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## Problem solving in the physics classroom. An analysis with secondary school students

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**Abstract.** The teaching of science, and specifically physics, has been associated with the acquisition of knowledge with a particular emphasis on problem solving, as an activity that brings students closer to the methodology and meaningful learning of science. However, problem solving is perhaps one of the sources of failure in physics teaching, which requires a careful analysis of this didactic activity. Therefore, the aim of this work is to analyze the development of students' problem-solving skills in a physics course. An analysis is presented using the quasi-experimental method through the application of a pre-test – post-test, for which a methodological intervention was used based on the problem-solving competence, which focused on identifying errors and difficulties by the students themselves and thus favoring the learning and development of this competence, which allowed the academic progress of the students to be analyzed. It is concluded that the intervention supported by problem solving improves students' performance, in addition to the positive assessment they make of the process, as well as its influence on the change in pedagogical practice.

### 1. Introduction

The teaching process around problem solving is articulated according to the four-phase process proposed by Polya [1] understanding the problem, devising a plan, executing the plan, and examining the solution obtained. According to the above, there are studies that show the difficulties that students have in solving problems correctly in disciplines such as mathematics and science [2-5].

Teachers in their pedagogical practice build their own problem-solving strategies, but in many cases, they do not work with students, especially due to methodological and conceptual problems [6]. Therefore, the importance of this study proposes a strategy that promotes and helps secondary school students to improve their strategies to solve physics problems. Science education should aim for students to be able to solve problems to develop metacognitive competences, but in the case of physics it is reduced to a traditional teaching of not solving problems but showing ready-made solutions that do not allow the development of these competences and which transmit attitudinal and methodological deficiencies that make it difficult to succeed in new problems [7].

The strategy is based on the steps proposed by [6] and which are methodologically based on those proposed by Polya [1]: reading comprehensively (reading silently and attentively), representing the problem by placing the data, either by means of a diagram, a drawing or simply a list, identifying the process that takes place (thinking about what type of physics problems it is related to), planning the



solution by selecting the laws that govern the process (posing equations by means of the laws, one equation per unknown), formulate an anticipation of the solution, even if it is qualitative of what will happen, solve the equations mathematically, analyze the solution logically to detect possible errors in the application of physics knowledge in the planning or inconsistencies and finally express the final solution clearly indicating the corresponding units by writing a sentence that includes the solution.

Problem solving constitutes one of the main axes of learning in disciplines such as mathematics and science, which makes it possible to verify in the classroom the difficulties encountered by students when they go to solve it. On the other hand, solving a problem, without emphasizing the linkage and its application to real contexts known to students, creates obstacles in the form of errors, which are inadequate cognitive schemas [8]. Moreover, problem solving is addressed in science education through various tasks, which are present in the teaching of physics, but these tasks often have several points of contact through interdisciplinary relationships that are currently manifested in the teaching of mathematics, physics, and science in general [9].

For the teacher, mistakes are fundamental for students to learn, so if mistakes are considered to show ineptitude on the part of the student, they can lead to school failure reflected in low academic performance, high repetition rates, and school dropout rates, among others [10]. The teacher must recognize that there are students who are more competent than others to recognize the obstacles they must overcome when solving a problem and avoid repetition and mechanization [11]. Therefore, the error should not be seen as a deficiency, but as an opportunity for the student to overcome each situation that arises (problem solving) both academically and in their lives, so that learning is a process of self-regulation of metacognitive type [12].

On the other hand, the assessment process conditions what students learn and how they learn, however, teachers forget that this process is sequential and that they should identify errors and systematize them instead of looking for the best way to explain. The aim of assessment is for students to identify their own way of thinking and differentiate it from what is proposed to them, thus overcoming obstacles to understanding. The purpose of assessment for learning should be to propose strategies to identify errors and overcome them from the student's perspective, since their difficulties stem from how they perceive knowledge and how they express it through speech and writing [13].

## 2. Methodology

This research was framed within a quantitative experimental approach, as it consists of subjecting a group of individuals (students) to a certain treatment (independent variable - intervention supported by a problem-solving methodology), to observe the effects produced (dependent variable - development of problem-solving skills).

### 2.1. Research design

The chosen design is quasi-experimental, since the students are not randomly assigned to groups, but the groups were already constituted before the experiment (intact) [14]. This study corresponds to a group of students taking the subject physics in grade 11, to carry out a measurement before and after. In addition, within the quasi-experimental design is the single-group pre-experimental design with pre-test - post-test measures. The design consists of a single group with one observation before (diagnostic test) and one observation after (final test) the intervention (problem-solving methodology) [15].

### 2.2. Variables

For the definition of the variables, the independent variable is the teacher's methodological intervention based on a problem-solving strategy in physics, and the dependent variable is the value obtained by the student that measures his or her problem-solving ability in physics.

### 2.3. Sample

The population to which the study was oriented is finite; furthermore, the sample and the type of sampling used is non-probabilistic, as the choice of elements depends on the characteristics of the study,

which was determined intentionally by the authors. The study was carried out in a classroom of 11th grade secondary school students taking physics, made up of 32 students, 20 boys and 12 girls, aged between 16 years old and 17 years old, in a public educational institution in Norte de Santander, Colombia.

#### 2.4. Techniques and materials for data collection

A pre-test and an equivalent test were applied in the post-test; the pre-test allowed for the diagnosis of the students' prior knowledge, which provided a starting point of reference as to the level of knowledge and ability of the students.

#### 2.5. Design and application of the diagnostic test – pre-test

The starting point was the level of ability to solve physics problems; for this purpose, an assessment was designed with 10 exercises on problem solving in physics to determine the students' prior knowledge. The topics on which the assessment exercises were based are related to kinematics problem solving. The scores obtained by the students were adjusted to the scale of the evaluation system of the educational institution: 1.0-3.4 (low performance), 3.5-4.2 (basic performance), 4.3-4.7 (high performance) and 4.8-5.0 (superior performance). To obtain the final test score, the same value is given to each question, *i.e.*, 0.5, to obtain 5.0 when adding up the 10 correct answers of the test.

#### 2.6. Implementation of the strategy

For students to identify their difficulties when solving a problem and for the teacher to understand the strategies they apply, a self-assessment form (Table 1), proposed by [6], was used; each student fills it out for each problem ( $P_i$ ), placing a value of 1 in the cells in which they have encountered difficulties and then analyzing it with the teacher to indicate the possible causes and advice for the student to reflect on.

**Table 1.** Student self-assessment form.

		P <sub>1</sub>	P <sub>2</sub>	P <sub>3</sub>	P <sub>i</sub>	Total	Comments on the student's difficulties
Understanding	Problems in reading						
	Identify the process to be applied						
Planning	Plan the solution						
	Identify units to be used						
Resolution	Mathematical processes and calculations to be used						
	Analysis of the results						
Analysis	Explain the analysis						
	Unforced errors (lack of attention)						
Formalism	I understand the concept but don't know how to write it down mathematically						
	Grade you got:						
	Grade you expected:						

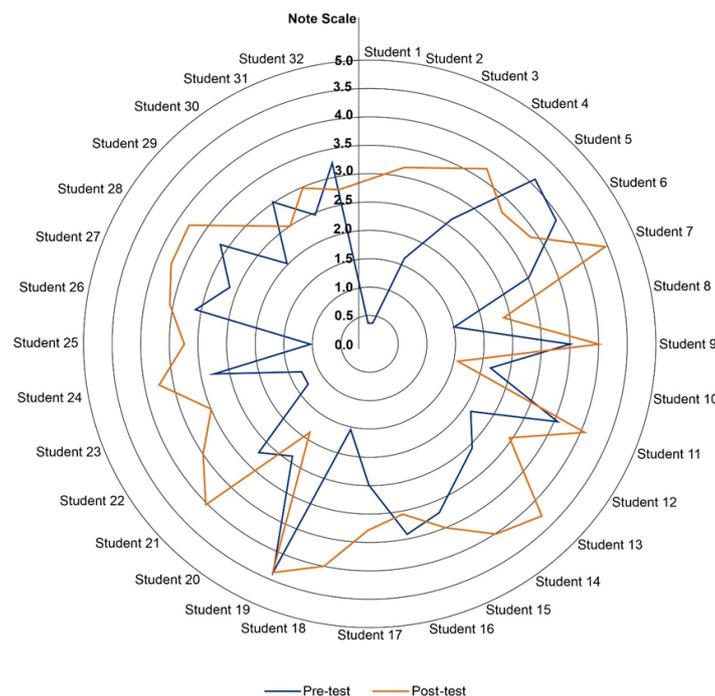
### 3. Results

Table 2 shows the pre-test and post-test statistics. The mean of the post-test improves by 0.9 compared to the pre-test to 3.4. The standard deviation shows that students' scores are less dispersed in the post-test (0.7), showing a smaller variation in the scores obtained after the self-assessment arising from the methodological strategy of problem solving, which shows that the strategy improves not significantly, but it does show that the development of this competence is slightly equal for all pupils.

**Table 2.** Pre-test and post-test statistics.

Statistic	Pre-test	Post-test
Mean	2.5	3.4
Standard deviation	1.0	0.7

Figure 1 presents the numerical scores compared between the pre-test (blue) and after (orange) applying the self-assessment arising from the problem-solving methodological strategy. The information presented in Figure 1 corroborates the results obtained in Table 2, which verify that the students' scores are better in the post-test after the application of the self-assessment arising from the problem-solving methodological strategy.

**Figure 1.** Comparison between pre-test and post-test scores.

On the other hand, Figure 2 shows the normal curves of the pre-test and post-test scores; it can be seen in Figure 2 that there is an improvement in 12 students with grades below 3.0 in the pre-test, which may indicate that students with scores above the pass mark are capable of self-evaluating when solving a problem. But this improvement is not substantial, which indicates that although many of them have improved their results, it is not enough to have a good level when solving problems, so it is necessary to continue implementing and improving the proposed strategy.

The implementation of the problem-solving strategy has enabled students to read the problem carefully and then look for a schematic representation (drawing) every time they are going to solve it, and from here they formulate questions for self-appraisal and then discuss the answers, before continuing with the solution. In this way students are encouraged to make the connection between the problem being solved and their prior knowledge; therefore, they can organize their learning and improve it. In this way problem solving becomes a metacognitive strategy [16].

Another effect that deserves attention is the motivational aspect of the student, especially for those with more difficulties, as they realize that with the strategy, they can improve their results and that this is a cause of success [17].

Likewise, the difficulties identified by students can be overcome, sometimes individually, to solve problems with different approaches that activate motivation, flexibility, and creativity [18] and sometimes with the help of classmates and the teacher himself, so that the methodology implemented

becomes a collaborative problem solving, very effective for learning physics [19]. If the student perceives the difficulties as approachable, he/she does not get discouraged and is motivated.

Another effect is the improvement of the motivational aspect of the student, especially for those with difficulties, since they realize that with the strategy, they can improve their results and that this is a cause of success [16], as it constitutes a strategy that allows students to approach a more contextualized vision of science [20].

In addition, another contribution of this study is the interpretation made by students using complementary strategies, for example, concept maps, which allow to graphically represent the resolution of school physics problems carried out by students, the results of which will be presented in another report [21].

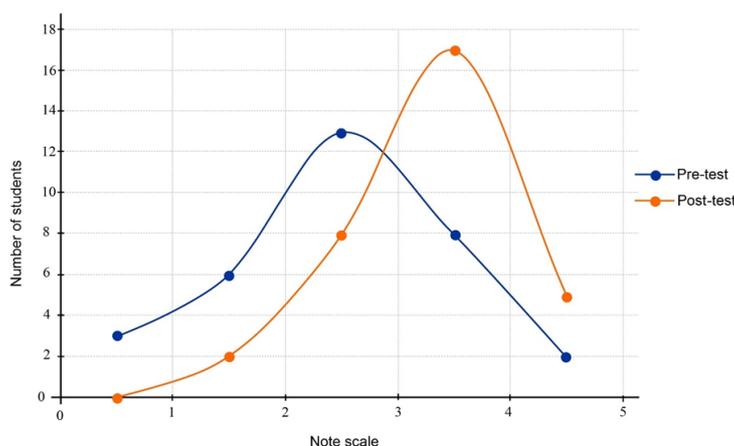


Figure 2. Comparison of pre-test and post-test normal curves.

#### 4. Conclusion

The results of the pre-test and post-test show a slight improvement in the students' scores, in addition to the positive assessment they make of the process, but the important thing is that, through the implementation of the problem-solving strategy, students can identify the necessary arguments in a problem in which they identify their difficulties and obstacles to overcome and thus know what their level of assimilation of the content and competences is. The above also allows the teacher to recognize how to improve the explanation and teaching process applied and thus improve their pedagogical practice, because they should propose interesting situations to teach problem solving that involve the use of scientific thinking and leave aside the traditional practice of solving exercises that students must memorize and then reproduce. There are variations that are not captured by descriptive analysis, so it is necessary to combine it with qualitative forms of analysis. From the above, it is necessary to continue this study by characterizing the processes of scientific reasoning in physics, to record and analyze the perceptions of students and teachers, and to highlight the differences in their analysis.

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