVES OF THE STUDY

This paper focused on the effect of using structured problem solving in teaching Physics and mathematical ability
in the performance of engineering students. It aimed to answer 1) Is there significant effect of using structured
problem solving approach in students’ Physics performance in the pre-test, post-test and gained score? 2) Is there
significant effect of mathematical ability (MA) on students’ performance in Physics in the pre-test, post-test and
 gained score? 3) Is there significant interaction effect between the methods of teaching and mathematical ability
on students’ performance in Physics in the pre-test, post-test and gained score?

Theoretical Framework

The study was based on David Ausubel’s learning paradigm called “Subsumption Theory” which emphasizes on
the influences of prior knowledge of subsequent learning; that the most important factor influencing learning is
what the learner already knows. Learning is determined by the organization of the learner’s prior knowledge that
allows facile incorporation of verbal and textual information [10]. The same theory views “cognitive structure” as
hierarchical set of concepts called subsumes to which new information can be associated during a meaningful
learning when the problem solver internalizes new elements, thus differentiating some concepts further and
forming new associations among subordinate concepts such as a hierarchical set of concepts in Figure 1.

Similarly, the theory of “cognitive process instruction” discussed by [9], is an approach to teaching which
emphasizes understanding, learning and reasoning skills as opposed to emphasizing rote memorization of factual
information. They developed a program called Explicitly Structured Physics Instruction (ESPI) to help students
organize their work, increase accuracy and confidence in problem solving. The most important element of ESPI
was the WISE strategy, the letters of which has unique details; W stands for “What’s happening” which asks the
student to list the knowns and unknowns of the problem, draw suitable diagram, and identify the basic principles
therein. Second letter I is for “Isolate the Unknown” to be done by selecting an equation and solving it
symbolically for the unknown, using the physical principles involved in the problem and to select other equations
if one is not sufficient. Third letter S is for “Substitute”, the student plugs in both the numbers and units into the
solved equation, and finally, letter E is for “Evaluation”, which tells the students to check the sign, units and
magnitude of the answer.
The study conceptualized that the effect of teaching methods on the performance of students in Physics may also depend on students’ mathematical ability. Structured problem solving approach explicitly taught to students can be an effective measure towards better outcomes. The WISE strategy of [9], was considered because of its specific features easy to understand. Two steps are very important in solving problem: identification of basic principles involved in the problem, and evaluation. It was premised that students’ math ability may influence the solution plan, speed and accuracy by which a physics problem is solved. Most engineering courses have math subjects like Algebra and Trigonometry as prerequisites of Physics. It was assumed that students who performed well in mathematics need little assistance in solving physics problems than those who are less inclined in Math. Based on mathematical proficiency test, high and low math ability students may be considered. The independent variable in the study (Figure 2) was Teaching Methods used with Mathematical Ability as antecedent variable while Physics Performance was the dependent variable.

Hypotheses formulated for the study
1. There is no significant effect of using structured problem solving on Physics performance in the pre-test, post-test and gained score.
2. There is no significant effect of student’s MA on Physics performance in the pre-test, post-test and gained score.
3. There is no significant interaction effect of methods of teaching and MA on Physics performance in the pre-test, post-test and gained score.

III. MATERIALS AND METHODS

On research design, quasi-experimental with non-equivalent control group was employed since four intact Physics classes of second year engineering students were utilized in the study [5], [11]-[13]. The experimental group (n=56) were Physics students from Bachelor of Science in Agricultural Engineering and Bachelor of Science in Civil Engineering, while the control group (n=61) were from Bachelor of Science in Electrical Engineering and Bachelor of Science in Mechanical Engineering. A 2x2 factorial design (Fig. 3) with two levels in each factor was followed [14] - [15]. Factor A for the teaching methods: either experimental with structured problem solving or control without structured problem solving. Factor B for the types of students based on mathematical ability: either high math ability or low math ability.
Subjects of the study

Four sections with a total of 117 engineering students enrolled in Physics 101 who had finished Algebra and Trigonometry were the subjects of the study. Two sections were randomly assigned as the control group while the other two were assigned as the experimental group.

Physics Achievement Test

This instrument was an 80-item test about Kinematics particularly horizontal motion, free fall and projectile made by the researcher to measure students’ performance in Physics. This was validated by Physics and Math experts of the college and refined accordingly. Said instrument were administered to students who were not subjects of the study to look into its reliability, after which final version of the test was printed.

Mathematical Proficiency Test

To determine the mathematical ability of the subjects, a 50-item test in Algebra and Trigonometry was made and submitted to math experts of the college for content validation. To ensure clarity of the instrument, this was administered to non-engineering students for further refinement, then the final version was administered to the subjects. Those who got scores of 26 and above were considered high math ability group and those who got 25 and below were considered low math ability group.

Data Gathering Procedures

Before the experimentation, pre-tests using Physics achievement and Math proficiency tests were given to the subjects [11], [15], to determine their physics performance and mathematical ability. The teacher then taught the subjects the lessons based on the approved course syllabus. The same teaching and learning activities in the lecture and laboratory were conducted for both groups. Also, enrichment activities and required outputs were the same; the only difference was in the teaching methods employed. In the control group, the students were taught in the conventional way; without structured problem solving. A concept was introduced and then problem solutions were discussed with applications in a variety of contexts. Students’ laboratory activities were conducted the conventional way as well. Students gathered data from the experiments performed and solved related problem exercises as required. In the experimental group, the teacher explicitly taught the structured problem solving approach by illustrating the steps of the WISE strategy. The steps were explained, problem solutions using the strategy were demonstrated and students were provided with ample time for practice. The students were required to use WISE strategy in solving all problems encountered in the exercises, assignments, and tests. After teaching the lessons, both groups were given the post-tests using the same instrument in the pre-test [11], [14], to determine their performances.

Statistical Analysis

To test the hypotheses, two-way analysis of variance (ANOVA) was used, the general technique for increasing the precision of any experimental design. It is the statistical tool for evaluating two or more factors affecting a dependent variable and how they interact with each other [14]- [16]. The dependent variable was Physics performance in terms of scores in post-test while the independent variables were the methods of teaching employed and mathematical ability of students. Also, ANOVA was employed for the gained score to determine the joint interaction effect of method of teaching and mathematical ability in student’s achievement. In all data analyses, the researcher compared results at 5% level of significance.

IV. RESULTS AND DISCUSSION

Performance of the Subjects in Math Proficiency Test
Out of 117 students who took the test (Table 1), 58 got scores of 26 and above who were considered the High Math Ability group; 30 were from the experimental group and 28 from the control. Fifty-nine students got scores of 25 and below who were considered the Low Math Ability group. A total of 56 students were considered for the experimental and 61 for the control.

**Performance of the Subjects in the Pre-test**

The experimental group obtained mean performance of 20.15 (Table 2) and 20.35 for the control group. The high MA group got 20.42 mean performance and the low MA group got 20.08. Results of ANOVA (Table 3) on methods of teaching was not significant (0.035 < 3.96) thus, the hypothesis “There is no significant effect of structured problem solving on Physics performance in the pre-test” was not rejected.

**Table I. Mathematical Proficiency Test Results**

<table>
<thead>
<tr>
<th>Math Ability (MA)</th>
<th>Methods of Teaching (MT)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Experimental</td>
<td>Control</td>
</tr>
<tr>
<td>High</td>
<td>30</td>
<td>28</td>
</tr>
<tr>
<td>Low</td>
<td>26</td>
<td>33</td>
</tr>
<tr>
<td>Total</td>
<td>56</td>
<td>61</td>
</tr>
</tbody>
</table>

**Table II. Physics Performance Results in the Pre-test**

<table>
<thead>
<tr>
<th>Math Ability (MA)</th>
<th>Methods of Teaching (MT)</th>
<th>Mean (MA)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Experimental</td>
<td>Control</td>
</tr>
<tr>
<td>High</td>
<td>21.08</td>
<td>19.75</td>
</tr>
<tr>
<td>Low</td>
<td>19.21</td>
<td>20.95</td>
</tr>
<tr>
<td>Mean (MT)</td>
<td>20.15</td>
<td>20.35</td>
</tr>
</tbody>
</table>

**Table III. Analysis of Variance for the Pre-test**

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BetweenColumns (MT)</td>
<td>1.04</td>
<td>1</td>
<td>1.04</td>
<td>0.035**</td>
<td>&lt; 3.96</td>
</tr>
<tr>
<td>Between rows (MA)</td>
<td>2.67</td>
<td>1</td>
<td>2.67</td>
<td>0.089**</td>
<td>&lt; 3.96</td>
</tr>
<tr>
<td>Interaction(MT x MA)</td>
<td>57.04</td>
<td>1</td>
<td>57.04</td>
<td>1.91**</td>
<td>&lt; 3.96</td>
</tr>
<tr>
<td>Within Groups (Error)</td>
<td>754.5</td>
<td>92</td>
<td>29.94</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2815</td>
<td>95</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note: ns – not statistically significant*

This implied that whatever teaching methods employed to the students before experimentation had no significant effect on their Physics performance in the pre-test.

Concerning mathematical ability, the difference was not significant based on the given criterion (0.089 < 3.96) therefore the hypothesis “There is no significant effect of mathematical ability (MA) on physics performance in the pre-test” was not rejected. This means that mathematical ability of the students before the start of the experimentation had no significant effect on their performance in the pre-test. Also, for the interaction effect, the result was not statistically significant (1.91< 3.96), therefore the hypothesis “There is no significant interaction effect of methods of teaching and math ability on Physics performance in the pre-test” was not rejected. It can be inferred that there was no significant combined effect of method of teaching and mathematical ability on the performance of the subjects in the pre-test. These ANOVA results in the pre-test allowed further investigation for the study [15].

For the post-test results, mean performance of 57.69 and 37.31 (Table 4) were obtained by experimental and control group respectively. High math ability students got a mean of 54.56 while low math ability got 40.44. Students under experimental group obtained higher scores than those in the control.

ANOVA (Table 5) showed significant difference (57.66 > 3.96) in the methods of teaching thus, the hypothesis “There is no significant effect of structured problem solving on Physics performance in the post-test” was rejected. This implied that the step-by-step procedure in structured problem solving technique described in the WISE strategy improved the students’ understanding of the problem items to come up with correct solutions [9]. Structured problem solving of the WISE strategy can help students organize their work, increase their accuracy...
and confidence in finding solutions to a given problem [9], and that providing a standard format in presenting the problem solution, students are given a mechanism for describing their thinking [5].

### Table IV. Physics Performance Results in the Post-test

<table>
<thead>
<tr>
<th>Math Ability (MA)</th>
<th>Methods of Teaching (MT)</th>
<th>Mean (MA)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Experimental</td>
<td>Control</td>
</tr>
<tr>
<td>High</td>
<td>66.54</td>
<td>42.58</td>
</tr>
<tr>
<td>Low</td>
<td>48.83</td>
<td>32.04</td>
</tr>
<tr>
<td>Mean (MT)</td>
<td>57.69</td>
<td>37.31</td>
</tr>
</tbody>
</table>

### Table V. Analysis of Variance for the Post-test

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BetweenColumns (MT)</td>
<td>9963</td>
<td>1</td>
<td>9963</td>
<td>57.66</td>
<td>&lt; 3.96</td>
</tr>
<tr>
<td>Between rows (MA)</td>
<td>4788</td>
<td>1</td>
<td>4788</td>
<td>27.71</td>
<td>&lt; 3.96</td>
</tr>
<tr>
<td>Interaction(MT x MA)</td>
<td>308</td>
<td>1</td>
<td>308</td>
<td>1.78</td>
<td>&gt; 3.96</td>
</tr>
<tr>
<td>Within Groups (Error)</td>
<td>15898</td>
<td>92</td>
<td>173</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>30958</td>
<td>95</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: ns – not statistically significant
* – Significant at 5% level

Also, it sustained the claim [5] that students who had acquired knowledge of particular physics problem in strategically organized form perform various recalls and problem solving tasks better than those who had acquired the same knowledge organized at a single level. Moreover, [17] revealed that there is a close link between identified difficulties in Physics and traditional teaching approaches.

On mathematical ability (Table 5), the difference between means of high MA and low MA students was statistically significant (27.71 > 3.96). This indicated that there was a significant effect of mathematical ability on students’ Physics performance therefore, the hypothesis “There is no significant effect of mathematical ability (MA) on Physics performance in the post-test” was rejected. This proved correct [7]; that students with high math ability performed better than those with low math ability simply because mathematical knowledge is required to tackle numerical problems in Physics. Also, this attested premise [6] that a student who is excellent in Mathematics is expected to be excellent in Physics as well.

For the interaction effect of methods of teaching and mathematical ability on Physics performance, the result was not significant (1.78 < 3.96) and therefore the hypothesis “There is no significant interaction effect of methods of teaching and math ability on Physics performance in the post-test” was not rejected. This implied that test scores of the students were not affected by the interaction of teaching methods and math ability of the students.

**Performance of the Students in the Gained Score**

Mean performance of 37.54 and 17.08 were obtained by the students in the experimental group and control group respectively. ANOVA revealed that the difference was statistically significant (Table 7); so the hypothesis “There is no significant effect of structured problem solving on Physics performance in the gained score” was rejected. This strengthened the result in the post-test and consequently sustained the inference that the use structured problem solving increased students’ performance in Physics.

Along with these findings, some of the many difficulties among students during solving physics problems identified in [2] and [3] may have been addressed by the step by step procedure of the WISE strategy used in the experiment creating better understanding of the problem solution.

Considering students’ mathematical ability (Table 6), high MA students obtained mean of 34.27 while low MA students got 20.35. The difference was significant (Table 7) based on the established criterion (24.0 > 3.96) thus, the rejection of hypothesis “There is no significant effect of mathematical ability (MA) on Physics performance in gained score”. It supported the result in the post-test which proved that there was a significant effect of mathematical ability on students’ Physics performance. Such result was attested by [6]; who claimed that Physics curriculum had similar aims with mathematics curriculum since both emphasize skills in decision making and
problem solving. All mathematics skills have a strong positive influence and strongly predictive value on physics students’ performance in Senior Secondary Schools.

The interaction effect of teaching methods and students’ mathematical ability on students’ performance showed no significant effect (0.455 < 3.96) therefore, the hypothesis

Table VI. Performance of Students in the Gained Score

<table>
<thead>
<tr>
<th>Math Ability (MA)</th>
<th>Methods of Teaching (MT)</th>
<th>Mean (MA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Experimental</td>
<td>45.46</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>23.08</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>34.27</td>
</tr>
<tr>
<td>Low</td>
<td>Experimental</td>
<td>29.62</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>11.08</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>20.35</td>
</tr>
<tr>
<td>Mean (MT)</td>
<td></td>
<td>37.54</td>
</tr>
<tr>
<td></td>
<td></td>
<td>17.08</td>
</tr>
</tbody>
</table>

Table VII. Analysis of Variance for the Gained score

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BetweenColumns (MT)</td>
<td>10045</td>
<td>1</td>
<td>10045</td>
<td>51.86</td>
<td>&lt; 3.96</td>
</tr>
<tr>
<td>Between rows (MA)</td>
<td>4648</td>
<td>1</td>
<td>4648</td>
<td>24.00*</td>
<td>&lt; 3.96</td>
</tr>
<tr>
<td>Interaction(MT x MA)</td>
<td>88.17</td>
<td>1</td>
<td>88.17</td>
<td>0.455ns</td>
<td>&gt; 3.96</td>
</tr>
<tr>
<td>Within Groups (Error)</td>
<td>17825</td>
<td>92</td>
<td>193.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>3261</td>
<td>95</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: ns – not statistically significant
* – Significant at 5% level

“There is no significant interaction effect of methods of teaching and math ability on Physics performance in the gained score” was not rejected. This means that the performance of the students in the gained score was not affected by the interaction of teaching methods and mathematical ability of the students, although both factors separately affected physics performance of the students.

Structured problem solving when used as integral teaching technique in Physics among engineering students would significantly improve performance in the subject. Students’ mathematical ability has a significant effect on Physics performance and it would be better therefore to look into students’ mathematical ability prior to admission in any engineering courses. Similar experiments maybe conducted for non-engineering students for comparison of results.

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