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Structured Problem-Solving Approach for Physics Word Problems

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Abstract: The paper is a part of a larger study which aims to design a sustainable enhancement course for non-Physics majors who are teaching Physics topics to junior high schools. The study sought to address the difficulty in solving Physics word problems of General Science pre-service teachers. First, a 30-item 4-tier multiple-choice test was used to determine their ability to perform the steps necessary to solve word problems. The effect of the structured problem-solving approach was then determined by comparing the solutions of the participants to word problems that were administered before and after the approach was taught. The findings indicate that the participants were unskilled at performing all the steps that were important in solving word problems. Also, the structured problem-solving approach, helped the participants became more conceptual problem solvers. However, follow up studies/sessions are necessary to establish this observation. Insights gained from the study by the researcher includes the value of asking the participants to provide an example and a non-example of the concepts, using small grouping for concept mapping activities; conducting the sessions during the day; and increasing the time allotted for the sessions.

Key Words: Structured Problem Solving; Physics word problems; Action Research; K-12 Spiraling Curriculum

1. INTRODUCTION

1.1 Purpose and rationale

Physics is considered as a problematic field among researchers and science educators. Although perceived as useful and essential for progress, Physics is often the least preferred Science subject among students. In these studies, one of the factors affecting students' decision of pursuing Physics-related fields is their attitude towards Physics. Their attitude, in turn, is affected by their experience in the subject and their teachers.

According to Hattie (2003) and other researchers, teachers are the most important school-related factor affecting students' academic performance. Moreover, studies have shown that their influence persists up to three years after their students leave their class. These studies also indicate a cumulative effect on students' academic performance as students who were taught by high-quality teachers for a successive number of years perform better than those who did not have the same experience.

In today's classroom, where constructivist approaches are espoused to provide more meaningful learning experiences to students, teachers must become effective facilitators of learning. For this to happen, teachers must have a deep understanding of the subjects that they teach (Etkina, 2018). Teachers who have a good command of the subject matter can have a richer repertoire of resources such as examples/analogies and strategies/techniques that they can use in their class. Moreover, since pedagogical content knowledge (PCK) is subject-specific, content-competent teachers are better at assessing and addressing students' misconceptions and difficulties. Content knowledge is also believed to be related to teaching self-efficacy belief (Mojavezi & Tamiz, 2012), which has been shown to impact learner positively.

In the Philippines were Science was taught using the disciplinal approach for decades, many of the current in-service teachers have been trained (or were encouraged to) to specialize in either Biology, Chemistry, or Physics. Now that the spiraling approach is implemented in the junior high school (JHS) Science curriculum, these teachers must teach topics that are traditionally considered as outside their fields of specialization. As such, there is an apparent institutionalization of out-of-field teaching among JHS Science teachers. As expected, the Department of Education (DepEd) is trying to address this mismatch by conducting professional development programs. However, with limited resources, it is necessary to identify what aspect of professional training requires the most attention.

Before the conduct of this study, the authors conducted (and reported elsewhere) a survey to high school students and JHS Science teachers who are non-Physics majors. The survey identified solving Physics word problems as the activity/skill that most students and teachers find most challenging to master. This finding is not surprising since various authors have tried to address multiple aspects of this problem over the years (Icne, 2018).

Despite being especially tricky for students Icne (2018) points out that problem-solving is one of the most important 21st-century skills that students need to learn. Gagne in (Susiana, 2010) believes that the primary objective of education is to teach students to think, use their intellectual skills, and become problem solvers. In Physics, problem-solving plays a central role in instruction as it serves as the goal, the means of achieving the goal, and as an assessment tool (Gaigher, Rogan, & Braun, 2007). As expected, students' problem-solving skills are influenced by the teachers' teaching ability. It is for this reason that this study focuses on problem-solving.

According to Gunduz and Corlu (2015), problem-solving requires a series of operations or steps that are accomplished through specific rules. Its success depends on reasoning processes that are executed correctly. In the context of Physics word problems, the reasoning process is guided by the problem solver's existing schema and knowledge structure that are related to the Physics concepts. On the other hand, the execution of the reasoning process is often influenced by the problem solver's adeptness in Math. Studies that compare expert and novice problem solvers reveal that although there are major differences in the way they solve problems, these distinctions can be blurred as novice problem solvers can behave like experts in certain situations (Leak et al., 2017). These distinctions include the following: (1) expert problem solvers tend to have a more hierarchical knowledge structure and that they are better at accessing the information that they need to solve problems; (2) expert problem solvers tend to plan better without relying on equations using the "knowledge-development" approach whereas novice tend to use the "means-end" approach relying heavily on equations; (3) experts also tend to invest in visualizing the problem while novice tend to focus on solving the problem (Ince, 2018). Finally, studies have linked metacognition and divergent thinking to success in problem-solving.

Structured problem solving is one of the approaches that can be used to help learners solve word problems. This approach is anchored on Greeno's Model for Scientific Problem Solving. Greeno believes that there are four domains of knowledge (concrete, models, abstract, and symbolic) each with two layers (layer ***a*** for parts and layer ***b*** for whole) (Gaigher, Rogan, & Braun, 2007). Proponents of the structured problem approach assert that the approach promotes conceptual learning compared to the more popular formula-based approach to problem-solving because it encourages more translations between the knowledge domains. Moreover, it encourages learners to visualize the problem; to identify the principles for solving the problem, and to assess their answer. The process for solving problems using the approach follows these steps:

1. Diagram construction
2. Identification and labeling of information
3. Identification of unknown quantities
4. Problem analysis via Physics principles
5. Expressing variable relationships
6. Substitution and solution
7. Interpretation of numerical answers

This paper describes the pilot training implementation that introduces (modified) structured problem-solving approach to a class of graduating General Science (GenSci) students. The goals of the pilot implementation are to determine the (1) effect of the approach on the problem-solving performance of the participants and (2) areas of the training that requires improvement. The findings of this study will be used to inform the design of a Physics Enhancement Course for junior high school Science teachers who are non-Physics majors.

1.2 Context

The study is conducted among GenSci graduating students who are undergoing their practice teaching (on-the-job training) in different private and public schools in the community. These students were purposely selected to become the participants in the pilot implementation for two reasons. First, like the target participants of the Physics Enhancement Course, their exposure to Physics topics have been limited and it has been at least 3 years since their last exposure to Physics topics. Secondly, while the target participants are adjusting to their new roles as Physics teachers, these GenSci students are still adjusting to their roles as teachers. Although it is desirable to have in-service teachers to become participants in the pilot training, the schedule makes it impossible since the pilot training was conducted towards the end of the school year when teachers are busiest. Moreover, even if teachers are interested to attend the training, administrators would rarely (if ever) allow class interruptions during this month.

The primary author served as the facilitator of the training under the guidance of the second author. Experienced high school teachers (2 Physics majors and 1 Chemistry major) were invited to observe the pilot training. The students' cooperating teachers assisted in arranging the schedule of the participants so that they could attend the training. The participants were treated as adult learners and were informed about the objectives, the schedule, and their role in the study. It was also made clear to them that their personal information will not be disclosed and that they have the right to withdraw from the study anytime that they wish to.

2. METHODOLOGY

The training was scheduled for three 2-hour sessions after the participants' practice class schedules. Two weeks before the actual sessions, the participants were enrolled in an online classroom where learning materials were posted for them to study. The students were then instructed (via their cooperating teachers) to review the learning materials.

During the first session, the students took a 30-item 4-tiered multiple-choice test. The items in the test were constructed based on the steps of solving word problems (diagram construction, identification of relevant Physics principles, writing mathematical statements, and evaluating the answer). The topics that were included in the test (projectile motion, work, power, conservation of mechanical energy, and momentum) were based on the findings of another survey that was reported by the authors on another paper. The survey identified Physics topics that high school students and Science teachers (non-Physics majors) considered difficult to understand and teach. The topics in the test were mechanics topics that are supposed to be learned by Grade 9 students.

For each item of the 4-tiered multiple-choice test, the students had to support their answer either with an explanation or a solution. They were then requested to indicate their confidence level to their answer and their explanation/solution. A sample item is shown in Figure 1.

The plan was to use the first hour for the test and the second hour for explaining the rationale of the action research and to discuss the structured problem-solving technique. However, due to the participants' request, the test was extended half an hour so that the second presentation was moved for the next day.

On the second day, the students were given a word problem for them to answer individually. Then the structured problem-solving approach was introduced to them and was used to solve the problem. Supposedly the students were to edit an online concept map to show how they link different

Physics concepts to the concept of projectile motion, but before the end of the session, the class agreed that the students would create their concept maps individually.

In the movie the Gods Must be Crazy, a cola bottle accidentally fell from an airplane. Assume that the plane is travelling horizontally at 200.0 km/h, 1.5 km from the ground.

Which principle/s can be used to determine the velocity of the bottle as it hits the ground?
i. The acceleration due to gravity is independent of the object's mass.
ii. When no external force acts on an object it maintains its state of motion.
iii. Motion along the vertical and horizontal axes can be treated independent of each other.

a. i & ii only b. ii & iii only c. i & iii only d. i, ii, & iii

Confidence Rating

1	2	3	4	5	6
Just Guessing	Very Unconfident	Unconfident	Confident	Very Confident	Absolutely Confident

Explain your reasoning for your choice of answer. (Support your choice of answer)

Please indicate your reason or solution here. (3 points)

Confidence Rating

1	2	3	4	5	6
Just Guessing	Very Unconfident	Unconfident	Confident	Very Confident	Absolutely Confident

Fig. 1. Sample 4-tier multiple-choice item.

On the third day, the class discussed projectile motion in preparation for the application of solving a word problem using the structured problem-solving approach. The first author facilitated the creation of a class concept map explaining how this graphical organizer can be used to guide their study of Physics. An essential step in the discussion of projectile motion was asking the participants to give examples or non-examples of projectile motions. This step was based on Piaget's concept of assimilation. The authors contend that for learners to fully grasp an idea or a principle, they must be able to understand its limitations and the assumptions. For them to do this on their own, they need to be presented with various opportunities to assimilate new information from examples and non-examples. After the discussion, the participants answered a word problem in groups of 3 or 4 members. Originally, the participants were supposed to solve a problem and to fill out an evaluation form individually, but due to lack of time, this was rescheduled a month after pilot training.

After the pilot training, the MCQ test responses were analyzed, paying attention not only to the choices of the students but also on their confidence level and their justification of their choices. The students' scores will serve as the base level of the participants' problem-solving skills. In the same manner, the word problem solutions were analyzed by creating solution maps and by computing for the conceptual index. The feedbacks of the observers were also collected to determine the aspects of the training the requires improvement.

3. RESULTS AND DISCUSSION

3.1 Story and outcomes

Considerable time was devoted to making logistic arrangements of the pilot training such as in identifying the participants and observers, training venue, and schedule. Permission were requested from the school administrators and the cooperating teachers of the participants. Substantial effort was also given in preparing the MCQ (expert-validated) and the word problems, the learning materials for the pre-requisite topics, the online classroom, and the training materials.

Considering the MCQ as an indicator of the participants' ability to solve word problems in mechanics (projectile motion, work, power, energy, impulse, and momentum), the average MCQ scores reveal that the participants have difficulty performing all the identified steps necessary for problem-solving. As shown in Fig.2, the average actual scores of the participants are way lower than 50% of the maximum points for each identified skill or step. Furthermore, Fig. 2 indicates that participants had the most difficulty in identifying the applicable laws and assumptions that can be used to solve the problems. This is consistent to findings of an exploratory research conducted (and reported elsewhere) by the first author. In the study, students tend to choose the equations that they use to solve the problem based the available quantities even if they do not have a clear reason why that is the most appropriate formula. This is consistent with descriptions of students solving problems using the formula-based approach. One explanation for this observation may be because the respondents are non-Physics majors. Another is that the participants may have been trained to use the formula-based approach in their Physics classes. This concern may be addressed by emphasizing the limitations & assumptions of principles/laws taught in Physics. In this study, this was done by asking the participants to provide examples and non-examples of projectiles. It could be used to strengthen students' understanding and to clarify possible misconceptions.

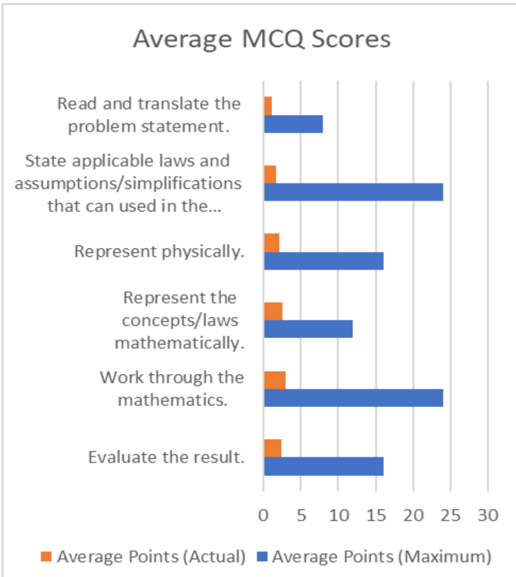

Fig. 2. Average MCQ scores of participants.

In addition to the MCQ scores, the participants' solutions to the word problems that were given before and after the introduction of the structured problem-solving approach were analyzed using solution maps (see Fig. 3). Before the approach was taught to the participants, none of them were conceptual problem solvers (uses diagrams to analyze and solve word problems (Ghaiger, 2006)). On the other hand, in the next word problem, all solutions have a diagram to illustrate the problem. The participants have also added brief notes that indicate what some values in their solutions represent. No notes of the same kind were present in their solutions to the first problem.

The primary suggestions of the observers are (1) to lengthen the training to provide more time for group work/activities and (2) to conduct the training during a weekend rather as an after-class event.

3.2 Self-reflection and learning

The most important realization gained from this study is the importance of timing. Since the sessions were scheduled after school hours (six to eight in the evening). Both the participants and the observers were already tired by the time the session starts. The participants came from the schools where they were practice teaching while the observers were also tired after an entire day of teaching. Moreover, most participants were unable to study the learning materials and prepare for the sessions since they were busy preparing for their respective classes and final demonstrations. Additionally, the allotted time for each session should have been increased to encourage interaction among the training attendees.

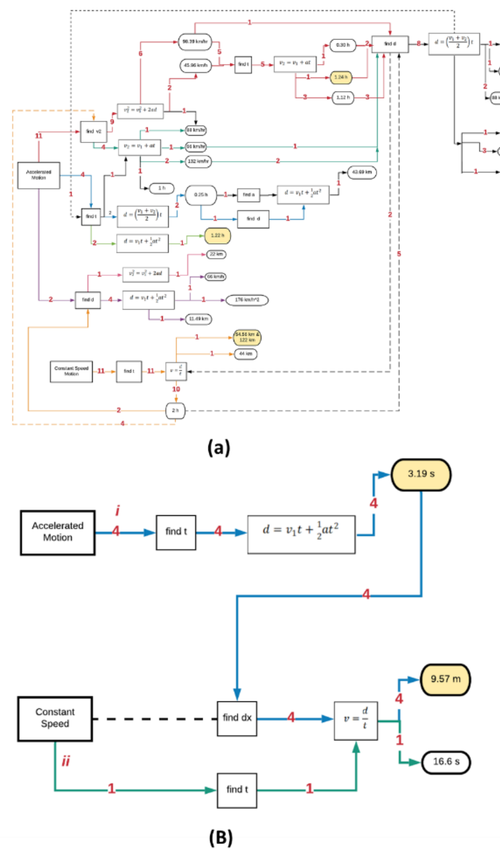

Fig. 3. (a) Solution map for problem 1 with only two conceptual problem solvers and three partially correct solutions. (b) Solution map for problem 2. All solutions were conceptual and only one group failed to answer the problem correctly. Note that shaded values are correct answers.

On a more positive note, the technique of asking participants to give an example or a non-example for the concept is very effective in drawing out students who otherwise would not participate. Moreover, it provides a rich room for sharing of ideas, clarifying possible misconceptions, and strengthening students understanding of the concepts.

The idea of using one concept map for the entire class may not work with kind of attitude/culture that we have. Aside from being busy, it is possible that the students did not edit the online concept map because they were afraid to make mistakes. In future trainings, it may be more practical to group the participants and ask them to create a concept map either online or using manila papers depending on the availability of resources.

Based on the first authors' observation, the participants had difficulty solving problems which require multiple-step solutions. Future trainings could provide simpler problems then progress gradually to more complex and difficult problems. Although the structured problem-solving approach is more demanding compared to the formula-based approach which will merely require students to match variables in their list of given to a set of formulas, it is more promising in terms of training learners to solve Physics word problems conceptually. Moreover, the approach embeds the practice of explaining the solution, so it is an approach that is suitable to teachers.

4. CONCLUSIONS

The action research described in this paper conducted three 2-hour pilot training sessions to GenSci pre-service teachers. Using a 4- tiered MCQ and by analyzing solutions to word problems, the problem-solving skills of the participants were gauged, and the effect of introducing the structured problem-solving approach to the participants' solutions was identified. By collecting the feedback of observers, the weaknesses and strengths of the pilot training were determined. These insights will be used to improve the session design as it will be used in training in-service Science teachers who are non-Physics majors.

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