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ORIGINAL RESEARCH PAPER

Using SOLO Model for Evaluation of Students' Physics Learning

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ABSTRACT

Quality and adequacy of learning physics concepts have been major concerns for physics education researchers. To evaluate the extent to which students learn physics concepts and the quality of their learning, different models or methods have been employed by physics instructors around the world. The efficiency of these evaluation methods or models is of great importance since teachers and instructors need to guide their students through the learning process based the evaluation results. Following the COVID-19 pandemic and the closures of schools, evaluation of students' learning became more challenging for many teachers, including physics teachers. Accordingly, there was a need for the teachers to familiarize themselves with new methods of evaluation. One of the practical taxonomies that can be used as a qualitative tool in evaluating the cognitive levels of students' learning is the SOLO model. The present study aimed at introducing this model in the form of two physics problems as well as examining the cognitive levels of students' learning in physics via the model.

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Introduction

One of the most important goals of physics education is to enable students to understand the world around them. However, numerous problems arise in this process of understanding, among which we can mention "lack of correct evaluation and inability to identify students' learning levels". Today, one of the topics of interest in education is learning and evaluation, because accurate evaluation is essential for designing the next steps of instruction. The main issue is which teaching and evaluation method can result in deep learning and long-term retention of physics, and identification of problems and their solutions. In addition, the universally shared experience of the corona virus epidemic has changed the conditions of instruction and learning all over the world, and there is a need for physics teachers and educators to reflect on such issues and find solutions for using the appropriate scientific tools and strategies (Sanita, Ahmed, Barbahuiya, Ganjan, Ansari, 2022).

The Structure of Observed Learning Outcome (SOLO) model is an efficient evaluation model that can be used as a qualitative tool in evaluating students' learning level. This model is rooted in Piaget's developmental stages and information processing theory which was first introduced by Biggs and Collis (1980 cited in Hall, Quinn, Gelnick, 2017). This model is considered to be a new and practical evaluation method that not only determines the students' learning levels, but also identifies their mental schemas and by providing useful solutions, instructs them to attain higher cognitive levels. So far, no research has been done regarding the classification of the cognitive levels of students' learning using SOLO classification in the field of physics, but such research has been carried out in different fields, especially mathematics.

In 2017, Ahmet Sukro Azdemir and Soda Gaktepe Yildiz investigated the spatial ability of pre-service elementary school math teachers based on the SOLO model in a research titled "Evaluation of the spatial ability of pre-service elementary school math teachers." For this purpose, three samples with different spatial skills were selected and clinical interviews were conducted on these samples. The analysis of the qualitative data showed that as teachers' spatial ability increases, their reasoning power also increases (Ozdemir & Yildiz, 2017).

Another research titled " Constructive Alignment and the SOLO Taxonomy: A Comparative Study of University Competences in Computer Science and Mathematics" was conducted in 2007 by Claus Brabrand from Copenhagen University of Information Technology and Bettina Dahl from Aarhus University in Denmark, in which the principles of ILO and SOLO were explained. This study explains examples of designing and producing new curricula (Barabrand & Dehl, 2007). A study entitled " The fundamental cycle of concept construction underlying various theoretical frameworks" dealt with the development of mathematical concepts over time using different theoretical perspectives, including the SOLO model and different theories of concept construction (Peg & Tal, 2005).

In 2006, Baxter and Dudley used the SOLO model to evaluate a specific aspect of physical education. Their goal was to challenge students to achieve deep learning step-by-step using the SOLO model. The results of this research showed that the SOLO classification effectively describes different levels of cognition and provides an effective framework for assigning grades (Baxter & Dudley, 2006).

As the above research shows, using this cognitive taxonomy, it is possible to identify students' problems in understanding concepts while identifying students' schemas and determining their cognitive learning levels. Therefore, this evaluation model has advantages which make it a suitable replacement for the old evaluation methods (Hati & Brown, 2004).

On the other hand, one of the fields that has been studied in science education today is the concept of "buoyancy" (South, 2008). Students' views on the concept of "buoyancy" were first reported by Inhalder and Piaget (1958). As understanding the laws of buoyancy requires advanced reasoning skills, students have difficulty understanding and analyzing this concept (Inhalder & Piaget, 1958).

Among researchers who have examined students' understanding of buoyancy, there is consensus that most students' difficulties with buoyancy stem from incorrect or incomplete understanding about underlying concepts such as volume, mass, density, force, and pressure (Halford et al., 1986; Jain, 1982; Mallett & Montcuquiol, 1988; Smith et al., 1985). Haider (1997 and Chalik (2005) also suggests that students' retention of concepts is fragmented. Hence, there is a need to teach and assess this concept more efficiently to minimize students' misconceptions (Brown, & Thompson, 1986; Halford, Hewson & Hewson, 1983; Jain, 1982; Kariotogluoi, Koumaras, & Psilos, 1993; Smith, Carey, & Wieser, 1985; Smith, Sneer, & Grasslight, 1992; Symington, 1983).

This research strives to answer the following questions:

How can students' answers to a physics problem be analyzed using the SOLO model?

What is the cognitive level of students with regard to buoyancy in this study?

The SOLO Model

This model was initially a general model of intellectual development which was later modified (Cheek, 1998). SOLO is based on the view that there are natural stages in the learning process of any complicated skill or topic. These stages are similar but not identical to Piaget's stages of intellectual development. The learners' responses to the questions based on SOLO model follow specific principles. Compared to the traditional method that determines the quantity of material to be learned, this model focuses on the quality of learning (Pegg & Tal, 2005).

In the SOLO model the answer, or in other words, the visible learning result, is created by a question containing data. Both the question and the data are clues to the answer. So, the concepts and processes, the degree of difficulty of the question and the cognitive ability of the learner creates the response. The SOLO model describes the quality of a learner's answer to a question using five cognitive levels (Cheek, 1998). In the following, we will examine these five cognitive levels:

Pre-structural: At this level, the student uses wrong data or solutions, so his response is incorrect or irrelevant. The student has little information that is unrelated, so his answers do not form a unified concept and are meaningless (Molbar, Rahman and Ahmar, 2017).

Unistructural: At this level, the student focuses on one aspect of the question and uses it to produce a valid but simple answer. Therefore, from level one to two, the student has progressed to recognizing relevant information and is able to handle one piece of data that is related to the problem. At this level, a student is able to make clear and relevant connections and is able to use correct terms, remember material, memorize, follow simple instructions, identify, name, count, interpret a sentence, etc. (Barabrand & Dehl, 2007). At this level, the student uses general information to reach a definite answer. This type of response uses language but does not go any further.

Multi-structural: From level two to three, we see little progress. The student now has the ability to deal with several pieces of information that are independent of each other and are not related. For example, the student cannot see the forest for the trees. He is able to count, describe, classify, combine, use methods, structure, carry out steps, etc. (Barabrand, Dehl, 2007).

Relational: At the fourth level, learners begin to make qualitative improvements by combining details to form a structure. The student may now understand the relationships between several pieces of information and how they may fit together to form a complete and structured response.
The student now sees how many trees together form the woods. Therefore, the student may have the ability to compare, communicate, analyze, apply theory, explain in terms of cause and effect, etc. (Barabrand, Dehl, 2007).

Extended abstraction: From level four to five, we see more qualitative improvements because cognitive structure is generalized and the student is able to deal with hypothetical information that is not given. In this fifth level, which is the highest level, the student can now understand the structure of knowledge from different perspectives and produce multiple answers based on the perspective and hypothetical information available. Here, the student may be able to generalize, hypothesize, criticize, theorize, or transfer a theory to a new field, etc. (Brabrand, Dehl, 2007). In this stage, answers are structurally similar to relational answers, but here data, concepts, and processes are mapped outside the domain of knowledge and experience assumed in the question. Biggs, 2003).

According to the above information, the following can be said about learning based on the SOLO model. The first stage of SOLO is really a level of ignorance that is actually outside the classification. The next two levels (unistructural and multi-structural) are both levels of superficial understanding, where knowledge is evaluated more quantitatively. The last two stages of SOLO emphasizes the quality of knowledge and are characterized by increasing abstraction (Biggs, 2003).

The following diagram describes well the different levels of SOLO:

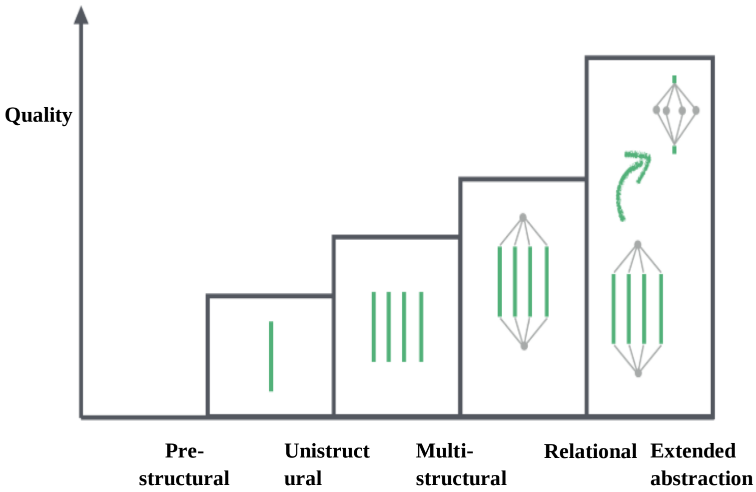

Figure (1) - The SOLO model

This figure shows well that as we go from elementary levels to higher levels, the students' answers increase in quality and complexity. Solo classification can be used in designing standard and targeted questions. For this purpose, the following steps must be taken:

1- First, choose your desired learning goal.

2- Design a question that is related to your learning goal and the student find one or more concepts of the educational goals upon its completion.

3- Prepare a list of related concepts for yourself and design questions that asks the learner for the relationships between the concepts.

4- Design an analytical question in a new context using the general rules used in relational questions so that the student can reach the highest level of learning by solving this problem. (Hall, Kevin and Glennick, 2017).

There are two methods to design questions and analyze students’ responses. These will be explained in the following section.

1. Questions designed by SOLO levels

In this method, a separate question can be designed for each level of SOLO, and if the student is able to answer that question, it can be said that he has reached that level of learning. For example, the following question is designed based on SOLO levels:
Example 1: Answer the following questions according to the concepts of energy and energy sustainability.

a) What is the unit of energy in SI system?

b) How many types of energy have you encountered so far? Name them.

c) We release a ball from a known height. Assuming air resistance is ignored, what is the relationship between the changes in kinetic and potential energy of this ball as it falls to the ground? Explain.

d) Discuss energy sustainability in the design of a roller coaster (Figure 2).

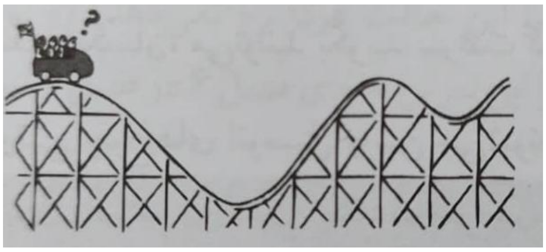

Figure (2) - The image related to part (d) of the question (Hewitt, 2009).

If you pay attention to part A of this question, you will realize that the student only needs to remember the unit of energy, joule. According to the SOLO model, this question is at the unistructural level. At this level, the student focuses on one aspect of the question and uses his memory to answer the question. In the next part of the question, the student needs to remember different pieces of information, but this time he should pay attention to several points independent of one another. This question is multi-structural. This level is similar to the previous level except that the student now has the ability to deal with multiple aspects. The multi-structural level, like the unistructural level, only examines the quantity of learning.

In order to solve the third part of this problem, the student needs more complex mental processes. The learner needs to consider the information as a coherent and meaningful whole and use all the information given and understand the relationship between them (Lake, 1999). In order to answer this question, the student must be fully familiar with the concepts of kinetic and potential energy, the relationship between these two energies and how they are transformed into each other. According to the SOLO model, this question is at the relational level. These levels are among the higher levels of learning, which, unlike the previous levels, evaluate the quality of learning.

Part d is placed at the highest level of SOLO. A student at this level, uses all the available information and meaningful connections given in the question to evaluate the abstract structures suggested by the question. He uses deductive logic to connect specific data with general rules and generalizes about hypothetical situations (Lake, 1999). While establishing a meaningful relationship between kinetic energy and potential energy and the transformations of these two energies into each other, he should hypothesize about how to design this roller coaster and use the data in his mind to determine the appropriate location and height of the roller coaster's peaks. Extended abstract answers are structurally similar to relational answers, but the data and concepts are outside the information given in the question. This stage also evaluates the quality of learning (Sutton, Williams, 2007).

In addition to the levels explained in this question, this model has another level called prestructural. At this level, which is the lowest level of SOLO, the student uses wrong data or solutions, so his solution is incorrect or irrelevant. The student has little information that is unrelated, so his answers do not form any specific concept and have no meaning (Molbar, Rahman and Ahmar, 2017).

2. Designing a general question and analyzing its answers based on SOLO levels

In this method, a question is designed and based on the students answer and analysis, his cognitive level is determined based on the SOLO model. An example follows:

Example 2: A balloon is attached to a weight. The weight makes it difficult for the balloon to float on water. The balloon is pushed under water. Will the balloon rise to the surface, remain under water, or sink? Explain. (Hint: Will the density of the balloon change?) (Hewitt, 2009).

First, we will study the answer. It is clear that after pushing the balloon down, the balloon sinks further into the water. From the lessons on pressure, we remember that as the balloon is pushed down and the fluid increases, the resulting pressure will also increase. The balloon is able to change volume so as it goes deeper and the pressure of water increases its volume decreases and its density increases. On the other hand, we know that the buoyancy force is equal to the weight of the fluid displaced by the object. So here, by reducing the volume of the balloon, the weight of the water displaced by the balloon also decreases and the buoyancy force decreases. So, as the balloon goes deeper, the buoyancy force becomes less and less and weight will overcome it. As a result, the balloon sinks.

According to the type of question and its answer, we realize that this question is at higher levels of learning (relational level) and complex mental processes are needed to solve this problem. This question has been answered by 100 tenth grade students of Alborz province. The data will be analyzed in the next section in the form of a quantitative research.

Methodology

This study is a survey using a questionnaire. The participants were 100 female students aged 15 to 16 years who were selected through multi-stage random cluster sampling. The second example analyzed above and based on the SOLO model was selected from the book titled "Conceptual Physics" by Paul J. Hewitt. This problem was given to the students and they were asked to solve it.

Results

We examined the students' answers to the second example. Some students had only mentioned one issue, i.e., the force of weight was greater than the force of buoyancy. So, their answer was at a unistructural level. However, the students who were at the multi-structural level had paid attention to the decrease in the volume of the balloon and the increase in its density, but they had not been able to relate this to the buoyancy force, so their answer wase incorrect. Meanwhile, few students answered the question on a relational level. These learners not only used several pieces of information (increase in water pressure due to the change in depth, decrease in the volume of the balloon due to the increase in water pressure, change in the density of the balloon and its sinking) to solve the problem, but also understood the relation between them in order to produce a correct answer. The results are summarized in the graph and table below.

Academic grade	level of SOLO	percentage
10th	Relational	٪**3**
	Multi-structural	٪**25**
	Unistructural	٪**38**
	Pre-structural	٪**34**

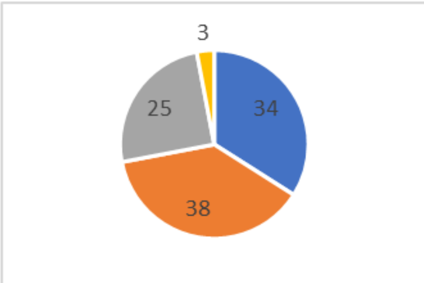

Chart 1 and Table 1

Chart 1 and Table 1 show that 63% of the students are at the unistructural and multi-structural level and 3% are at the relational and extended abstraction level, and the rest either did not answer this question or their answers are incorrect and are placed at the pre-structural level. These findings indicate that the performance of most students in this test was very weak, which indicates that they were at low levels of learning. In other words, most of the learners have a superficial and simplistic understanding of the concepts of buoyancy and have only memorized the material related to this topic without deep and conceptual understanding.

In this research, we were able to learn how to classify the cognitive levels of learners based on the SOLO model. We also realized that this model can be used in the physics course like other courses, and it can be used to measure the students' learning and identify their learning level.

Conclusion

The purpose of this research is to introduce the SOLO evaluation model and provide examples of its application in physics education. This approach classifies students' answers in five levels: pre-structural, unistructural, multi-structural, relational, and extended abstraction. In order to so, the model uses levels of cognitive development and classifies the quality of learning according to the age of the students, which reduces measurement error (Peg & Tal, 2005). Similarly, with the help of this model, it is possible to identify the misunderstandings of the learners, clarify them and take a significant step to improve the level of teaching and learning. Today, in the Corona pandemic, it has become more difficult for teachers and students to measure learning. Therefore, new and practical approaches should be used to measure learning as accurately as possible.

The quantitative results of this research indicate that the majority of students are at the unistructural and multi-structural levels in subject of buoyancy which is in line with the research conducted in the field of mathematics (Ozdemir & Yildiz, 2017). This shows that most students perform very weakly in analytical subjects and do not reach higher cognitive levels. In addition, this shows that this model is a good model for teaching different concepts of physics, including concepts of mechanics, electricity, fluids, etc. Considering the applicability of this model, it is suggested that it be used by teachers in the design of various lesson plans so that students can be guided to learn as deeply as possible. It seems that the SOLO model with its advantages can be a suitable alternative to the old evaluation methods.

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