Transformation of multiple representation in real world physics problem solving

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Abstract. Multiple representation (MR) refers to the use of more than one way of representing ideas, concepts, and processes such as pictorial, graphical, numerical, oral and table. Studies in physics education also found that using MR increases achievement of problem solving among students when more emphasis was placed on qualitative representation. However, students often fail to exploit the advantages of MR or are difficult to transform between MR. In this study, the transformation of MR (TMR) carried out by the secondary school students in real-world physics problems was studied. The Think-Aloud Protocol (TAP) and retrospective semi structured interview (ProTRet) were used to provide more information about how the students use TMR in solving real-world problems. The analysis was qualitative in nature, focusing mainly on the process of the TMRs employed as well as the underlying reasons for their applications. The research data was analysed using constant comparative method (CCM) including open coding axial, coding and selected coding that generates a concept. It was found that there were three types of TMR created by the participants at the early stage of problem-solving, which could be used as an evaluation guide for process monitoring.

1. Introduction

Problem-solving is a very important aspect of physics learning. It is a process that needs to be carried out in order to attain the objectives of action [1] or specific steps [2] and the transfer of knowledge [3] and existing skills to address the problem. However, many high schools as well as higher-level students have only poor and inadequate problem-solving skills and the efforts to improve students' ability to solve problems are often not enough [2].

Students are struggling to understand the problem-solving process [4] due to traditional teaching. Traditional teaching often emphasizes on the quantitative aspects of problem-solving that results in students finding algorithmic solutions by rote memorization the formula without understanding the concept [5]. This approach has led to student fail in constructing and connecting the meaning of the problem statement [5]. As a result, students lack mastery in problem-solving skills and are not able to solve real world problems.

Studies in cognitive science showed that expert problem solvers often use qualitative representations. For example, sketches, graphs, and diagrams are used to help them understand the problem before using equations to solve them quantitatively [6]. Studies in physics education further found that the achievement of student problem solving increased when more emphasis was placed on

qualitative representation [7–9]. Qualitative representations can facilitate understanding of the problem or task and so the problem can be solved properly. Hence, it is crucial for students to know and understand the use of representations to understand a problem before finding a solution.

Problem solving is also a repetition process of representing and finding solutions [1]. Representations are used repeatedly to achieve the expected solution in an assignment. When representation is used in a problem, it will facilitate the solution of the problem [7,10]. For example, a study shows a simple positive correlation between problem representation and problem-solving scores [11]. However, the finding only focuses on the concreteness of the visual representation used. Hence, students need to understand the problems raised by using appropriate representations and planning.

When students are able to interact with appropriate representations, their performance can be improved [12]. Studies have now focused on learning with more than one representation, which is based on the notion that 'two representations are better than one' [12]. The ability to re-transform the same concepts in different formats, including verbal, visual, mathematical, and pictorial representations is the ability to use multiple representations (MR) [13,14]. MR refers to the various ways in which one communicates concepts and problems.

Problem solving and the use of MR are combined because many physics problem solving research indicated that students who used representation across various representations could consistently solve problems better [6,15,16]. MR can help students in understanding [17] and solving physics problems [7,18]. In order to produce physics problem solvers, they need to be proficient in using MR [19] and use MR consistently [20]. Recognizing this importance, many researchers suggested the use of MR to help students solve problems [15,20–22].

However, students have difficulty solving their problems across MR. The difficulties faced by students in transformation across representations are formulas, values (quantitative), plug and chug and sketching or drawing [23,24]. How to help students overcome transformation difficulties across MR? This question requires further study because the transformation of problem statement by using multiple representation is very important and critical to lead to further solution. Furthermore, transformation between MR did not get attention in previous studies.

The TMR is important to study in the context of problem solving so that students have a guide to understand the problem and solve it better. Though, not many studies have focused on the transformation of MR in problem-solving among high school students. Therefore, researcher sees the importance of scholars and teachers to understand the process of transformation between MRs and to further develop a mental model of it to solve physics problems.

2. Method

This study adopted qualitative research method. Inquiry qualitative study is a form of interpretive study in which researchers make explanations and understandings of what they see, hear, and understand [25]. This method studies phenomena in their natural state, attempts to understand, or interpret them based on experiences or meanings seen by informants [26]. This approach was adopted to explore the transformation between MR that occurred during solving problems.

2.1. Participants

All participant in this study were from four students (age 15 to 16 years old) from the pure science stream. In Malaysia, the pure science stream is a branch of science specialization that requires students to take elective subjects such as physics, chemistry, and biology. The requirement to choose the pure science stream were students with an outstanding academic background. This excellence was measured based on the results of the Form Three Assessment (PT3).

Participants in this study were also students who had a good mastery level concepts for the topic of force and motion base on test score during topical test and mid-term exam as suggested by the subject's teacher. These students were selected from the secondary schools that have the best performance in physics subjects in the state of Johor. These criteria were selected to meet the needs of the study where students who have good knowledge of concepts are able to solve problems well. This is because, concept mastery is an important aspect of problem solving [27] as to avoid knowledge conflicts [28]. In addition,

the participants of this study also considered the suggestions from the subject teachers regarding the ability of the participants to communicate their thoughts when solving problems and the willingness to participate in this study.

2.2. Data Collection Method
Data for this study were obtained from three instruments consisting of a paper and pencil test, a think-aloud protocol (TAP) and a semi-structured retrospective interview protocol (ProTRet). The Think-Aloud Protocol (TAP) was conducted to gather more information on the extent to which selected students can solve force and motion problems, as well as the MR transformation process during problem-solving. Further study would be carried out through interviews to understand the student's thinking processes while solving the problems of force and motion that explore student thinking processes while solving problems. All the problems posed to the participants were questions that revolved around real-world problems and follows the Malaysia Certificate of Education (MCE) examination standards. As in previous studies [29–32], participants were solving five problems by through think-aloud to explore student thinking processes while solving problems.

Then, the interviews were conducted immediately after the think aloud session. This interview was called a retrospective interview [33] in which it was a process of participants' reflection on the current experience of thinking-aloud problem-solving. This method was carried out face to face and one to one. During the interview, written answers for each participant problem were reviewed. Interviews with participants were conducted to gain an understanding of the minds [34,35] and to explore the solutions made by participants [36].

2.3. Data Analysis
The process used to analyze transcripts from think-aloud and retrospective interview sessions was a constant comparative method. There were three levels of analysis, namely: (a) open coding; (b) axial coding; and (c) selective coding. Continuous comparisons were used at each level of analysis to further filter the data until a theme emerges from the data.

Written problem-solving paper content would also be analyzed to triangulate the finding. The researcher would examine the answers to identify the transformation of the MR carried out by the participants as suggested by previous study [37]. The content analysis involved the process of organizing information according to categories related to the study. There were three steps involved in analyzing student written paper. The steps were (1) reading by means of scanning techniques; (2) reading in detail; and (3) interpreting [38]. In addition, content analysis and constant comparative analysis elements would also be used throughout this process.

3. Results and Discussion

According to the analysis results on the instruments, there were three types of TMR based on the thinking process of the participants. The following Table 1 presents the types of TMR and the explanation discovered in during think-aloud and retrospective interview.

Table 1. Types of TMR and the description of the process

No	TMR	Process
1	Text-Sketch	Immediately after the participants read the problem, they made a sketch about the situation.
2	Text-Numerical	After reading the problem, the participants transferred the information they thought was important by writing numerical value and symbols.
3	Text-Formula	After reading the problem, the participants retrieved the formula relevant to the situation that they thought suits the situation.

According to Table 1, first transformation discovered was Text-Sketch. The Text-Sketch was coded based on the process of reading the problem and preceded by the sketch. The sketch was based on their interpretation of the situation. The following diagram (**Figure 1**) is the Text-Sketch example.

There is a girl throwing a ball vertically upwards. When reach at position X, the ball is falling towards the ground. What is the velocity of the ball at position X? Describe the motion of the ball in this situation.

Figure 1. The outcome of Text-Sketch

Text-Numerical was coded for the action of reading the problem and at the same time participants wrote down the physical quantity using the numerical value, symbols, and unit. **Figure 2** shows the output of the Text-Numerical as an example.

Kamil is cycling in the velocity of 2.0 ms⁻¹, Shafiq is skating in the acceleration of 2.0 ms⁻² from rest, and Ganesh is riding in the deceleration of 5.0 ms⁻² from a velocity of 10 ms⁻¹. In a distance of 10.0 m, who will reach the finishing line first?
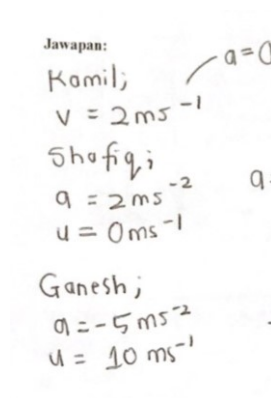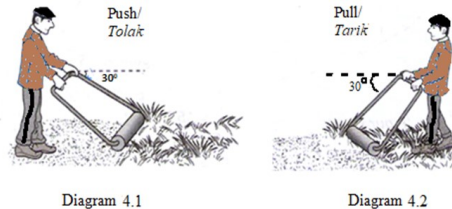

Figure 2. The outcome of Text-Numerical

Finally, the TMR of the Text-Formula was coded for the process of reading the problem and then the participants began to retrieve the formula from their memory that was relevant to the situation they understood The formula was symbolic and mnemonic as the manner in which it was remembered. For example, **Figure 3** shows the result of the Text-Formula transformation.

Diagram 4.1 shows a worker pushing a concrete roller along a field with a force of 250N and then pulls roller with the same force as shown in Diagram 4.2. Compare the method used in Diagram 4.1 and 4.2. Which of the methods will be more effective to press the soil on the ground? Explain how this method will be more effective.

Figure 3 The outcome of Text-Formula

Based on the results, the participants were able to transform the text problem provided to another type of representation which were sketch, numerical and formula. This indicates that they have flexibility in the use of MR [13,14] which is helpful to finding a solution, as emphasised in the previous study [18,23]. In addition, the transformation shows that they understand the problem [7,18,22] and able to transform it into a different type of representation [22]. These three types of TMR provide a deeper understanding of thinking process among secondary school students while dealing with MR in real-world problem-solving. However, these findings do not propose a specific type of TMR that is most effective in finding solutions.

4. Conclusion

To conclude, the present research provides empirical evidence on the type and characteristics of the transformation process of MR in problem-solving. The process of TMR are also able to be guidance in evaluating students' ability to solve problems more flexibly and fluently. These results further contribute to our understanding of MR and are therefore highly relevant for the further development of theories on teaching and learning with MRs.

Acknowledgements

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