Section 3. Pedagogy

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APPLICATION OF G. POLYA'S PROBLEM-SOLVING PROCESS IN TEACHING HIGH-SCHOOL PHYSICS

Abtract. The study investigates the application of G. Polya's four-step problem-solving process in teaching Physics. This teaching method helps students form and develop problem-solving skills in learning, including: 1) Understanding the problem; 2) Making a plan; 3) Executing the plan; 4) Looking back and reflecting. An experimental teaching session on "some forces in practice" for 300 tenth graders in two high schools (grade 10) was conducted as part of this study. Experimental results at first show that more than 80% of students have significantly improved their problem-solving skills. These experimental results are expected to enable teachers and students to teach and learn Physics effectively, meeting the expected outcomes of the General Education Program.

Keywords: Skill; problem solving; problem solving process; teaching Physics; G. Polya.

1. Introduction

The new general education program (2018) aims to create and develop learners' qualities and competencies. Through the program, learners can master general knowledge and effectively apply the knowledge and skills learned in life and lifelong self-learning. Some common competencies created and developed through all subjects include problem-solving and creativity, autonomy and self-learning, and communicative and collaborative competencies.

The four-step problem-solving process proposed by G. Polya has been investigated and adopted in teaching since the 1960 s. At first, it was applied to teaching how to make a plan to solve common problems in life "How to Solve It (1957)". Later, it was prevalent in education (teaching) in medicine, Mathematics, Business, and Engineering. Okafor T. U. (2019) examined the impact of Polya's problem-solving technique according to Shaibu's observation criteria (1987) and compared it with conventional problem-solving guiding techniques on students' cognitive achievement in teaching Physics. The results showed that students provided with Polya's problem-solving techniques had performed better than those provided with conventional problem-solving techniques [4]. The study by Riyadi &

et al. (2021) on assessing students' problem-solving skills from Polya's four-step approach among primary school students revealed that the percentage of Polya's steps had consistently decreased since not all students mastered how to solve the problems. Based on the question types, the percentage of solving one-step problems was better than that of two-step problems, while the percentage of solving two-step problems was higher than that of multi-step problems [5]. That is, a student's problem-solving skills depend on the complexity of the assigned task.

The four-step problem-solving process in teaching comprises: 1) Understanding the problem; 2) Making a plan; 3) Executing the plan; 4) Looking back and reflecting.

This study focuses on answering the following two questions:

– How to apply G. Polya's four steps of problem-solving in teaching Physics?

– How does teaching and learning the topic "*Some forces in practice*" happen according to Polya's 4-step process? Has the students' problem-solving competency developed?

2. Literature review on problem-solving teaching

According to Schlechty (1990), with the "*problem-raising and solving teaching*" method, the teaching organization and learning situations often have a typical structure, reducing self-direction and meaningful collaborative learning [2]. Robert Delisle (1997) supposes that Polya's four-step learning process keeps all students active, self-reliant, and creative, making teaching strategies ideal for uneven classrooms, and enabling students to self-find how to solve problems, collaborate, and bring together individual talents to "*invent*" solutions. With practical learning situations, G. Polya's four-step problem-solving learning process (1960) helps train work discipline, especially self-direction skills in problem-solving, information mining, small group cooperative learning, critical thinking, and self-assessment skills. Learning in a 4-step process enables students to develop their own problem-solving competencies. In addition, students' communication, collaboration, and other skills necessary for lifelong learning are also enhanced [2]. *"In all my years as a student and teacher, I have never seen another that lives up to George Polya's title by teaching you how to go about solving problems"* – A. H. Schoenfeld accurately described its importance in his paper in 1987.

Problem-solving involves a complex cognitive process in which the problem solver must use linguistic information, identify the missing information, identify the problem to be solved, and then make arguments to provide problem-solving strategies (Vula et al., 2017). Some research results reveal the reliance of problem-solving strategies on actual circumstances, somehow leading to different problem solutions (Mayer, 1992; Funke & Frensch, 2007). A good problem solver can understand the facts and relationships in a problem entirely and accurately. Meanwhile, a poor problem solver often fails to realize the importance of correctly reading and comprehending all the information, resulting in problem-solving failure (Whimbey & Lockhead, 2013). Students' problem-solving skills in learning Physics include explaining the relationships among physical objects, phenomena, and processes; making judgments and building hypotheses; making an implementation plan: building a logical framework for the content of study; selecting the appropriate method; developing a study implementation plan; designing models, making plans, proposing and implementing some new methods or measures; Implementing the plan: Collecting and storing data from the overall, experimental and investigation results; evaluating results based on analysis and processing of data with simple statistical parameters; comparing the results with the hypothesis; interpreting and drawing conclusions and making adjustments as necessary; Writing and presenting reports and discussing: Using language, drawings, diagrams, charts and tables to express the study process and results; writing a report after studying… [7]

4-step problem-solving process

G. Polya (1960) proposed problem-solving process in teaching should be carried out in 4 steps (see Figure 1): First, students must understand the problem. They must have reading comprehension skills to identify requirements in learning situations. The most challenging part of working through a problem is understanding exactly what the problem is about. The teachers should know how to present a problem so that students can draw consequences, thereby proposing solutions. In order to promote students' self-reliance and creativity, it is vital to determine whether to disclose information about the problem from the beginning or only to a certain extent. *Second*, it is necessary to find how minor problems (various problems) are connected so that students can come to solutions and plan solutions. *Third*, teachers often assign tasks to groups of students to implement the agreed plan and adjust the solution to suit the reality in case of a change. *Fourth*, it is required to look back at the completed solution and review and discuss the implemented plan. The process of guiding students to solve the problem is as follows:

+ *Step 1:* Understand the problem: This step is to form in students' minds the manifestations of each piece of information contained in the problem, including discovering the problematic situation: observing it; looking for information; finding out limitations or obstacles; understanding the information given and the information discovered when thinking about the problematic situation; demonstrating an understanding of concepts relevant to the situation; and stating the problem.

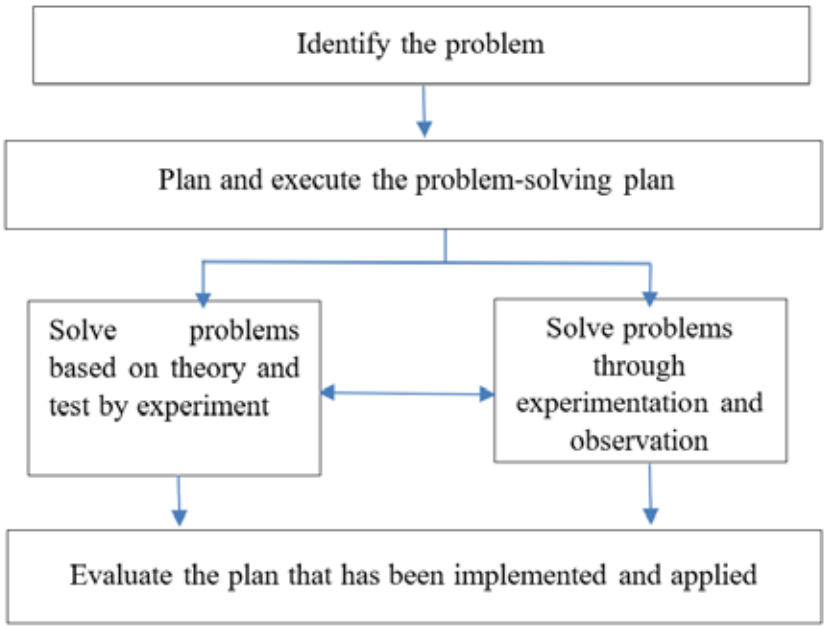

Figure 1. Flowchart of teaching problem solving in Physics subject

+ *Step 2: Make a plan*: Step 2 aims to build a clear symbol of the problematic situation (a situation model or problem model). The main result in solution selection is the ideation of a plan. Such idea may appear gradually or suddenly after seemingly unsuccessful trials and a period of hesitation. To do this, relevant information must be selected, organized in mind, and integrated with relevant acquired knowledge. It includes presenting the problem by constructing tabular, graphical, symbolic, or verbal representations and converting between formats; Formulating hypotheses by identifying relevant factors in the problem and their correlations; and Organizing and critically evaluating the information.

+ *Step 3: Execute the plan:* The determination of the plan's goals involves Setting goals, clarifying the overall goals, and setting sub-goals (if necessary); Developing a plan: a strategy to achieve the goal

and expected steps to be taken; Executing the plan: assigning tasks (to be done in groups), completion time, and expected outcomes.

+ Step 4: Looking back and reflecting (self-assessing the implemented solution): The step involves checking the progress in achieving the goals at each stage, including checking intermediate and final results, detecting unexpected events, and taking remedial measures when necessary; Analyzing and assessing solutions from different perspectives; critically evaluating hypotheses and finding alternatives; Looking for additional information or clarification. Teachers need to train students in methods and experience to work independently. However, if a student is left alone without any help or with insufficient help, he or she may not make progress at all.

On the contrary, if teachers help too much or do all students' tasks, students' competencies cannot be developed. Teachers should help, but not too much or too little so that students can *share* the work appropriately [3].

A combination of Polya's four steps in problem-solving is shown in the diagram in Figure 1. The process of guiding students to solve the problem is shown in Figure 1.

3. Methodology

This study combined both quantitative and qualitative methods. Quantitative methods were used to analyze quantitative data obtained from tests of problem-solving skills. Qualitative research methods were employed to further interpret the test research results from the quantitative results. The results were analyzed and graphed using MS Excel software.

Pedagogical experiments were carried out at Phan Huy Chu and Doan Thi Diem High Schools, Hanoi City. The participants were 300 tenth graders attending the program using the "connecting knowledge with life" textbook. Observation, interview (during class), and constructed-response tests were employed to collect data. During class, the teacher observed the learning process and evaluated problem-solving skills with Rubric. After each experimental session, the teacher used a 25-minute constructed-response test. Scores were converted to percentages to determine how well students were progressing in meeting the steps of Polya's teaching process. Rubrics (peer assessment) and three tests after three experimental sessions were used. Then, MS Excel software was used to analyze the assessment data. Results were satisfactory when 75% of students had four skills: Understanding the problem; Making a plan; Executing the plan; Looking back and reflecting (self-assessment) increased from level 1 to level 3.

4. Research results

4.1. Example of teaching the topic "Gravity"

**** Expected learning outcomes***

– State and write the expression of the law of universal gravitation. State the characteristics of the gravitational force vector between two particles.

– Write the weight and free fall acceleration expression depending on the height above the ground.

– State the definition of the center of gravity of an object.

– Name some effects of gravitational force/gravity.

– Apply the expression for calculating the force of gravity and the expression for calculating the weight to solve simple problems.

– Explain qualitatively the real-life phenomena related to gravitational force/gravity, such as free fall, tidal phenomenon, the motion of planets, satellites, etc.

**** The logic of the teaching process***

The logic of the teaching process is described in (Figure 2).

Activity 1: Understand the problem

From the described practical situations, photo slideshows, and simulations, students observe and understand the problem to be solved. Then they can ask the question: What is the effect of force on objects?

Activity 2: Propose a solution

– Students make predictions and propose experimental plans to determine the characteristics of gravity.

– Students learn information about the gravitational force between two particles. Then, they are

guided to propose a plan to determine the characteristics of gravity.

– Students discuss and propose a solution to determine the characteristics of gravity.

Activity 3: Execute the solution to the problem

– Students identify and represent the direction of gravity. Students apply the law of universal gravitation to write down the expression for the magnitude of gravity. The teacher assigns tasks to the groups to follow the agreed solution.

– Students execute the agreed solution.

Activity 4: Assess the solution and apply the knowledge

– Groups report the solution execution results and conduct peer assessments. Then, they can conclude the characteristics of gravity

– Students give examples to distinguish between weight and mass

– Students apply what they have learned to determine the center of gravity of an object.

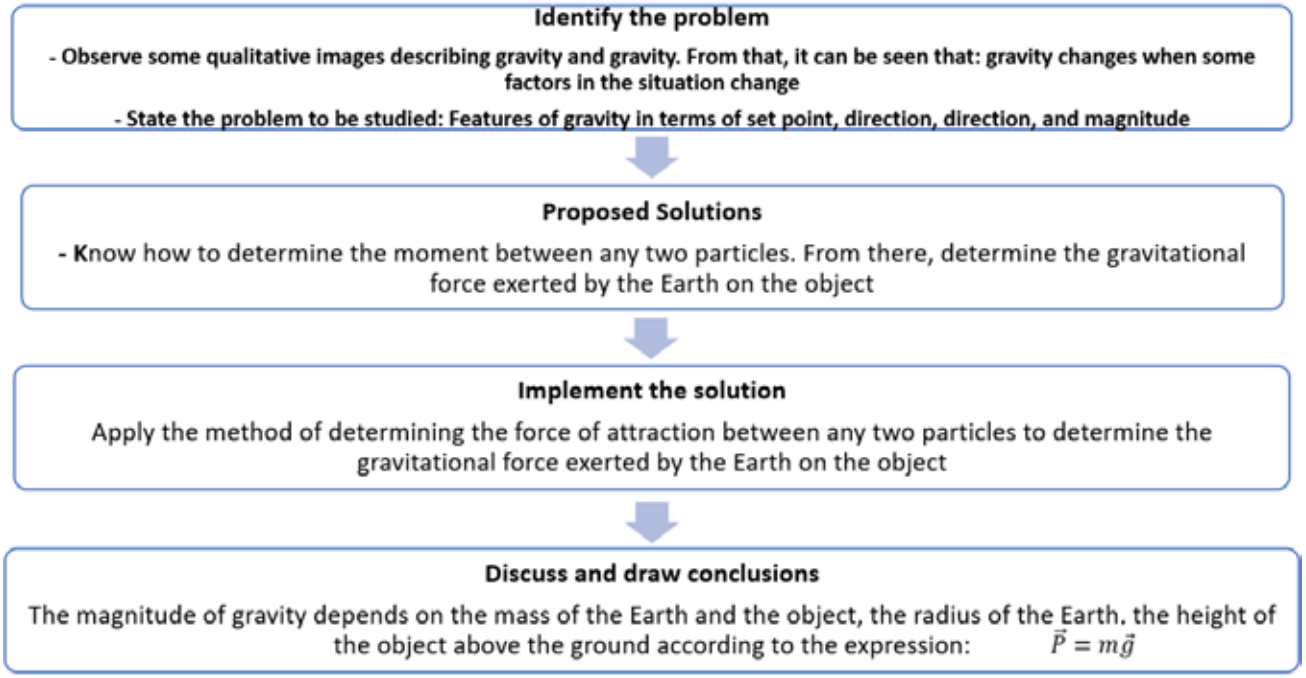

Figure 2. The logic of the teaching process about "Gravity"

4.2. Assessment of students' problem-solving skills in teaching the topic "Some forces in practice"

Based on the complexity of the tasks assigned to students or the extent of self-reliance and creativity, Rubrics to assess students' problem-solving skills while learning were developed according to 3 attainable levels of the 4 problem-solving skills: Understanding the problem (skill 1); Making a plan (skill 2); Executing the plan (skill 3); and Assessing the plan (skill 4):

Table 1.– Percentages of students' problem-solving skills at level 1

Teaching process (Skills)	Level of achievement (%)			
	Very proficient (good)	Proficient (fair)	Not skillful (Medium)	Can't do it (least)
Identify the problem (Skill 1)	17.3	34.3	46.8	1.6
Planning (Skill 2)	14.4	28.8	49.5	7.3
Implement the plan (Skill 3)	19.6	22.3	46.7	11.4
Review the plan (Skill 4)	17.8	28.8	44.7	8.7

The assessment results of students' 4 skills at level 2 are shown in the table below:

Table 2. – Percentage of students' problem-solving skills at level 2

Teaching process (Skills)	Level of achievement (%)			
	Very proficient (good)	Proficient (fair)	Not skillful (Medium)	Can't do it (least)
Identify the problem (Skill 1)	28.2	41.1	30.7	0
Planning (Skill 2)	27.1	39.0	33.9	0
Implement the plan (Skill 3)	29.1	40.9	25.1	4.9
Review the plan (Skill 4)	31.3	41.8	21.5	5.4

The assessment results of students' 4 skills at level 3 are shown in the table below:

Table 3. – Percentage of students' problem-solving skills at level 3

Teaching process (Skills)	Level of achievement (%)			
	Very proficient (good)	Proficient (fair)	Not skillful (Medium)	Can't do it (least)
Identify the problem (Skill 1)	34.7	58.8	6.5	0
Planning (Skill 2)	36.9	57.6	5.5	0
Implement the plan (Skill 3)	35.5	54.7	9.8	0
Review the plan (Skill 4)	37.2	55.4	7.4	0

4.3. Discussion

The percentage results indicated an increase in skill level from level 1 to level 3 after the lessons. Nevertheless, problem-solving skills among students in the four steps were not evenly developed. Skill 1 (understanding the problem) was better than skills 2 and 4. Meanwhile, the best results were found in skill 3. When students understand the problem and propose a solution, they can entirely execute it. Notably, clear progress in executing the solution was observed throughout the lessons. Through direct observation, students had clear improvement in skills of performing steps 1, 2, and 3 with a high percentage. Students often faced difficulty in solving problems in lessons using experiments, mainly due to new learning methods and the teacher's improper instructions. Students found adapting the experiment plan to the existing laboratory equipment difficult. Some were not proficient in thinking of different strategies for solving problems, while others needed to gain knowledge about error calculation when processing experimental data.

Regarding the two steps of making and executing the plan, many students could not correctly write down the steps to take. Most students solved the problem immediately without writing down the steps. Even good students still needed help in selecting and identifying Physics research methods to solve the problem. It was observed that this happened due to, among other reasons, students' lack of training in writing down specific steps and how to execute the plan. Writing down the steps is essential to select a proper strategy for solving the problem. This finding is consistent with Anderson's study (2011) which argues that strategic orientation to problem-solving is a significant part of problem-solving. By guiding students to write down strategies and expected outcomes before solving problems, teachers will know to what extent students understand the problem and at what stage assistance will work for students' self-reliance and creativity [5].

5. Conclusions

In this article, applying G. Polya's four-step problem-solving approach to teaching Physics, the author found out how to organize the teaching of three lessons: "Gravity and tension force, friction force, and elastic force" in the topic "Some forces in reality" – Physics Grade 10.

In adopting Polya's four steps of problem-solving in teaching Physics, **making a plan and executing the plan** should be conducted in two ways: solving the problem through theoretical reasoning and testing by experiment, and solving the problem through experiments and observation. Experimental results indicate that applying the four-step problem-solving process, as described in the article, helps develop students' problem-solving ability, meeting the expected learning outcomes under the general education program 2018.

Polya's four-step problem-solving process has been widely adopted in teaching Mathematics in many countries worldwide (e.g., the USA, UK, Korea, Singapore, Indonesia, and Thailand); however, there have been few studies on its application in teaching Physics. Hence, in the teaching process, especially in steps 3 and 4 (making a plan and executing the plan), it is necessary for teachers to orient students on how to solve problems according to the characteristics of Physics research and learning and regularly provide them with exercises that require students to follow such four-step problem-solving process. This study was pedagogically experimental with a small sample size. Therefore, more mass studies with large samples in many other high schools should be further conducted.

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