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Analysis of Student Problem Solving Processes in Physics

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Abstract: The main goal of learning physics is to understand physics concepts in-depth and apply them in the problem solving process. This article presents a synthesis of what students do when solving physics problems. The five topics discussed in this article consist of: (1) the difference between expert and novice in problem solving, (2) Physics Problem Solving Approach, (3) the use of examples in problem solving, and (4) the use of representation in physics problem solving. This article is the result of studies of problem solving research literature. Each topic section will be discussed related to the development of research results for each topic and problem solutions for future research. Although we do not limit the year as the reference source for this article, most of the reference sources are taken from the research of the last 20 years on solving physics problems.

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INTRODUCTION

The main objective of learning physics is to increase mastery of concepts (Etkina et al., 2006; Nugraha et al., 2016; Steinberg et al., 2009), understand physics concepts in depth and be able to apply them in the problem solving process (Riantoni, Yuliati, & Mufti, 2017; Sutopo & Waldrip, 2014). In addition, increasing the quantitative understanding of the principles of physics is also the goal of learning physics (Etkina et al., 2006). This is because to master physics thoroughly, one must be able to link conceptual understanding and quantitative understanding of the principles of physics.

There are six main topics that are mostly researched in Physics education, namely (1) conceptual understanding, (2) problem solving, (3) curriculum and teaching, (4) assessment, (5) cognitive psychology, and (6) attitudes and beliefs. about teaching and learning [6]. The six topics are a major unit that is interconnected in creating success for students researching physics. However, in its development, research related to these topics is carried out separately. Each topic has a theoretical description of the important parts that must be studied continuously. It is intended to find strategies so that physics is easy to discuss.

One of the important topics of the six highlighted topics is problem solving (Leak et al., 2017). At the high school and college level, in researching physics problem solving skills have always been an emphasis in learning (Tuminaro & Redish, 2007; Walsh et al., 2007). Problem solving is always highlighted in physics education because it is a key component in learning physics (Ibrahim & Rebello, 2012). This is because the problem solving research area is related to cognitive psychology (Docktor & Mestre, 2014) and problem solving ability is used as a process to solve a problem when the way to solve the problem is not clear (Adams & Wieman, 2015; Ibrahim & Rebello, 2012; Ryan et al., 2016). Usually physics teachers use this problem solving ability as a way of teaching physics concepts and to assess students' abilities if the material has been studied (Ceberio et al., 2016). Lecturers in the field of physics are usually very concerned about how students solve problems because in the problem solving process students can understand concepts and one of the strategies to assess student achievement (Adams & Wieman, 2015; Ceberio et al., 2016; Ibrahim & Rebello, 2012).

Five frequently asked topics related to problem solving include, (1) expert and novice problem solving, (2) problem solving examples and discussion, (3) representations used in physics problem solving, (4) mathematical ability in problem solving, (5) evaluate the effectiveness of the strategy in problem solving (Docktor & Mestre, 2014). Of the five topics, mathematical abilities and representations used in problem solving are the most frequently discussed (Adams & Wieman, 2015). This is because research on representation in problem solving has a long history (Kohl et al., 2007) and many assumptions assume that students' difficulties in problem solving are caused by a lack of mathematical ability. This article will discuss some research topics of physics problem solving with the main objective of explaining what students do when solving physics problems.

METHOD

This article is the result of a literature research. The literature analysis process was carried out by means of a systematic review with six stages (Jesson et al, 2012). First, do the mapping through a review of the information you want to find. Second, conduct a comprehensive search by accessing electronic databases and searching using keywords. Third, assessing quality by reading the writing in full and applying a quality assessment to decide whether the writing is appropriate or not with the topic. Fourth, perform data extraction by writing the relevant data on the previously designed extraction sheet. Fifth, carry out a synthesis by combining data from each article into one. In addition, it shows what we know now and what we still need to know. Sixth, write the results of the review.

Given the breadth of problem solving research in physics, we organize the synthesis in this article on four topic areas based on previous research on problem solving physics. The four areas are (1) the difference between experts and beginners in problem solving, (2) Physics Problem Solving Approaches, (3) the use of examples in problem solving, and (4) the use of representations in solving physics problems. In order for the presentation to be done consistently, each topic section will focus on the development of research results for each topic. Although we do not limit the year as the reference source for this article, most of the reference sources are taken from the research of the last 20 years on solving physics problems.

RESULT AND DISCUSSION

Difference Between Expert and Novice in Problem-Solving

The first research of physics problem solving is to investigate how students solve physics problems and how they use them compared to experienced people such as lecturers. There are two questions discussed in this topic, including how do the troubleshooting procedures used by inexperienced problem solvers compare to those used by experienced problem solvers? How do experts and beginners judge whether the problem will be solved in the same way?,

Based on the results of the synthesis there are several findings related to physics problem solving procedures for beginners and experts. Some research results show that an expert begins to solve physics problems by describing information from the questions qualitatively and using that information to determine the strategy to be used (Docktor et al., 2016; Hull et al., 2013; Yerushalmi et al., 2010). Meanwhile, a novice starts the problem solving process by writing a formula that is matched with the values in the problem statement (Hull et al., 2013; Rosengrant et al., 2009; Walsh et al., 2007). An expert solves problems in an organized manner and always prioritizes concepts in the process of determining answers (Ogilvie, 2009; Rosengrant et al., 2009)(Nehru et al., 2022; Ramadhani & Nurita, 2022; Yusuf et al., 2022), while a novice usually focuses on variables or quantitative values in questions (Ryan et al., 2016) such as variables in the known problem (Rosengrant et al., 2009; Yerushalmi et al., 2010)(Misbah et al., 2022; Rahim & Nadira, 2022). Experts organize knowledge very structured while novices are not based on knowledge structures, their understanding consists of random facts and has little conceptual meaning (Perkins et al., 2006). If there are obstacles in the problem solving process, an expert has various ways to make it easier to solve the problem, while a novice is slower in finding other alternatives if experiencing difficulties (Hull et al., 2013).

The difference between expert and novice in solving specific problems can be presented as follows (See Table 1).

Table 1. Differences Between Expert and Novice in Solving Physics Problems

Category	Characteristics in Problem Solving	Referencee
Expert	• Experts solve problems starting with analyzing the problem qualitatively to limit the problem and get the essence of the problem • Experts categorize and solve problems based on relevant principles or basic concepts of physics • An expert applies concepts or principles of physics in solving problems in an organized manner, using strategies to	(Docktor et al., 2016; Hull et al., 2013; Kohl et al., 2007; Rosengrant et al., 2009; Ryan et al., 2016; Savelsbergh et al, 2011; Wolf et al., 2012; Yerushalmi et al., 2010)

	assess the solving process and final results • Experts organize their knowledge in a coherent and interconnected manner • Experts also have strong metacognitive skills, including monitoring the progress of their solutions to check whether the method they choose still has the potential to get results, as well as evaluation skills such as testing solutions against assumptions made. • Experts have many ways and representations to make it easier to get a solution, where a series of ways leads to the right solution • Experts see the problem as a whole • Experts always have enough time in troubleshooting	
Novice	• Novice solves problems focusing on quantitative values and tries to match them with mathematical procedures or formulas. • Novice may perform qualitative analysis, but is not perfect and does not do it directly • Novice solves problems not based on the basic principles or concepts of physics, but based on variables and equation manipulation • Novices do not have organized knowledge to solve problems, they solve problems randomly and have little conceptual meaning • Novice has knowledge of being disconnected, weak or unconnected • Novices are very quick to get into trouble and slow to find other alternatives in solving problems • Novice believes a problem has a special way of solving it • Novice sees the problem in pieces • Novice has weaknesses in conceptual, mathematical skills, and the ability to transfer knowledge	(Docktor et al., 2016; Hull et al., 2013; Kohl et al., 2007; Rosengrant et al., 2009; Ryan et al., 2016; Savelsbergh et al, 2011; Wolf et al., 2012; Yerushalmi et al., 2010)

First year students can be categorized as beginners in terms of solving physics problems, because they do not have much experience in solving physics problems. Based on the characteristics of a beginner in problem solving, many things need to be improved related to problem solving procedures. For this reason, it is necessary to provide appropriate interventions so that students are able to solve problems well.

The main problem that needs to be fixed is related to the application of the concept in the problem solving process. Judging from the problem-solving category, a student who is categorized as a beginner is more focused on solving problems based on the variables contained in the given problems and mathematical processes, and does not apply concepts in terms of finding solutions. This is because lecturers often emphasize quantitative aspects of problem solving such as mathematical equations and procedures rather than qualitative analysis to select appropriate concepts and principles (Docktor et al., 2015). Whereas conceptual knowledge is one part that students must know to solve physics problems (Ogilvie, 2009). In addition, one of the important goals in learning physics is to deliver students to understand in depth the basic concepts in physics so that they are able to use them in solving problems (Sutopo & Waldrip, 2014). Therefore, in this section it is necessary to design interventions to direct students to apply concepts in the problem solving process. As in Hellers' research, which was based on the prescriptive theory of expert problem solving, asked students to "visualize the problem, "understand the problem", use formal concepts and equations to "represent the problem", write a "solution plan", execute the plan, and then "interpret" and evaluation of solutions" (Burkholder et al., 2020).

Approach in Physics Problem Solving

In finding solutions to problems, the results of several studies categorize students' ways of solving problems in four approaches, namely Scientific approach, plug and chug, memory based approach, and no clear approach (Riantoni, Yuliati, Mufti, et al., 2017; Walsh et al., 2007; Yuliati et al., 2018). These approaches have their own characteristics which can be explained as follows (Walsh et al., 2007): First is the scientific approach, students who fall into the category of using a scientific approach in problem solving always start the problem solving process by analyzing the problems in the problem by referring to the physics concept that involved. Next, students outline a plan to solve the problem and then identify the variables that will be used to find answers. The focus in the scientific approach is how concepts are linked and used in finding solutions. When viewed from its characteristics, the scientific approach is a form of conceptual problem solving. This is because the main characteristic of the scientific approach is that every process in finding a solution is based on the physics concepts involved (Yuliati et al., 2018).

The second is the plug and chug approach, students who solve problems using a plug and chug approach are divided into two forms, namely students who fall into the category of a structured manner plug and chug approach with the characteristics of starting the problem solving process by analyzing the problem by determining the type of formula to be used to solve problems. Meanwhile, students who fall into the category of unstructured manner plug and chug approach start the problem solving process by analyzing the problem by concentrating only on identifying the necessary variables. Students relate the variables given in the problem to a formula they believe can be used to solve the problem.

The third is the memory based approach. Students who fall into the category of memory based approach solve problems by analyzing and adjusting the problems they have encountered in the past. They solve problems by trying to remember the type of equation they used or which relates to a similar problem they have worked on before. Students who use this approach believe that the same way can solve other problems.

The fourth is the no clear approach. Students who fall into the no clear approach category solve problems with unclear strategies and do not refer to variables related to concepts. The focus of this process is not on the concepts involved, nor is it based on any particular method. Students tend to manipulate the given variables in a somewhat random way to provide answers. More specifically, the four methods used by students in problem solving can be distinguished as shown in Table 2.

Table 2. Approaches in solving Physics problems (Riantoni et al., 2017; Yuliati et al., 2018)

Category	Characteristics
Scientific approach	• Analyzing the physical situation qualitatively and referring to the physics concepts involved • Plan and find solutions systematically based on analysis • Refer to concepts in the process of finding solutions • Evaluating solutions
Plug and chug : a. Sructured manner	• Qualitative analysis of the situation based on the required formula • planning solutions based on systematic variables and procedures • Refer to the concept in the process of getting a solution • Evaluating solutions
b. Unstructured manner	• Situation analysis based on the variables involved • Start the process by selecting a formula based on the variables in the trial and error system • Refers to the concept as a variable • Not evaluating solutions
Memory based approach	• Analyze problems based on situations encountered in the past • The process starts by trying to match the given variable with the example that has been given • Refers to the concept as a variable • Not evaluating solutions
No clear approach	• Situation analysis based on given variables • The procedure starts by trying to use the variable in a random way • Applying variables as terms • Not evaluating solutions

This approach is basically used by students to find solutions to the problems given. All approaches used by students allow students to find the correct solution to the problem, but the steps of the scientific approach are the best steps in the process of finding a solution to the problem (Yuliati et al., 2018). This is because the scientific approach emphasizes the application of systematic concepts and processes in problem solving (Nehru et al., 2020).

There are several studies that show the tendency of the approach used by students in the process of solving physics problems. For example, in a research conducted by Yuliati et al (2018), when students were asked to solve electrical problems, the data showed that of the 34 prospective physics teacher students, they were more likely to solve problems using three approaches, namely unstructured manner, memory based approach and no clear approach. Meanwhile, in the research conducted by Riantoni et al (2017) on energy and power materials, the results showed that the way students solve problems was more likely to fall into the category of using the memory-based approach and the no-clear approach. This causes most of the students in the two studies to have difficulty finding the correct solution to the problem. These studies show that students are not taught to solve problems using a scientific approach.

Use of Examples in Physics Problem Solving

The third research of physics problem solving is to explore how students use the solutions to problems they have worked on or previously solved problems to solve new problems. There are several student findings in using the examples that have been done before as a guide for solving new problems. In general, students use examples they have worked on as a benchmark to find information and solution procedures that they can copy to solve new problems they face (Docktor et al., 2010). The problem is that students do not try to understand the concepts and process of solving problems from the examples given.

There are two categories of students in utilizing the examples they have worked on in solving new problems. The first category is students who use examples that have been done before as an aspect to examine the solution procedure they are working on (Fergusonhessler & Jong, 1987). Such students have a deep understanding of concepts and solutions. While the second category is students who copy the examples they have worked on before to get new problem solutions(Chi, M.T.H., Lewis, M.W., Reimann, P., 1989; Fergusonhessler & Jong, 1987). Students in this second category do not consider whether the new problem they are working on is the same as the previous problem they have worked on. This second category procedure in the problem solving approach is called the memory based approach procedure, in which students who fall into the memory based approach category solve problems by analyzing and adjusting the problems they have encountered in the past (Yuliati et al., 2018). They solve problems by trying to remember the type of equation they used or which relates to a similar problem they have worked on before.

Giving examples in problem solving is one of the best ways to improve students' problem solving abilities (Badeau et al., 2017), Several studies have shown that working examples can be very effective in helping students as they try to master problem solving concepts and skills, especially in highly structured domains such as physics (Atkinson et al., 2000; Badeau et al., 2017). In addition, researching examples can be much more effective than individual problem solving exercises (Badeau et al., 2017).

Use of Representations in Physics Problem Solving

One of the strategies used by experts to make it easier to solve physics problems is to use various representations. The use of representation has an important role in learning (Ibrahim & Rebello, 2012). Physical scientists use various representations as a means to understand physics (Meltzer, 2005). Therefore, one aspect of problem solving that is widely discussed in the physics education community is the problem of representation (De Cock, 2012; Ibrahim & Rebello, 2012). In addition, representation is also used to identify the special difficulties that students have (Meltzer, 2005).

The term representation has many interpretations, but for problem-solving research representation refers to the use of drawings or sketches, specific descriptions of physics (e.g., free-body diagrams, field-line diagrams, ray diagrams, or energy bar charts), concept maps, graphs, and equations. or symbolic notation (Docktor & Mestre, 2014). Representations have very diverse forms in which physical concepts can be understood and communicated (Ibrahim & Rebello, 2012; Meltzer, 2005). Skills in using different representations and in coordinating various representations are needed in physics, both as a tool for understanding concepts and as a means to facilitate problem solving (De Cock, 2012).

In general, students should use various representations in solving physics problems (Finkelstein & Pollock, 2005; Kohl et al., 2007). In building representations in the problem solving process, there are several abilities that students must possess. These abilities include the ability to interpret or construct representations, the ability to translate and switch between representations accurately and quickly, and the ability to determine the appropriate representation according to the problem at hand (De Cock, 2012). In addition, the ability to present information in various modes of representation, interpret and disassemble information from the given description, and use this information to produce different representations are scientific skills that students need to develop (Etkina et al., 2010).

Several researchers in physics education have tried to see how the representations used by students in problem solving and the effect on problem solving abilities. Many previous studies have shown that the use of various forms of representation in teaching physics concepts has great potential benefits (Meltzer, 2005). For example, research conducted by Kohl et al (2007) shows that some differences arise in terms of the use of representations, namely experts are more flexible and fast in terms of finding alternative representations when they have difficulty in solving problems, and beginners such as students tend to try many representations in problem solving. Research conducted by Meltzer (Meltzer, 2005) on the relationship between a given representation format and problem solving ability, shows that students' problem solving abilities are better when the representation format given is verbal rather than in the form of a diagram. The suitability of the choice of representation affects the success of problem solving, because the success of students in solving physics problems is related to the format of the representation of the problem (Nieminen et al., 2012).

CONCLUSION

Based on the results of the literature research that has been carried out, the author has presented how the differences between experts and novices in problem solving, the differences in the approaches used by students, the use of examples as a basis in problem solving and the application of various representations in problem solving. Of these various ways, applying the steps of an expert in solving problems, using a scientific problem-solving approach, utilizing various examples that have been worked on previously aspects to examine the solution procedures they are working on and utilizing various representations are alternative solutions that can be used. in the problem solving process. For further studies based on the literature research that has been carried out in this article, researchers can design learning to improve problem solving skills by embedding expert theory in problem solving, using scientific problem solving approach steps, applying examples, and applying various representations in learning design

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